GENERAL ELECTRIC REVIEW

INDEX TO VOLUME XVI

January, 1913 - - December, 1913

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AUTHOR'S INDEX

GENERAL ELECTRIC REVIEW

Published Monthly by the
GENERAL ELECTRIC COMPANY'S PUBLICATION BUREAU

Manager, M. P. RICE Editor, D. S. MARTIN Associate Editor, B. M. EOFF

Subscription Rates: United States and Mexico, $2.00 per year; Canada, $2.25 per year; Foreign, $2.50 a year, payable in advance. Remit by post-office or express money orders, bank checks or drafts, made payable to the *General Electric Review*, Schenectady, N. Y.

Entered as second-class matter, March 26, 1912, at the post office at Schenectady, N. Y., under the Act of March 3, 1879.

VOL. XVI., No. 1 JANUARY, 1913

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J. R. Lovejoy
Vice-President, General Electric Company

GENERAL ELECTRIC REVIEW

STANDARDS CONVENTION: THE OUTSIDE INTERESTS MUST BACK UP THE MANUFACTURER

An important meeting of the A.I.E.E. is to be held in New York at the end of February next, when, under the auspices of the Standards Committee, the general subject of the rating and testing of electrical apparatus will be discussed. The amount of power which may be demanded from an electrical machine is given by its rating; and this midwinter convention has been called simply to discuss how electrical machinery shall be rated, and the preferable ways and means which shall be followed in determining its ability to reproduce in practice its rated performance, before it is handed over from seller to purchaser. The matter therefore is genuinely concerned with the fundamentals of the business; and, more than any other, requires the most careful, free and frank discussion by the operating companies, the consulting engineers, and the manufacturers.

The thorough nature of the preliminary work which has been performed by the Standards Committee should render such discussion easy. A circular containing details of the *agenda*, and a request for papers to be presented on the subjects therein contained, was mailed to the full membership of the Institute on the 15th of November. The date set for the receipt of manuscripts is January 1, 1913—early enough to allow of circulation of the papers to the membership, the receipt of a written discussion, and further mailing of such discussion to the members, before they convene in New York on the 26th of February next. This should lead to a much more careful consideration of the subject, and a much more conservative expression of opinion, than could be expected from a hurried presentation of a few papers followed by an off-hand discussion. The circular invites contributions on a number of specific topics related to measurement of temperature of electrical apparatus, correction for varying room temperatures and pressures, measurement of losses, equivalent-load-tests, guarantees, and other matters classed under the heading of "miscellaneous."

This, in brief, is the ground which will be covered; and at this time it is not necessary to deal with the separate items of the *agenda* in any greater detail. At this time, however, it emphatically *is* necessary to advertise thoroughly the fact that such business is toward, and to impress on all interested parties the fact that these questions of ratings, standards, temperature limits and measurements, and so on, are really vital questions which must receive adequate discussion; that there is now an opportunity for adequate discussion which cannot, in the nature of things, recur for several years; and that any hasty formulation of rules, as has already been abundantly proved by past Institute experience, is capable of more harm than good, is frequently productive of doubt and confusion, and at best can only be an inadequate method of meeting the present needs for revision. The invitation to contribute is a wide-open one, and the circular which has been sent to all the members gives a pretty good idea of the subjects upon which opinion is required. If members with something to say have no time to prepare papers, or no facilities for obtaining the data upon which good constructive criticism of existing rules and methods can be based, let them content themselves for the present with marking up the date of the convention; let them make arrangements now for being in New York on the 26th of February next; let them formulate their opinions now so that, when they receive their copies of the papers, they may, as far as possible, be ready with some helpful discussion, which contributions can then be distributed before the convention date.

It is only in this way that a maximum of profit to the industry in general will result; and only in this way that the utmost advantage may be extracted from the mass of material which is now being put together by various manufacturers. The Westinghouse Electric & Manufacturing Company is working hard in order that the subjects allotted to it may receive adequate treatment. Under the very able direction of Mr. B. G. Lamme and some of his corps of engineers, many gangs of men in the Pittsburgh factory are working full time and overtime on methods of testing converters, generators, motors and so on. The General Electric Company, with Dr. Steinmetz actively interested, is equally busy, and for weeks now scores of testers have been detailed off practically exclusively to Institute work. Other manufacturing firms are making their quota to the list of papers down for presentation. Regular production meanwhile has to go forward, and it is sometimes difficult to take care of the extra work. The manufacturer, however, grudges neither the time nor the money, provided the time and the money are going to be well-spent. Whether he is in business purely for profit or not, his motives here would seem to be fairly altruistic. He builds his machines to meet a given rating. He builds to sell, and he is only one of the parties to the transaction. The purchasers have as big a say as he in the matter of ratings, and he desires only that they shall understand everything pertaining to the subject. He has the facilities for getting the figures on such matters as, say, the effect of humidity or room temperature on the degrees rise of a transformer; and he is now using these facilities up to the hilt for getting the figures. To make them of any use they must be adequately studied by the outside interests carefully, thoroughly, and intelligently. We are now two months from the Ratings Convention. Now is the time to get busy.

The I. E. S. PRIMER AND ITS CRITICS

"Light: It[illegible] U[illegible]e and Misuse," a primer on light and illumination published by the Illuminating Engineering Society, has already gone into a second edition. The Primer has been extensively reviewed in the weekly technical press, and [illegible] our readers will be well acq[illegible] [illegible] general nature, scope and pur[illegible] [illegible] a clear and simple [illegible] reading, the pamphlet [illegible] [illegible]diate favor. It has [illegible] [illegible]limentary criticism [illegible] [illegible]nerally supposed [illegible] [illegible] interest in the subje[illegible] [illegible] the heads of engin[illegible] [illegible] departments of schools [illegible] [illegible] has received numerous letters of commendation, together with requests for quantities of the primer for distribution to students. Architects, engineers, oculists, merchants, and others have also expressed their appreciation of the publication. Several lighting companies are planning to issue it to their customers. One large manufacturing company in London has cabled for permission to print and distribute a large edition in Europe. It is not unlikely that the primer will go into many editions.

The verdict of approval is nearly unanimous, but not quite. Some are criticizing the book quite severely. It is not perfect: perfection, in a first attempt of this kind, was not to be expected. Doubtless in other editions a few changes will be made, additions and omissions. But whatever the flaws in the present edition—and, in our opinion, they are trivial—we can find no justification for the somewhat scathing criticism which has been directed from certain quarters at the Illuminating Engineering Society on the publication of their little book. It will not be necessary to mention the source of this criticism. All those who are interested in illuminating engineering will have been aware of it, and will probably think as little of it as do we. The particular criticism which we have in mind was couched in somewhat grandiloquent terms; and, though the style of diction sometimes rendered the meaning of a passage very obscure, it was plain that the writer's opinion was that the *Primer* was too simple, too direct, too utilitarian. The criticism contained a plea for a broader treatment of the subject, suggesting that it be "divided into two parts, viz., natural and artificial light, these two principles then being sub-divided into the various chief factors entering therein, such as physiological, sociological, psychological, aesthetic, engineering, etc." In our opinion, that represents exactly the layout which emphatically should *not* be followed in a primer on the use and misuse of light. The I.E.S. may add our humble expression of commendation to the others which they have received. They have evolved a booklet which may be put into the hands of the man-in-the-street, who wants to hear nothing about the sociological and psychological aspects of light ; but who needs a few simple instructions on how to get the best illumination from a given expenditure at his lamps, whether oil, gas or electric. Give him a few half-tones such as the ones in the *Primer*, showing what is a bad installation and what good; confine yourself to a straight talk on artificial illuminants, since the average man is past the stage when he needs instruction on the use of God's daylight; give him a few clean-cut home-truths such as "*Judge the light you are getting by the way it helps you to see.*"

Maybe in later editions a few changes will be found desirable. For the present let us be thankful that the present *Primer* is as highly valuable as it is. At any rate it *is* a primer, a sheet for the perusal of the humblest light-user. Text-books, bedecked with polysyllabic technicalities, are common enough; are essential to the professional men; are worthless to the man-in-the-street.

THE APPROACHING CHANGES IN WIRELESS PRACTICE

Wireless telegraphy has always appealed to the imagination of the layman, and several things have occurred during 1912 to keep the matter before his attention even more prominently than usual. On the purely technical side there are many new and interesting developments. We are concerned mainly with the strictly electrical phase of the subject. The generator of the future will be an entirely special machine, inasmuch as its speed will be many times greater than the speed called for by the requirements of all standard electrical service. A few years ago an alternator which could produce current at a frequency of, say, 200,000 cycles a second was regarded as an utter impossibility. Its existence is now an accomplished fact. Mr. Alexanderson's article on page 16 of this issue describes his high-frequency alternator in considerable detail; and the result of his work during the last few years on this very intricate engineering problem will probably be fraught with great consequences to the future of wireless telegraphy and telephony.

The ability to produce continuous trains of waves of high frequency (say, 40,000 cycles a second and upward) will mean eventually the entire supersession of the spark-gap method now commonly employed. The New York *Times*, for October 6th last, contained an article on this very subject. To show the commercial significance of this part of Mr. Alexanderson's work, we will quote:

According to Prof. I. Pupin, of Columbia University, wireless telegraphy is about to make some phenomenal advances. The professor believes that instead of the spark-gap method, of sending it oscillations there will be used instead powerful high-frequency electrical generators. To the layman this gives no hint of the tremendous importance of the step, but the student of wireless progress and development sees in it the promise of vast improvement. He foresees the transmission of wireless messages at all times and in all weathers, and a new independence of atmospheric conditions. He foresees messages sent a far greater distance than at present, and far more easily. He foresees the removal of many of the most besetting difficulties of wireless telephony. Above all, he foresees wireless brought down nearer to the level of its ultimate desire, the ordinary level of the ordinary telephone—the "foolproof" level.

When reviewed recently Prof. Pupin explained that it was originally felt necessary that the oscillations for wireless transmission should be of very high frequency. The oscillations in wireless telegraphy are the aerial vibrations sent out from the transmitter of a wireless station, to be caught by the receiver of a station within the radius of the waves produced. At the outset the operation called for as many as a half-million or a million oscillations a second—high frequency such as only a spark-gap could produce. These were necessary for any great distance work, and yet there were difficulties involved in their use. Such high oscillations are constantly lost in sun-lit air, and, furthermore, besides being dependable on the weather, they are as discontinuous and irregular as the spit-spit of the crackling spark-gap itself. Gradually, by such experimentation as is afforded only by the practical, commercial use of wireless, it was learned that messages could be sent across the water with a far lower frequency oscillation, as low as from twenty to forty thousand a second. This was recently announced by Mr. Marconi himself, and with the announcement the electricians rose and said: "If you can use oscillations of as low a frequency as that for wireless, then we can make you powerful dynamo-electric generators that will produce them. You will no longer have to depend on the spark-gap with its intermittent explosions. We will give you a powerful high-frequency machine that will send out a continuous, smooth train of oscillations and yet will have a hundred horse power to drive them as far as you wish."

We may note again that these high-frequency alternators for the generation of smooth continuous waves have been developed for frequencies far in excess of the 40,000 cycles mentioned in the extract. Already machines for 100,000 cycles and 200,000 cycles have been built; although these, of course, have been machines of relatively small capacity, for use in stations of small output for long-distance work, and there may be a greater market for machines of the lower frequencies (30,000 and 40,000 cycles) built for greater capacities.

"And when that was made possible," said Prof. Pupin, "the practical problems of wireless were greatly simplified. For sending by slow oscillations is practically independent of the weather. The slow, continuous oscillations sent out from a 100 h.p. machine will go through any kind of atmosphere. The sunlight, which disintegrates the constituents of the air and destroys its capacity as a non-conductor, is ruination to the high-frequency oscillation, which calls for rain and cloud and darkness. The demands are just the reverse of those of the sailor's. The weather for ships is not good weather for the wireless, since good weather for wireless is good weather for ducks, as the saying goes. But the slow, powerful oscillations from the machine will go through any wind and weather, and the stations need not be idle just because the sun is shining. This means an immense saving of time in that feature alone. Professor Pupin believes that within a year many high-frequency generators will be installed at the wireless stations on both sides of the Atlantic. He himself has ordered one for use in the laboratory at Columbia University. Besides the fact that with this new method wireless transmission can go on at all times of the day, regardless of the weather, the use of the powerful machines such as can now be manufactured for a station will mean a considerable extension of the practicable distance range of the stations. "It will surely increase the distance," said Professor Pupin. "How much I do not know. It may double it or even treble it. That is something we will have to find out."

Prof. Pupin is an old friend of Marconi, and knows his subject thoroughly. He prophesies radical changes in wireless practice through the successful development of the high-frequency alternators. This lends great interest to Mr. Alexanderson's article.

*THE RELATION OF CORPORATION GRADUATE TRAINING TO THE COLLEGE MAN

Is the college man handicapped by his college training? The consensus of opinion seems to be that the first year out of college must be spent in living down many of the things which have been held up to him as ideals—liberal thinking, poise, individuality, enthusiasm and self-confidence, and he must instead become a very insignificant part of a large general scheme. If this represents the true state of affairs, the modern college training is no longer an advantage.

But is there not some way of utilizing to excellent advantage in the modern corporation these self-same characteristics? Modify but do not destroy them. Direct these energies so that they may become the greatest factors in the development of modern industrial efficiency. This is the chief function of the training of graduates by a modern corporation; to maintain in the college man the traits which four years of study have developed, to study his personality, to find out the things for which he is best suited, to gradually get him accustomed to company discipline, and to fit him into that particular niche in the organization for which he is best fitted. If the corporation can accomplish these results it will have bridged the gap between the college and a successful business career.

Specialization is the tendency of the times. The average technical student, realizing this, has begun to specialize while in college. Find out his specialty and if practicable use it. At least try and fit him into something along these lines. "Find the round holes for the round pegs." In any large organization, there is room for a diversity of personality.

The chief function of corporation graduate training is to carry the men through the transition stage. There must be enough of the college atmosphere, therefore, to make the man feel at ease; and, at the same time, enough of the new atmosphere must be introduced in gradually increasing quantities until the transition is complete. A relatively small amount of time spent in actual class-room will be all that is required to preserve something of this college atmosphere; and a big percentage of the week's time may safely be spent from the outset on real factory work. In the case of a large manufacturing establishment, for instance, a ratio of 45 hours for work to 5 hours for instruction may be found desirable and efficacious within quite a short time of the commencement of the factory experience.

The weakness of the average college man may be summarized as lack of initiative, lack of system and little sense of responsibility—all results of too much and too close supervision. The corporation training must remedy this condition. It must also give the man the theory and the practice of the new field. The big corporation, possessing within its ranks many of the ablest men in the field, is in a position to offer graduate instruction absolutely unobtainable by the colleges. Instead of the laboratory in the college imparting theoretical practice, the man enters the shops and factories under operating conditions wherein he obtains invaluable operating experience.

The training of the college man by the corporation if carried on continuously and thoroughly should in time result in building up the greatest possible degree of human efficiency.

SYDNEY W. ASHE

* Towards the end of our November number we published a short review of "A Syllabus of Instruction on Illumination and Salesmanship," issued by the educational department of the Edison Lamp Works, Harrison, N. J. The department probably represents the greatest degree of development which has yet been reached in this modern idea of the Corporation School. Mr. Ashe writes of course, from the standpoint of the director of some of the educational work in a manufacturing establishment. Much work in the development of the corporation school has been performed by other combinations in the electrical industry. Some of the larger operating companies, for instance, have for several years been conducting very thorough and elaborate schemes for the education of their employees: and to work of this character we may have some further occasion to refer at a later date.—EDITOR.

ENTROPY AND TEMPERATURE

(Illustrated by Analogs)

V. Karapetoff

Professor of Electrical Engineering, Cornell University

In dealing with the common forms of energy we consider two factors, an intensity factor and a quantity factor. For instance, in electrical energy, the ampere-hour, or quantity of electricity, is the quantity factor, and the voltage is the intensity factor. The nature of each of these factors is easy of conception. Heat energy is characterized by temperature, an intensity factor, and entropy, a quantity factor; the concept of temperature being familiar to us all from our everyday experience. * An understanding of the nature of entropy, however, is usually acquired with considerable difficulty, and in order to give a tangible picture of this quantity factor, the author first reviews three old analogs in explanation of entropy, one by Zeuner and two by Mach, and then proposes and discusses a fourth, in which a fictitious heat-fluid or *caloric* is ingeniously introduced. The entropy of a body is defined as the quantity of caloric in it, and the temperature as the pressure of this caloric. Some caloric is assumed to be in a bound state within the molecules of the body, and to be liberated during irreversible processes. A review is made of the principal thermodynamic phenomena in the light of this analog or picture, and it is shown that changes in entropy, temperature, volume and pressure can be predicted by a simple reasoning.—Editor.

Thermodynamics is not the specialty of the writer of this article, but a few years ago he became incidentally interested in a certain phase of it, and made an effort to make clear to himself the physical concept of entropy. He finally worked out a mechanical analog, which may be of some interest to those who, like himself, are not satisfied with mathematical definitions, but wish to have a physical picture, however imperfect. The analog is based upon the old idea of heat-fluid or caloric.**

In the two well known forms of energy, namely, mechanical energy and electrical energy, we usually distinguish the *quantity factor* and the *intensity factor*. Thus, the energy of the water in a storage reservoir is a product of the weight of the water, which is the quantity factor, by the hydraulic head which is the intensity factor. The energy of a gas compressed in a tank is proportional to the quantity of gas, which is the quantity factor, and depends upon the pressure, which is the intensity factor. Again, in the case of electrical energy, the quantity of electricity, say in ampere-hours (or coulombs), is the quantity factor, and the voltage is the intensity factor.

*Editor's Note.—The Standard Dictionary gives as the definition of entropy the following: In thermodynamics, a property of a body, expressed as a mathematical quantity which remains constant when a gas or other body changes its volume or does work without any heat entering or leaving it, but which, if a small amount of heat enters or leaves the body, is increased or diminished proportionally to this amount divided by the absolute temperature. * * * * * Since heat always flows from a higher to a lower temperature, a body that gains heat always gains more entropy than is lost by the body losing that heat; hence, with every flow of heat the total entropy of a system of bodies rises, and thus tends toward a maximum.

** After this article had been written, the author was gratified to read Professor H. L. Callendar's address on "The Nature of Heat," in which this distinguished authority shows that "we might with advantage import into our modern theory some of the ideas of the old caloric or material theory which has for so long a time been forgotten and discredited." *Science*, Vol. XXXVI, Sept. 13, 1912, page 321.

Similarly, heat energy is characterized by an intensity factor, temperature, and a quanity factor called entropy. The concept of temperature is familiar to us all from our every-day experience, while that of entropy is entirely outside this experience, and therefore presents considerable difficulty to a beginner. It is therefore desirable to explain entropy by means of analogs before taking up the study of mathematical thermodynamics. We shall first describe two older analogs to temperature and entropy, and then develop a closer simile to heat phenomena.

Zeuner's Analog

In a simple analog proposed by Zeuner † temperature is compared to a difference of levels, and entropy to the weight of a body to be raised or lowered. The quantity of heat, being the product of the two, represents the amount of work necessary to raise the body by a certain height. For this reason entropy is sometimes called the "heat-weight." The familiar Carnot cycle, Fig. 1, is easily illustrated by this analogy. Think of a freight elevator which transfers, say barrels of flour from the upper to the lower floor of a warehouse. While barrels are being loaded on the elevator, its level, or temperature, remains constant, while the quantity of flour upon it, or its entropy, increases. This corresponds to the isothermal expansion along the part *a b* of the cycle. The energy of the elevator for positions above the lower floor of the warehouse increases with the distance, since the barrels represent a certain amount of stored energy.

Now, let the elevator be descending: its entropy, or the quantity of flour on it remains constant, while the height above the lower

† Zeuner, *Technical Thermodynamics*, Vol. I, Art. 11.

floor (or what is called in thermodynamics, the refrigerator) decreases. This corresponds to the adiabatic (or isoentropic) expansion *b c*. Unloading the barrels on the lower floor

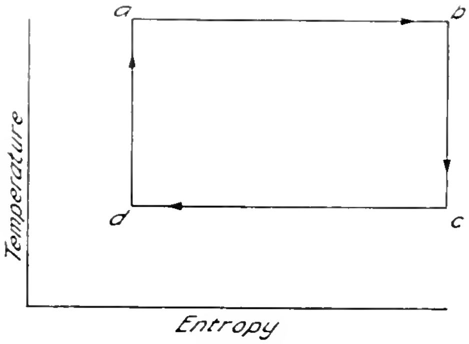

Fig. 1. Carnot Cycle for a Perfect Gas

corresponds to the isothermal rejection of heat during the part *c d* of the Carnot cycle. The flour may still possess a considerable amount of energy of position, say above the sea level, but this energy can not be utilized, and must be considered as waste. Finally, the elevator returns into its original upper position, rising at a constant entropy, which in this case is the weight of the elevator proper; this corresponds to the adiabatic compression *d a*. After this, the process is repeated in the same order.

work is performed during the period of loading the barrels, while a considerable amount of work is done by the gas during the isothermal expansion.

Mach's Analogs

A better analog has been developed by Mach.* His idea is shown in Fig. 2 in application to a hydraulic motor, in which the head of the working fluid is analogous to temperature, and the quantity of the fluid behind the piston corresponds to entropy. A cycle analogous to that of Carnot may be realized on this model as follows: Let the piston *C* be originally in its extreme left position, the gate *a* being open. The pressure on the piston corresponds then to the level of the water in the reservoir *A*, which for our purpose must be assumed to be infinitely large, so that its level remains constant. The piston starts to the right, performing mechanical work, the gate *a* being open, and the water filling the space behind the piston. This corresponds to the isothermal expansion, during which the temperature is being kept constant, while the entropy increases. At a certain point of the travel, the gate *a* is closed, and the piston *C* allowed to move under the pressure of the water in the engine itself. As the volume of the space behind the piston increases, the level of the liquid becomes lower. This corresponds to the adiabatic expansion. The quantity of entropy (or water) remains

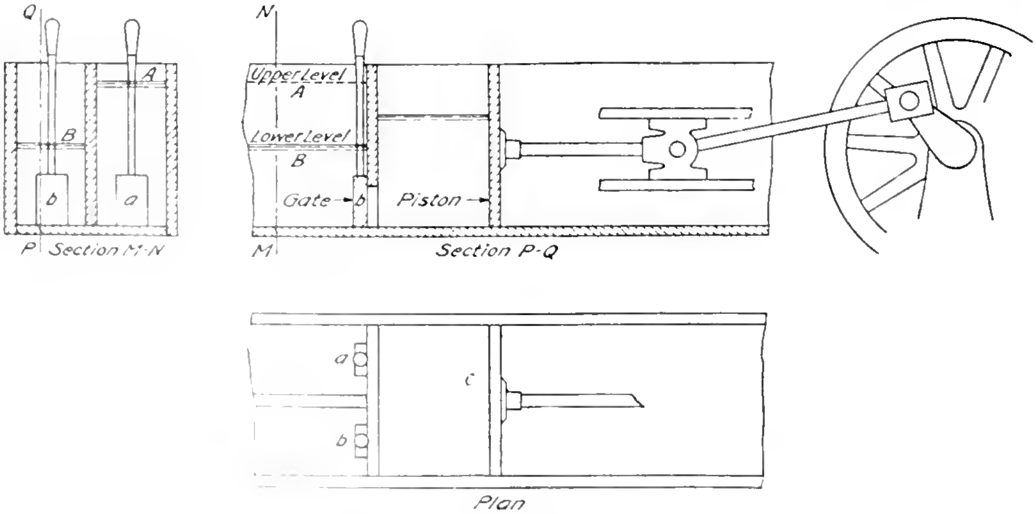

Fig. 2. A Hydraulic Analog to Carnot Cycle

This analog, in spite of its usefulness for the beginner, has a limited application only, and moreover, some of its inconsistences are apparent at once. For instance, no external

constant, its temperature (water head) drops, and the work is performed at the expense of the potential energy of the water.

* E. Mach, *Principien der Waermelehre*, p. 329.

The piston is allowed to move until the level of the water sinks to that in the reservoir B, which corresponds to the refrigerator in thermodynamics. The gate b is now opened and the piston begins its return stroke, forcing the water into the reservoir B. At a certain point of the stroke, the gate b is closed and for the rest of the movement the level of the water behind the piston rises to its original level, just as in the reservoir A. The two last parts of the cycle are analogous respectively to the isothermal and adiabatic compressions in Carnot cycle.

The result of the process is that a certain quantity of water has been transferred to a lower level, and the energy thus lost has been converted into mechanical work. Not all of the energy of the water taken from the higher reservoir can be converted into work, since the "exhaust" water in the motor must be at least at the level of the water in the reservoir B. The efficiency of the arrangement depends upon the ratio of the heads in the two reservoirs above the sea-level. Similarly, the efficiency of a Carnot cycle depends upon the ratio of the absolute temperatures of the source of heat and the refrigerator.

Mach has suggested also an electrical analog, in which temperatures correspond to electrostatic potentials and entropy takes the place of electric charges. Let two very large metal bodies A and B be kept at constant potentials like the reservoirs A and B in Fig. 2. Let a conducting sphere C, of a radius R_0, be brought in contact with the body A, which has a higher potential T_1, and let the sphere become charged with a certain quantity of electricity ϕ_1. Let now the sphere C expand to a larger radius R_1, keeping in contact with A; in other words, expanding at constant potential. The charge (or the entropy) increases to a value ϕ_2, and an amount of electrical energy equal to $(\phi_2 - \phi_1)\ T_1$ is thereby transferred at constant potential from the source A to the sphere C. Now let the connection between the two be broken and let the sphere be allowed to expand further to a radius R_2 such that the potential of the sphere drops to the value T_2, equal to that of the refrigerator B. A connection is now established between B and C, and the sphere is compressed by an external force so as to transfer the part $(\phi_2 - \phi_1)$ of the charge to B. Finally the connection is broken and the sphere is further compressed to its original radius R_0, its potential acquiring again the value T_1. The cycle may then be repeated in the same order.

Proposed Analog

In the proposed analog, we endow matter with a certain structure which permits us to form a clear picture of the phenomena in which temperature and entropy enter. No claim whatever is made that the suggested picture is more than an analog. It cannot be called an hypothesis of the structure of matter.

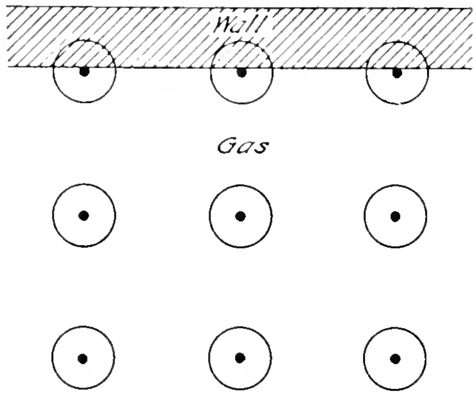

Fig. 3. Particles of a Gas, Each Surrounded by an Atmosphere of Caloric

Consider gases and vapors to consist of very small particles (Fig. 3) separated by comparatively large spaces. The particles are assumed to be absolutely rigid and not in any motion vibratory or translational, as is presupposed by modern theories of matter. To account for heat phenomena, we introduce again the old discarded *caloric*, or a hypothetical *heat fluid*. An atmosphere of this caloric is supposed to surround each particle of gas, as shown in Fig. 3, the particle itself being conceived as some sort of nucleus for the caloric. This conception of a gas is similar to that of Rankine's, except that he assumes the atmospheres to be elastic, and revolving or oscillating about their central points;* while for our purpose it is sufficient to suppose the substance of these atmospheres to be stationary.

Particles of caloric are supposed to repel each other, like the elements of an electric charge, and this repulsion is taken to be the cause of the elasticity of gases and vapors. *The quantity of caloric in a given weight of gas represents its entropy, while the pressure in the caloric, due to the mutual repulsions of its particles is a measure of the temperature of the gas.* In this wise, the quantity and

* W. J. M. Rankine, *Miscellaneous Scientific Papers*, p. 17.

the intensity factors of heat energy are represented by simple mechanical concepts.

The particles of gas, or the nuclei, attract each other according to the ordinary law of gravitation, but the intermolecular distances being large, these attractions are supposed to be negligibly small as compared to the repulsions caused by the caloric. Incidentally, these small attractions may be said to account for the deviation of gases from Boyle's law, and may be made to explain the behavior of saturated vapors, and the phenomena of liquefaction and solidification, as will be shown below.

The process of communicating heat to a gas can be pictured by saying that the gas is connected to another body in which caloric is at a higher pressure than is the caloric in the gas. The caloric is thus forced to flow from the heat source into the gas and becomes associated with the atmospheres of its particles, increasing its entropy, which, according to the definition, is the quantity of caloric. Similarly, withdrawal of heat consists in connecting the gas to another body in which caloric is at a lower pressure, so that part of the heat matter or caloric constituting the atmosphere is dissociated and transferred to the colder body, where it becomes part of the atmospheres of its particles.

The intrinsic energy of a gas is the sum of the energies necessary to build up the atmospheres of its particles, bringing these particles together against their mutual repulsion. It will thus be seen that the heat energy, according to this picture, depends upon the temperature and entropy of the gas, in other words, upon the intensity and the quantity factors of thermal energy. This is similar to charging an insulated conductor with electricity: when bringing new infinitesimal charges to the conductor, it is necessary to overcome the repulsion of the charges already communicated to it, and the work done is stored as the potential energy of the charged conductor.

The above picture is not complete in one respect; namely, it does not account for irreversible thermodynamic processes, such as sudden expansion, friction, etc. Assuming that the whole universe were constituted as is described above, the entropy of the universe or the amount of caloric in it, would be constant, since caloric is considered as a sort of fluid, which is exchanged between bodies. But it is known that in reality the entropy of a system increases during an irreversible process, without any heat or entropy being communicated from outside. We shall assume, therefore, that in addition to the free caloric which constitutes the atmospheres of particles, the nuclei themselves contain vast stores of caloric *in a bound state*. Or, going a step further, might we not say that these nuclei are nothing else but that same caloric in a peculiar bound state; this certainly would be in accordance with the modern trend of physical theory to construct matter out of electricity. However, for our picture it is sufficient to imagine the nuclei of matter to be "porous," the crevices being filled with bound inactive caloric, as a sponge is soaked with water.

As long as heat exchange takes place infinitely slow, all the particles of the gas participate in it equally, and the process is reversible, that is to say, may go either way. If, however, heat is communicated to only one part of the gas, or at a high rate disturbing the temperature balance, or if the equilibrium of some particles is disturbed mechanically, as during the process of friction, then some of the bound caloric is liberated out of the crevices of the nuclei. This assumption is made to account for the fact that entropy increases during an irreversible process. Entropy or caloric once liberated cannot be reduced back to the bound state, hence the total amount of entropy in the universe increases, this being a well known statement of thermodynamics.

It may be objected to the foregoing view that if a certain amount of gas be subjected to a great number of irreversible processes, it might finally lose all its bound caloric and thus change its physical or chemical properties. But, in the first place, the proposed structure of matter is intended merely to give a tangible picture of the actual phenomena—an analog which may go so far and no further. In the second place, it is possible to assume that a molecule of gas contains an enormous quantity of bound caloric, so that it is impossible to say how many millions of changes it has to undergo before the change would become noticeable. A minute piece of radium emits its powerful radiations for years without changing in weight or in other properties to any measurable extent.

The proposed structure, Fig. 3, presupposes an action at a distance, leaving unexplained the mechanism of repulsions between molecules. A more concrete picture is shown in Fig. 4. Here rigid molecules of gas are connected by spiral springs which tend to separate the molecules from each other, thus imitating the elasticity of actual gases. The number of turns in each spring is analogous to entropy of the gas, while the mechanical stress in the material of the springs may be compared to temperature. An isothermal expansion consists in adding new turns to springs, leaving the stress unchanged; an adiabatic expansion corresponds to letting the springs expand without adding new turns. In this case the stress in the springs, or the temperature decreases. This analogy is perhaps simpler to understand than that of caloric atmospheres, but it is also cruder, and therefore is not followed out any further in the present article. The reader will have no difficulty in adapting the theory of gases, vapors and liquids, given below on the basis of molecular atmospheres, by using intermolecular spiral springs instead.

The principal difficulties in the way of a clear understanding of thermodynamic phenomena, from a physical point of view, are:

(1) The mysterious mechanism of conversion of heat into mechanical work, and *vice versa*.

(2) The temperature and the pressure of a gas being closely interdependent; but while one is a thermal property, the other is a mechanical property.

(3) Entropy, in spite of its great practical importance, remains but an abstract mathematical expression.

(4) The changes from a liquid or a solid state into a gaseous state with the latent heats, critical point, change in volume, etc., are to be accepted as separate facts, without seeing the internal mechanism of these changes.

(5) It is not clear why the state of a substance may be defined by its thermal characteristics, entropy and temperature, as well as by its mechanical features, volume and pressure.

(6) In the study of irreversible phenomena the fact of an increase in entropy without communication of heat from outside is obscure and seems contradictory in view of the original definition of entropy as $d\phi = dq/T$.

The analogy described above makes an understanding of these points much easier because one of the forms of energy, namely heat, is eliminated from the beginning, and its factors, temperature and entropy, are replaced by simple mechanical properties of a hypothetical fluid. Therefore an understanding of the six points enumerated above is facilitated in the following manner:

(1) The conversion of heat into work is replaced by a conversion of the potential energy of mechanical repulsions between particles into external work.

(2) Temperature, being compared to the pressure or potential of the caloric, naturally

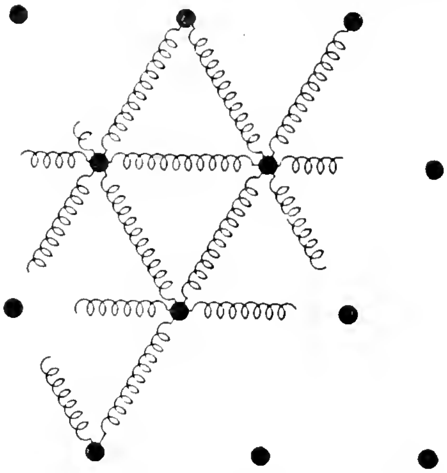

Fig. 4. Repulsions Between Particles of Gas Represented by Spiral Springs

determines the forces of repulsion between particles, hence enters as a factor which determines the pressure of the gas.

(3) Entropy becomes simply the quantity of hypothetical caloric or heat-matter, a concept easy to understand. Communication of heat is pictured as adding a certain quantity of this matter at a certain pressure; that is, against definite repulsive forces.

(4) Changes of state are easily explained by considering the repulsive forces of the caloric and the forces of attraction between the nuclei.

(5) The physical state of a body is completely defined by its entropy and temperature (provided that a zero point of entropy is given), because these two determine the size of molecular atmospheres, and the distances at which these atmospheres must be placed in order that the caloric may have the required pressure. Hence, the volume of the gas and the forces of repulsion which determine its pressure become known.

(6) The study of irreversible phenomena is simplified by the assumption of liberation of bound caloric whenever unbalancing or mechanical shocks take place within the mass of the substance.

Some fundamental thermodynamic phenomena will now be described, using the language of the caloric theory, the structure of matter being assumed to be that shown in Fig. 3.

Perfect Gases

A perfect gas, by definition, is one in which the distances between molecules are so large

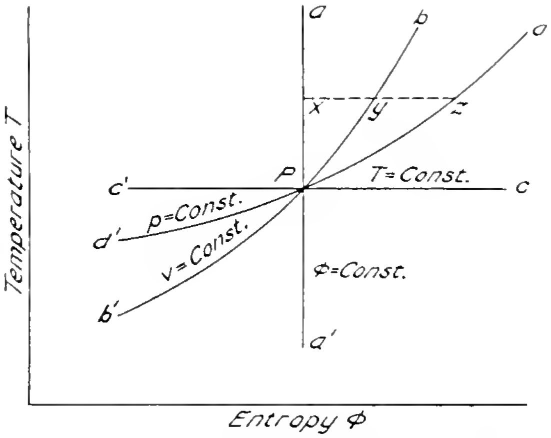

Fig. 5. Thermodynamic Changes in a Perfect Gas Represented in Terms of its Entropy and Temperature

that the forces of attraction between them may be neglected altogether. The properties of such a gas are determined completely by the chemical structure of the molecule and by the quantity and pressure of the caloric associated with it. Let us consider four fundamental changes in such a gas, namely:

(a) At constant entropy (adiabatic);

(b) At constant volume;

(c) At constant temperature (isothermal);

(d) At constant pressure.

In all cases the changes will be presupposed to be so slow and uniform throughout the mass of gas that no bound caloric is liberated, hence the processes are reversible. In the following treatment, a kilogram of gas is supposed to be enclosed in a cylinder, the volume and the pressure being varied by means of a piston.

(a) *A change at constant entropy.* Let P (Fig. 5) represent a definite state of a kilogram of gas in the temperature-entropy diagram, and let Q (Fig. 6) represent the same state in the pressure-volume diagram. A change at constant entropy is represented in Fig. 5 by the vertical line aa', the arrow indicating the direction in which the temperature increases. Referring to Fig. 3, it is easy to describe the physical character of the process, as shown by the corresponding curve $\alpha\alpha'$ in Fig. 6. Let the change be accompanied by an increase in volume, the distance between molecules increasing. By supposition, the entropy, or the quantity of caloric, remains constant, so that no heat is added to the gas; in other words, the molecular atmospheres in the new state possess the same amount of caloric as in the original state. The temperature is lower in the new position because we have defined temperature as the pressure to which caloric is subjected on account of the mutual repulsions of molecular atmospheres. This repulsion decreases as the distance between particles increases. Hence, the change is represented by the line Pa'.

The pressure of the gas decreases for two reasons: first, the repulsions between particles decrease, as is explained above, and secondly, there are fewer particles per square meter of the piston in the new state than in the original state of the gas. Therefore, the pressure-volume curve has the shape $Q\alpha'$, the pressure approaching zero as the volume increases indefinitely.

(b) *A change at constant volume.* Let a certain quantity of gas be heated at constant volume, or, according to our analogy, be connected to a body containing caloric at a higher pressure. Caloric will then flow into the gas and become associated with its atmospheres. Since the distances between the molecules remain the same, the repulsions within the caloric increase, so that both pressure and temperature increase. This change is represented by $Q\beta$ in Fig. 6, and by Pb in Fig. 5. If the gas is cooled, instead of being heated, the change is represented by the parts $Q\beta_1$ and Pb_1 of the curves.

(c) *A change at a constant temperature.* This change may be accompanied either by an increase or by a decrease in volume. Let us consider an isothermal compression. The pressure in the caloric (but not in the gas) must, by assumption, remain the same as the distance between the molecules decreases. If the entropy were to remain constant, the pressure in the caloric would increase, because the repulsions between particles of the caloric are stronger at shorter distances. Hence, in order to keep the same temperature of the gas, part of the caloric must be removed as the intermolecular distances decrease. In other words, an isothermal compression is accompanied by withdrawal of heat, and the entropy of the gas decreases. This is shown by curve Pc' in Fig. 5.

The corresponding curve $Q\zeta'$ shows the increase in pressure during this process; this curve is not as steep as the curve $Q\alpha'$ of the adiabatic compression, because during the latter process no entropy or caloric is abstracted from the gas, so that both the pressure and the temperature increase more rapidly. An isothermal expansion is represented by the parts *Pc* and *Qζ* of the curves. Here entropy must be added to the gas, as otherwise the pressure in the caloric would decrease with the increase in distance between the molecules.

(*d*) *A change at constant pressure.* Let the process be an expansion represented by *Qδ* in Fig. 6. Since with the increase in volume fewer particles of gas press upon one square unit of the area of the piston, the force of repulsion exerted by each particle must be increased in order that the sum of the forces per unit area of the piston remain constant. Without the addition of caloric, both the temperature and the pressure decrease during the expansion, as is shown by the curves *Pa′* and *Qα′*; hence in the process under consideration, entropy must be added during the expansion. Next it can be shown that more entropy must be added than for the same change in volume when the expansion is isothermal. This follows directly from the shape of the curve *Qζ′*, because there the caloric added is not sufficient to keep the pressure constant. Therefore, when enough caloric is added to keep the pressure constant, the temperature of the gas increases, and hence the curve has the shape *Pd*, showing that the temperature increases with the entropy.

It remains to show that *Pd* lies below the curve *Pb* corresponding to a constant volume. This is equivalent to saying that for a given increase in temperature, such as *Px* in Fig. 5, more caloric must be added along *Pd* than along *Pb*. This becomes self-evident when it is remembered that in the state represented by the point *z*, the particles are further apart than in that represented by point *y*, so that more caloric is necessary to produce the same pressure in it. Hence, *xz* is larger than *xy*, and the curve *Pd* lies below *Pb*.

Another way of demonstrating this is by saying that with the expansion at constant pressure the energy added to the gas is partly expended in external work, so that with the same limits of temperature more entropy must be added when the volume increases. A direct result of this statement is that the specific heat at constant pressure is larger than the specific heat at constant volume.*

* Specific heat is represented graphically by the length of the subtangent to the temperature-entropy curve. We have by definition $dQ = cdT = Td\phi$ so that $c = T(d\phi/dT)$, which is the length of the subtangent to the curve $T = f(\phi)$.

The diagram in Fig. 5 is divided by the line *aa′* into two parts. For all points to the left of this line the entropy, or the quantity of caloric, is less than in the state represented by the point *P*; for all points to the right the

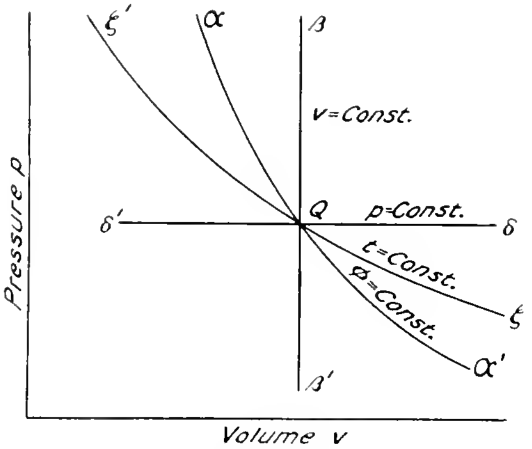

Fig. 6. Thermodynamic Changes in a Perfect Gas Represented in Terms of its Volume and Pressure

entropy is larger than in the initial state represented by *P*. Similarly, the line cc_1 divides the plane into two parts corresponding to temperatures respectively higher and lower than at *P*. The curve *bb′* separates points of expansion from those of contraction and the curve *dd′* points of pressure higher than that in the initial state *P* from those lower than at *P*. Hence, it is possible to define qualitatively the state of a gas represented by a point, according to its place in one of the eight sectors of the diagram.

The pressure-volume diagram (Fig. 6) is similarly divided into eight sectors. In this wise, an arbitrary thermal change of state may be represented by a succession of two or more standard changes. One must keep in mind, however, that the heat added or subtracted and the external work performed depend upon the path, while changes in entropy and in intrinsic energy are independent of the path between two points, each representing a state of gas.

Vapors, Liquids and Solids

When the temperature of a gas is reduced and the pressure is increased, particles are brought closer and closer together, so that finally the forces of attraction between nuclei become of the same order of magnitude as the repulsions between the caloric atmospheres. Under these circumstances, changes of state are determined by the balance of repulsive and attractive forces, and in general three kinds of aggregation are possible (Fig. 7).

The first state, that of a vapor, is similar in general to the state of a perfect gas considered in the previous section, except that the disturbing action of attractive forces modifies the simple laws of change of state.

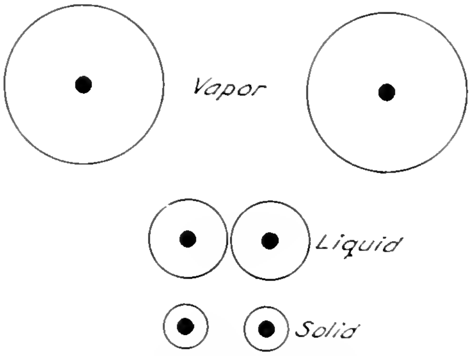

Fig. 7. Relative Distances Between Particles, and the Sizes of Caloric Atmospheres in a Vapor, Liquid and Solid State

By removing some caloric, the particles may be brought much closer together. Without the central nuclei, this would involve enormous repulsive forces, but the attraction between the nuclei compensates for a considerable portion of the repulsion, so that a new state with new properties becomes possible at moderate pressures—that of a liquid.

By removing still more caloric, it is possible to make the molecular attractions larger than the repulsions, so that the particles are held together at a definite distance without external pressure. This is the solid state. To change from the gaseous to the liquid state, considerable amounts of entropy or caloric must be removed. The energy thus abstracted per kilogram of the substance is called the latent heat of evaporation, when the temperature, or the caloric pressure, is the same in both states. Similarly, the energy abstracted per unit weight during the process of solidification is called the latent heat of fusion.

If the original temperature of a vapor is sufficiently high, the forces of repulsion between the caloric atmospheres increase so rapidly when the molecules are brought closer together, that it is impossible to find another position of equilibrium at the same pressure and temperature. This means that at this temperature the vapor cannot be condensed or liquefied. The highest temperature at which liquefaction is possible is called the critical temperature; to this temperature corresponds a definite pressure and volume, also called critical.

Irreversible Changes

It is mentioned above that in order to explain irreversible phenomena it is necessary to assume some of the caloric to be in a bound state within each molecule. This bound caloric is supposed to be liberated during irreversible phenomena, in order to account for an increase in entropy during such phenomena. We shall now consider some irreversible phenomena in the light of this picture.

(*a*) *Joule's experiment.* Joule's classical experiment consisted in expanding a gas without performing external work. A vessel was filled with a gas, and connected by a pipe provided with a stop-cock to another vessel maintained at a high vacuum. The whole system was immersed in a liquid bath. When a thermal equilibrium was established everywhere, the stop-cock was opened and the pressures in the two vessels were allowed to equalize. After the equilibrium had been again established, it was found that the temperature of the system was not changed. This showed that no energy was required to separate particles of gas, and no heat was added to the gas, since no external work was performed. At the same time it can be shown mathematically that the entropy in the expanded state is considerably higher than that in the initial state. In other words, the entropy of the system is in this case increased without adding any heat from outside. This can be explained in the light of our analogy as follows: The experiment shows the temperature in the expanded state to be the same as in the original state; this means that the pressure in the caloric remains the same. But in the final condition the particles are further apart; hence, in order to produce the same "caloric pressure" there must be more caloric in each molecular atmosphere. But since no heat has been added from outside, this caloric must be liberated out of the molecules themselves.

The liberation of the bound caloric may be explained as due to an unbalancing of pressure in the mass of the gas, and to mechanical shocks between the molecules during the process of equalizing of pressures. The efflux of the gas being sudden, it is accompanied by eddies; moreover, new molecules streaming out of the first vessel collide with those in the second vessel; and the energy of these shocks, not being utilized for external work, goes to liberate the bound caloric. Since the intrinsic energy of a perfect gas is a function of its temperature only, or of the pressure of its caloric, enough caloric is liberated to bring the pressure to its former value. This is required by the law of conservation of energy: No external work was performed, and the gas possesses no kinetic energy at the end of the experiment; therefore its potential energy must be the same as in the beginning.

The process is irreversible, because by assumption the caloric once liberated cannot be reduced again to the bound state. Should the gas be compressed to its original volume, the new caloric previously added to the old would raise the temperature of the gas. Or, if the compression be done at a constant temperature, some of the caloric has to be removed. In either case the conditions at the end are different from those at the beginning: mechanical work must be performed and an equivalent amount of heat stored in the gas or conducted away. A reversible process is by definition one which being repeated in the opposite direction cancels separately the work performed and the heat liberated or spent. In the light ot our analog, only such processes are reversible in which no bound caloric is liberated. Once some caloric is liberated the process becomes irreversible.

Clausius' famous maxim, "the entropy of the world tends toward a maximum," receives thus a simple meaning. Most processes in nature are more or less violent, unbalanced, and hence, using our picture, are accompanied by the liberation of some bound caloric. Thus the entropy of the world (the total quantity of liberated caloric) increases indefinitely, while the total energy remains constant.

(*b*) *Liberation of heat by friction.* Let two bodies, assumed to be poor conductors of heat, be rubbed one upon another: The process is necessarily accompanied by shocks communicated to the particles in contact and the energy of these shocks causes some caloric to be liberated. In this way, the pressure of the free caloric, or what is the same, the temperature of the bodies, is raised. The process is irreversible: a mere cooling of the surface would conduct away the extra caloric without producing any mechanical motion.

(*c*) *Conduction of heat.* Let two reservoirs of heat, A and B, be connected by a heat conductor C. Let the body A be at a higher temperature than that of the body B. The conductor C, through which heat is flowing, possesses temperatures varying between those of A and B.

The transfer of heat may be pictured as a flow of caloric from one molecule to the next, the cause being the difference of pressures in the atmospheres of these molecules. The molecule nearest the body B, being a little warmer than the body B itself, gives up part of its caloric, with the result that some caloric flows into it from the next warmer molecule, tending to equalize the caloric pressures. It is easy to see, however, that such a mechanism would contradict the law of conservation of energy, because the final result would be a transfer of some caloric from a higher to a lower pressure, without the performance of an equivalent amount of external work. But since there is no possibility of performing external work in the phenomenon itself, the energy of the caloric serves to liberate bound caloric of the molecules of the conductor C.

The phenomenon may be compared to that of a snow ball rolling slowly down a snow-covered hillside, and increasing in size by the addition of snow on its path. The speed of the ball does not increase, but its energy is used to accelerate new snow which adheres to it. So in the case of conduction of heat, each transfer of caloric from one molecule to the next is accompanied by the liberation of some bound caloric from the nucleus of the latter molecule. In the end, the lower reservoir receives more entropy than is lost by the upper reservoir, this being necessary to satisfy the law of conservation of energy.

The phenomenon is irreversible, first because the caloric once liberated cannot be reduced again to the bound state, and secondly, because it is impossible to make the caloric flow from a lower to a higher pressure.

GENERATING APPARATUS FOR WIRELESS TELEGRAPHY AND TELEPHONY

By E. F. W. Alexanderson

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This article commences with a few notes on the generating equipments used in present-day wireless telegraph stations in which the spark method with 500-cycle current is employed. It then enumerates the reasons why this system will probably be superseded in the near future by those using continuous trains of waves generated by high-frequency alternators. The paper then describes the design of an inductor alternator for producing current at 100,000 and 200,000 cycles direct, and an alternator in which telephone current is used for field excitation, and in which the current generated by the armature has a volume larger than the energy used in the telephone for excitation. The article contains many pertinent comments on what are at present some of the limiting features in wireless telegraphy and telephony development.—Editor.

The object of this paper is to indicate the probable course of development in the wireless art rather than to give detailed descriptions of apparatus which is in use at the present time, information upon which can always be obtained from modern text books and current literature.

Of recent years the station equipment for transmitting messages without wires has become more or less standardized, the generating apparatus usually being designed to furnish a current having a frequency of approximately 500 cycles. A high voltage transformer is introduced into the 500-cycle circuit and is arranged to create a spark impulse during every half-cycle. The details of the various equipments differ in the arrangement of the spark circuit, but the general tendency is the same, viz., to suppress the arc in the spark circuit immediately after the first energy impulse has been given, so as to leave the high frequency circuit free to swing, with its natural period of oscillation, without any tendency to pump back into the generating apparatus.

The introduction of the 500-cycle generator marked a great improvement upon earlier methods, because of the increased efficiency which was obtained in both the sending and the receiving circuits. Upon observation it became clear that the human ear is most sensitive to energy impulses at a rate of 1000 per second, which corresponds to an alternating current of 500 cycles. Furthermore, comparing a 500 cycle system with those in which a lower frequency is employed, an additional advantage lies in the fact that it is possible to transmit a greater amount of energy with the same size of antenna, since the energy which can be transmitted at any one impulse is limited, and the average energy is proportional to the number of impulses per second. The currents transmitted by this system partake of the nature of an impulse at every one-thousandth of a second, a train of waves following the impulse with a decreasing amplitude, and with a frequency depending upon the natural frequency of the antenna and the tuning arrangement used in combination therewith. The receiving apparatus for handling the messages consists of a telephone. Inasmuch as the telephone cannot respond to the high frequency of the electric waves, a form of rectifier must be interposed so as to change the vibrations into a uni-directional flow of current. With such an arrangement, the telephone receives 1000 current impulses per second all in the same direction, and the membrane of the telephone gives a note which is perceived by the operator.

There is no doubt that the apparatus in use at the present day will be considerably simplified and improved; and it may be of interest here to give a brief description of a type of 500-cycle alternator which has been developed by the author in order to simplify the generating equipment used with the spark method of transmission. The object in mind here has been to provide a machine that will occupy less space than the former equipment, while at the same time reducing the cost. Briefly, the apparatus simplifies the generating unit mentioned above by combining in a common frame both the direct current and alternating current windings. The economies which have thereby been effected are of the same nature as those which are inherent in the ordinary synchronous converter as compared with the motor-generator set, although the principle which has been adopted is somewhat different. In the ordinary converter, the alternating current and direct current circuits make use of the same field and also the same armature winding, in which case the frequency of the alternating current must bear a definite ratio to the number of poles and the speed of the direct current motor. In the 500-cycle converter there is no relation between the alternating frequency and the frequency in the direct current armature, but nevertheless the same magnetic field and the same winding for field excitation are employed. The principle of the machine is as follows: In any direct current motor or generator, eddy currents are generated in the pole faces. The energy produced by these eddy currents is suppressed as far as possible by the use of laminated poles designed to break up the eddy current circuit. In the 500-cycle converter, eddy currents are emphasized and represent the output of the machine. These currents are generated on a winding suitably placed in the face of the stationary pole. The magnetic structure of the alternating current winding is shown in Fig. 1, which represents a 2000-cycle converter built on the same principle as the 500-cycle converter. The machine is made from a standard direct current motor, and the alternating current winding does not occupy any space that would be used for any other purpose.

The Advantages of the High-Frequency System

Although considerable economies are effected by the substitution of a single-unit converter for the two-unit motor-generator set, and although, as has been pointed out, the present phase of the wireless art refers almost exclusively to telegraphy conducted by the spark method using 500-cycle generators, there are a number of reasons which lead one to the belief that this type of wireless outfit will, in the near future, be superseded by the system in which a continuous train of waves is used, generated by high frequency alternators. These reasons briefly are as follows:

(1) The antenna is the most expensive part of a sending station, and the radiating power of any certain antenna is much greater with continuous train of waves than it is with the spark method. With the spark system the antenna receives 1000 energy impulses in a second, each of which is followed by a train of waves as far as it is possible. With the high frequency alternator, however, the same antenna will receive 200,000 or 400,000 energy impulses per second if the 100,000 and 200,000 cycle alternators are used. The radiating power of the antenna is limited by the break-down voltage of the air during any one impulse, and therefore it is obvious how it can be used to greater advantage with the increased number of impulses.

(2) The voltages induced in electric circuits in the proximity of the sending stations

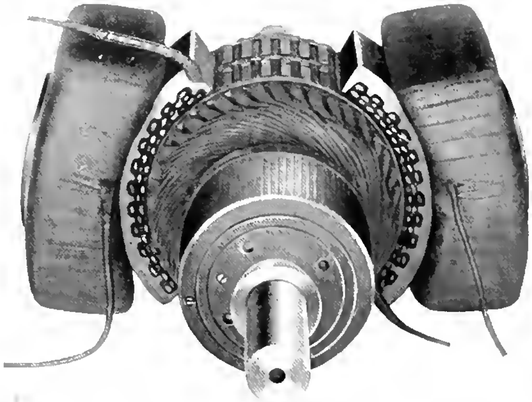

Fig. 1. D-C. Armature, A-C. Pole Face Winding and D-C. Field Coil of a 2000 Cycle Converter

are apt to be very high, and it is possible that rules of legislation may be introduced in order to protect property from destruction. The advantages of the high frequency alternator apply for the same reasons as above. Inasmuch as the number of energy impulses per second is so much greater, the voltage involved in each impulse may be correspondingly lower to radiate the same energy; and the consequent induction and destructive effect on other electric circuits will be correspondingly lower.

(3) The possibilities for tuning, or elimination of interferences, are much greater with the high frequency alternator system. With the spark system each impulse is followed by a short train of rapidly dying waves, and the number and power of the successive waves give the possibility for tuning. If only the initial wave were radiated no tuning would be possible. With the high frequency alternator the wave train is continuous, and the possibility for selective tuning is limited by practically nothing else than the possibilities for maintaining a constant speed of the generating apparatus.

(4) The spark system is used for telegraphy only, and cannot be used for the telephone; whereas a high frequency alternator system can be used equally well for both telegraph and telephone. In the former method, the only note that can be transmitted and received by the telephone is one which has a frequency corresponding to the 500-

cycle generating apparatus, and a signal can be given only by interrupting the sound in accordance with the Morse telegraph system. In order to transmit articulate speech, it is

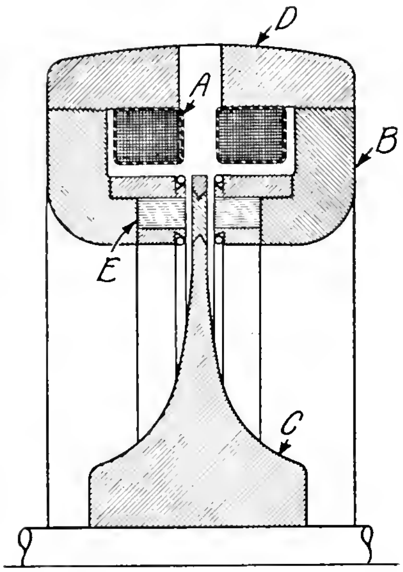

Fig. 2. Partial Section Through High-Frequency Alternator

necessary that a continuous flow of energy be used, which can be modulated in accordance with the vibrations of the human voice in articulate speech. In the 500-cycle commercial equipments all the requisite apparatus is present for the transmission of telephonic speech with the exception of the generating apparatus and the transmitter. The sending antenna with its tuning apparatus, the receiving antenna with its detector apparatus, and the telephone receiver are built on the same principle, whether they be used for telegraph or telephone. Inasmuch as a trans-atlantic communication by wireless telegraphy has been established for some years on a commercial basis, it is probable that it will soon be followed by a corresponding telephonic communication, and that the wireless telephone will be as much more important for business purposes as the wire telephone is more important than telegraphy. With regard to the design of a telephone transmitter capable of handling sufficient power, various schemes for overcoming the difficulties have been proposed; and it is probable that the next few years will see the apparatus available in commercial form.

High-Frequency Generating Apparatus

The high frequency alternator designed by the author is the result of several years of experimental work undertaken at the request of Prof. Fessenden. When this work was begun, although the use of continuous trains of waves for wireless transmission had been contemplated, no means had been provided, or were even believed possible, for generating such frequencies as were required for this method of transmission. In 1908 the author, in a paper before the American Institute of Electrical Engineers, described an alternator built for 100,000 cycles, previous to which the highest frequency which had been produced was 10,000 cycles—entirely inadequate for the purpose in hand. It was thought at the time that the 100,000 cycle alternator represented nearly the limit of what could be achieved. Since that time, however, a machine has been built for directly generating frequencies of over 200,000 cycles; while a frequency of 400,000 cycles has been produced by the use of this same machine in combination with a mercury arc rectifier.

The alternator is of the inductor type, and is provided with a novel arrangement of the magnetic circuit, allowing the construction of a rotor which can be operated at exceedingly high speeds. In the final form of the alternator (shown in section in Fig. 2), the rotor, *C*, consists of a steel disk with a thin rim and hub shaped for maximum strength. The field excitation is provided by two coils, *A*, located concentric with the disk and creating a flux that passes through the cast iron frame *D*, the laminated armature with its teeth, and the disk. *B* represents the two armatures which are secured in the frame by means of a thread, in order to allow an adjustment of the air-gap, the laminations carrying the conductors being located at *E*. Instead of poles or teeth, the disk *C* is provided with slots which are milled through the thin rim so as to leave spokes of steel between the slots. The slots are filled with a non-magnetic material which is riveted in place solidly, in order to stand the centrifugal force and to provide a smooth surface on the disk so as to reduce air friction.

The standard 100,000 cycle rotor with 300 slots is shown in Figs. 3 and 4. A complete view of a commercial high frequency alternator is shown in Fig. 5. The set is driven by a direct current shunt motor fitted with commutating poles running at 2000 r.p.m. which drives the alternator through a single-reduction, 10 to 1, helical-cut gearing at a speed of 20,000 r.p.m. Forced lubrication is provided for all the high-speed bearings, the pressure being derived from a small oil-pump located at the motor end, as shown in Fig. 5, and chain-driven from the motor shaft. Reference to Fig. 3 will show that both of the alternator bearings are thrust bearings; and in order to prevent any possibility of binding between these two thrust bearings, due to expansion of the shaft from heating, the machine is provided with a system of equalizing levers to compensate for such shaft heating. Any tendency which would cause a change in air-gap is counteracted by the automatic action of the levers. If the air-gap should tend to change at either side, the magnetic attraction at that side would cause an additional pressure and consequent heating on the thrust bearings at that end; and a consequent expansion of the shaft there would bring the rotating disk back to a central position. Without some such arrangement any inaccuracy in lining up the machine, etc., would be cumulative in its action; and the increase of pressure would lead to further wear of the bearings, and further increase of the fault, with the final result that binding would ensue.

A need has arisen for machines of even higher frequencies than 100,000 cycles, but the design of an alternator of this pattern for 200,000 cycles presents considerable difficulties. The standard 100,000 cycle alternator has 600 slots; and consequently the same type of winding for 200,000 cycles would require 1200 slots. A new type of winding was therefore

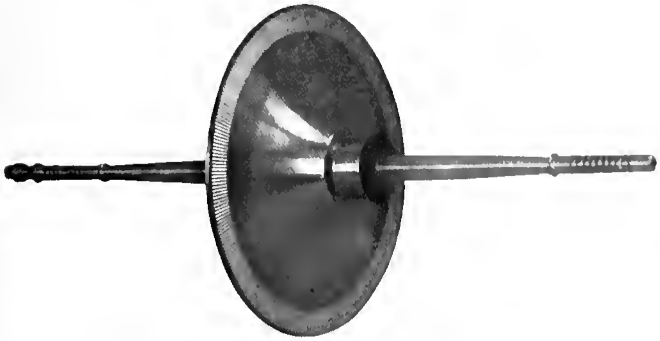

Fig. 3. Rotor and Shaft of Standard 100,000 Cycle Alternator

devised which allows the use of two-thirds as many slots as the effective number of poles. Figs. 6, 7 and 8 show the difference between the standard winding and the special winding. Where this special winding is used for the 100,000 cycle alternator, 400 slots are used instead of 600, while in the 200,000 cycle machine, 800 slots are employed instead

Fig. 4. Rotor of Standard 100,000 Cycle Alternator

of 1200. This form of winding may be applied to the design of machines of even lower frequency than those mentioned, if it is particularly desired to use wider slots and a greater amount of insulation. Both of the foregoing designs embody great simplicity in the construction of the rotor, which allows the use of very high speeds; and a much higher frequency may safely be obtained in this manner by direct generation than can be produced by those designs in which a laminated rotor with windings and collector rings is employed, since the latter construction necessarily involves a lower operating speed.

The transmission of messages by wireless telephone has been carried out successfully over distances as great as 200 miles by the use of the 100,000-cycle alternator. With this machine, the sending circuit becomes extremely simple. The alternator being connected directly between the antenna and ground, generates a potential of 100 to 200 volts, which in itself is rather low for wireless transmission. It is found, however, that by the use of suitable tuning apparatus the potential of the antenna can be raised to the break-down point of the air; so that the sending capacity is not limited by the potential of the alternator, but only by the radiating capacity of the antenna.

From the foregoing description of this alternator, it is evident that the amount of power which can be generated by a machine of any given size decreases with increasing frequency. At moderate frequencies like 50,000 cycles, power can be generated in greater quantities than at such frequencies as 200,000 and 400,000 cycles. This, however, is rather a fortunate circumstance; because a frequency of 50,000 cycles can be used to advantage for transmission over great distances where the antenna is comparatively high and its natural frequency is correspondingly low; whereas small antennæ for short distance transmission require a higher frequency, the required amount of power, on the other hand being less. The sending apparatus which has been employed up to the present in communication by wireless telephony has been a high power water-cooled carbon transmitter, designed to handle currents corresponding to the output of the alternator.

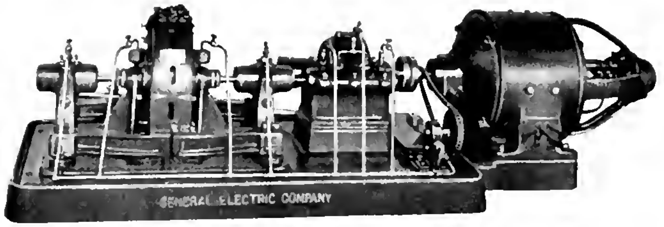

Fig. 5. 2 Kv-a. 100,000 Cycle Alternator Driven Through Single-Reduction Gearing by Direct Current Motor

In connection with long distance telephone transmission, it was foreseen some time ago that ultimately a limit would be reached where a sufficiently large power microphone could not be built. The author therefore made some experiments, and several years ago made a successful demonstration with a type of alternator in which a telephone current was used for field excitation, and in which the amount of current generated by the armature had a volume considerably larger than the energy used in the telephone for the purpose of excitation. The principle of this machine was somewhat different from that of the ordinary alternator, inasmuch as one winding was used for excitation and for generating the alternating current simultaneously. This arrangement was adopted because it seemed important that a winding design be employed which would involve the least amount of voltage loss through self-induction in the field winding. The self-induction between field and armature is obviously entirely eliminated where the current flows in the same manner.

Briefly, the principle of this alternator is as follows: If a coil is magnetized by direct current and the magnetic circuit of the same is closed through a moving part which continually varies the air gap, the flux will vary correspondingly, and an alternating e.m.f. will be introduced in the magnetizing coil.

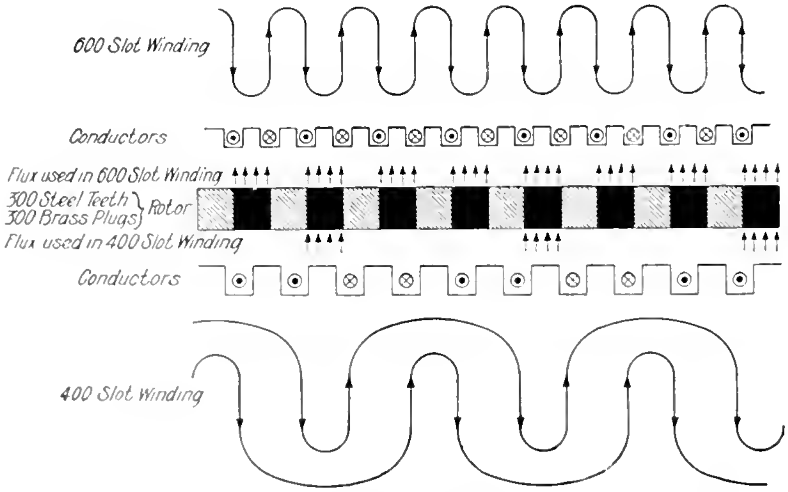

Fig. 6. Winding Scheme for 200,000 Cycle Alternator Using Two-thirds as Many Slots as Effective Number of Poles

In its simplest form the device is inoperative because the alternating voltage is short-circuited upon the direct current exciter. It is, therefore, necessary to use at least two coils connected in such a way that the alternating voltages are induced in opposition in reference to the direct current. This leads to two types of connections. In one the same wire is used for the flow of excitation and the alternating current, the exciting circuit flowing through the two coils in series and the alternating circuit through the same coils in multiple. In the other type of connection different wires are used, the exciting circuit always employing two exciting coils in series so as to eliminate the resulting induced voltage, whereas the alternating current winding can be connected either in series or in multiple. This type of machine has the characteristics that the coil pitch of the winding has no definite relation to the frequency. The winding may cover either one or as many poles as is desired. The frequency is produced simply by the relation of the teeth of the stationary and rotating members.

The first model of this type that was tried was the telephone relay, which was demonstrated experimentally. It had a winding where each coil comprised one tooth. Subsequently the same machine was rewound so as to employ coils comprising several teeth, the magnetic structure being otherwise the same (see Figs. 9 and 10). The voltage in this type of generator being produced by fluctuations in the strength of the magnetic flux, it is essential that the carrier of the flux on the moving member should also be laminated; and this fact constitutes the limitation of the usefulness of this type of machine.

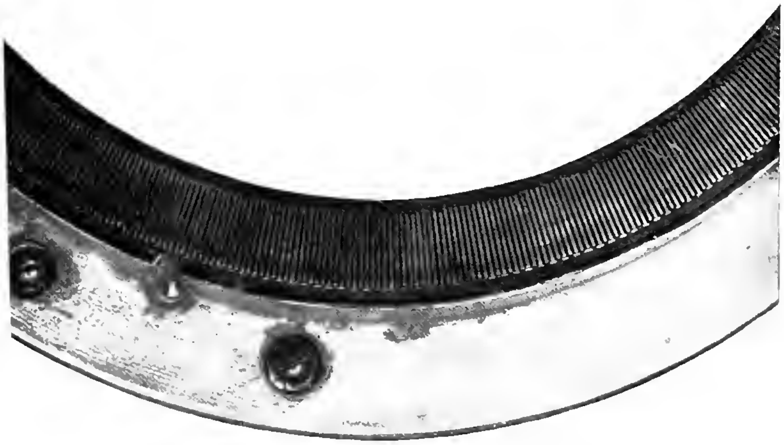

Fig. 7. Standard Winding for 100,000 Cycle Alternator, with 600 Slots

So far it has not been possible to employ speeds greater than two-thirds of the speeds used by a type of alternator with solid steel rotor, and even then with a lower factor of safety. The advantage that might be claimed for the same is the indefinite ratio between the winding pitch and the frequency, which makes it possible to use larger slots than may be used in the purely inductor type of alternator. However, with the improved winding of the inductor alternator described above, using two-thirds as many slots as the number of poles, the advantage is minimized. Whatever may be the usefulness of the high frequency alternator with laminated rotor for special purposes, there is no doubt that the solid steel rotor is better adapted for producing extremely high fre-

Fig. 8. Special Winding for 100,000 Cycle Alternator, with 400 Slots

quencies; and efforts are being made to find a method to control high frequency currents of greater intensity than those which can be handled by a carbon transmitter,

Fig. 9. Stationary Field and Armature of Single-Phase Telephone Relay

even if water-cooling is resorted to for increasing its capacity to a maximum. Some experiments in fact have been made with a high frequency amplifier, which gives

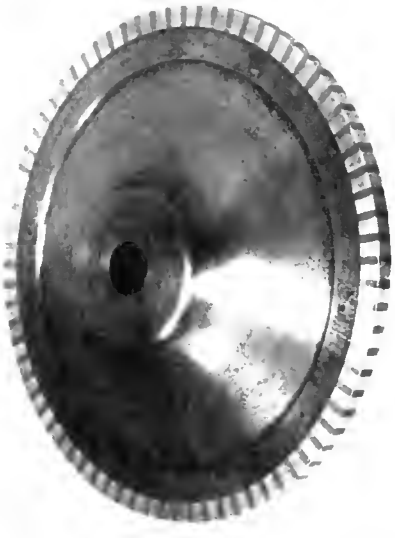

Fig. 10. Revolving Disk of Single-Phase Telephone Relay

promise of the same advantages as the use of the microphone in the exciting circuit, as described above; but yet makes it possible to use an alternator with solid steel rotor.

MAGNETIC LEAKAGE IN TRANSFORMERS

Part II

By J. Murray Weed

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In Part I of this article formulæ were derived for calculating the reactance of transformers and the eddy current losses in the conductors, both of which are directly due to the leakage flux. The present installment has reference to the nature and calculation of the mechanical stresses which are produced by this flux, and which, at times of short circuit, may result in serious damage to, or even destruction of the unit.—Editor.

Mechanical Stresses

Attention was drawn to the subject of Mechanical Forces in Magnetic Fields by Dr. C. P. Steinmetz in a paper read at the Schenectady-Pittsfield Convention of the A.I.E.E. last year. This subject was not new in connection with transformers, as the results of these forces had been seen in the damage or ruin of transformers which had been subjected to severe short circuits, and in building transformers of any size, it had been regular practice for several years to mechanically re-enforce the windings against these stresses. This resulted very satisfactory in most cases until quite recently. Central stations have now reached such enormous capacities as compared with the individual transformers which are connected to their busbars that they permit the maintenance of practically full normal voltage upon the primary terminals of a transformer, even though it be short circuited directly at the secondary terminals, this condition resulting in excessive currents, that are limited only by the impedances of the transformers. The resulting mechanical forces are very large, and have in some cases resulted in the destruction of the transformers, which, when they were built, were thought to be amply re-enforced against strains of this nature.

More careful study has, therefore, been given to this subject, from the standpoint of design. The forces to be considered are set up by the field of magnetic leakage between the windings of the transformer, and are due to those stresses well known

ERRATA. Part I, December Review: Page 755, Numerator of equation (1A) should be $6\pi\eta l\mu$ instead of $\pi\eta l\mu$. Page 757, numerator of equation (5) should be $\sqrt{2}\,\pi B\ldots\eta_0\,\overline{mlt}$ instead of $\sqrt{2}\,t B\ldots\eta_0\,\overline{mlt}$.

to exist in any magnetic field. These stresses, one of tension (or attraction) in a direction parallel to the field, and one of compression (or repulsion) in a direction perpendicular to the field, exist simultaneously with equal values at every point in the field, and are expressed in terms of the magnetic density by the equation:

$$S=\frac{B^2}{8\pi} \text{ dynes per sq. cm.} \qquad (18)$$

where B is the density of the flux in lines per sq. cm.

The physical basis upon which this formula rests may be explained as follows: Assume two infinite parallel planes, one charged with positive magnetic matter of density σ (Fig. 4) and the other with negative matter of the same density. That is, one plane is made up of an infinite number of infinitesimal positive poles, and the other of an infinite number of infinitesimal negative poles, the equivalent number of unit poles per square centimeter being σ for each plane. Since there are 4π lines of force emanating from a unit pole, considering each plane separately, we will find $2\pi\sigma$ lines of force per square centimeter emanating from each side of the plane. Considering both planes together, we find that in those regions which are not between planes, the two fields neutralize each other, producing zero flux, while in the region between the planes they add together, producing a field of density:

$$B=4\pi\sigma \text{ lines per sq. cm.} \qquad (19)$$

A stress of tension may be said to exist in the field B, due to the action of the field of the negatively charged plane upon the infinitesimal positive poles of the positively charged plane. The field of the negatively charged plane is:

$$B=2\pi\sigma \text{ lines per sq. cm.} \qquad (20)$$

The force acting upon a pole of strength m in a field of density B' is:

$$F=mB' \text{ dynes;} \qquad (21)$$

whence the total force acting upon the positive poles found in one square centimeter of the positive plane (which is the stress considered) is,

$$S=\sigma B' \text{ dynes per sq. c.m.} \qquad (22)$$

Substituting the value of B' from equation (20), we have

$$S=2\pi\sigma^2 \text{ dynes per sq. c.m.} \qquad (23)$$

and substituting for σ from equation (19),

$$S=\frac{B^2}{8\pi} \text{ dynes per sq. c.m.} \qquad (18)$$

It is interesting to note that since energy equals force multiplied by distance, and since the force per square centimeter required to separate the planes is $\frac{B^2}{8\pi}$, the energy stored in the magnetic field is $\frac{B^2}{8\pi}$ ergs. We may also make use of this relation of stored

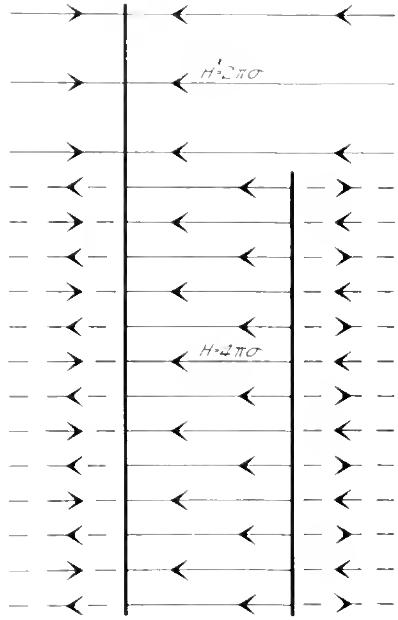


Fig. 4

energy to flux density in determining the stress of compression in directions at right angles to the field. Thus, consider one cubic centimeter of the field, containing $\frac{B^2}{8\pi}$ ergs of energy, and allow it to expand an infinitesimal amount in one direction only; the new dimension in this direction will be $1+dx$. The density of the field will be reduced to

$$B''=\frac{B}{1+dx} \qquad (24)$$

The stored energy will now be

$$\frac{B''^2}{8\pi}(1+dx)=\frac{B^2}{8\pi}\frac{}{1+dx}=\frac{B^2}{8\pi}(1-dx) \qquad (25)$$

The energy released by this expansion is therefore

$$\frac{B^2}{8\pi}-\frac{B^2}{8\pi}(1-dx)=\frac{B^2}{8\pi}dx; \qquad (26)$$

where dx is the distance factor. $\frac{B^2}{8}$ is therefore the force factor, acting upon one square centimeter of surface, so that

$$S=\frac{B^2}{8\pi} \text{ dynes per sq. cm.} \qquad (18)$$

If the distribution of the leakage field in the transformer is known, the stresses will be given by the equation (18), and the total force acting upon any part may be determined by multiplying this stress by the surface upon which it acts.

Considering still the shell type transformer represented in Fig. 1, it is seen that the stress of tension in a direction parallel to the field produces forces tending to draw together the faces of the core from which they emerge. For those portions of the flux which do not enter the core, but merely surround a portion of the windings, these forces tend to throttle or draw together the coils or portions of coils which they surround. The core is probably always strong enough to resist these forces, but their effects in throttling the windings have been seen in some cases.

The stress of compression, at right angles to the field, produces forces tending to separate the high tension and low tension windings. For that portion within the core, this is resisted by the core itself; but for the portion which extends beyond the core, though partially supported by the core through the mechanical rigidity of the coils, additional support is needed to prevent the coils from spreading apart.

The density of the leakage field varies for the different gaps between coils, and consequently the stress differs for the different gaps. If we substitute in equation (18) the value of B from equation (1), we obtain for the stress in any gap.

$$S_{max}=\frac{4n_g^2I^2}{100l^2} \text{ dynes per sq. c.m.;} \qquad (27)$$

where n_g is the equivalent number of turns active at the gap considered, l being expressed in centimeters. This becomes

$$S_{max}=\frac{2.82\times10^{-7}n_g^2I^2}{l^2} \text{ lbs. per sq. in.;} \qquad (28)$$

l being expressed in inches.

The resultant pressure acting on any coil is the difference between the stresses calculated by the above formula for the gaps on opposite sides of the coil. Double section coils must be considered as a single unit, since the sections are solidly spaced apart by a collar. The maximum pressure will be found acting upon the coil adjacent to that gap between primary and secondary where n_g is the maximum and is

$$P_{max}=\frac{2c-1}{c^2}S_{max}, \qquad (29)$$

c being the number of coils between the gaps, where n_g is maximum and where n_g is zero.

The resultant pressure per square inch on the face of the coil produces a maximum shear along the edges of the spacing strips of

$$\text{Shear}=\frac{P_{max}m}{2} \text{ pounds per inch along the strip;} \qquad (30)$$

where m is the distance between strips. This shear tends to slip one turn past the other, where the spacing strips are parallel to the conductors.

The resultant pressure on a coil produces, also, on a strip of the coil 1 in. wide, crossing the spacing strips at right angles, a maximum bending moment of

$$M=\frac{P_{max}m^2}{8} \text{ inch-pounds} \qquad (31)$$

This may result in splitting the coil where the conductors are parallel to the spacing strips, or in bending the conductors where they are at right angles to the spacing strips. This latter action may take place at the top and bottom ends of the coil. The distance between spacing strips is usually greater here, and this should be taken into account by using the larger value of m for this calculation.

The maximum force felt by the core and coil retaining clamps is that due to the stress in that gap between primary and secondary coils where the active ampere turns is maximum. That part of this force which is not due to the pressure on the outside coil is transmitted through the spacing strips from the inner coils. This total force is found by multiplying the pressure per square inch by the surface upon which it acts, which is

$$A=\overline{mlt}l \qquad (32)$$

So that, for the total force, we have

$$F_{max}=2.82\times10^{-7}\frac{n_{gmax}^2I^2\overline{mlt}}{l} \text{ lbs.} \qquad (33)$$

where n_{gmax} is the maximum number of turns active at any gap.

The force existing between those parts of the coils which extend beyond the ends of the core, and must be resisted by the coil retaining clamps, is,

$$F_{max}(\text{Clamps})=2.82\times10^{-7}\frac{n_{gmax}^2I^2(\overline{mlt}-2h)}{l} \text{ lbs.} \qquad (34)$$

where h equals the built-up height of core.

The actual total force varies from zero to F_{max} and back to zero twice during each cycle, with an average value which is ½ F_{max}, or

$$F_{(ave)}=1.41\times10^{-7}\frac{n_g^2I^2\overline{mlt}}{l} \text{ pounds.} \qquad (35)$$

If the resisting force is that of an absolutely rigid support, the force felt by the support at any instant will vary from zero to maximum, and the maximum force which the support must resist is that given by equation (33).

If the resisting force is perfectly flexible, and constant in value, as that due to gravity, or a uniform pressure, the force which would be effective in producing positive motion is the average force, given by equation (35). The variations in the actual force above and below this value will result in vibrations of the coils and support.

If the resisting force is that of a flexible support whose resistance is proportional to its displacement, vibrations will be set up which, should the frequency of the force be approximately the same as the natural frequency of vibration of coils and support, will be cumulative. This last condition might set up strains which are very much greater than those which we calculate.

Stresses or forces may be calculated by the above equations for any condition of load or short circuit by substituting the value of the current which would exist under this condition. The worst condition is that of short circuit at the secondary terminals of the transformer, with full voltage maintained at the primary terminals; current being limited only by the impedance of the transformer, as mentioned above.

If conditions in any case result in currents which are not sinusoidal, the maximum force may be calculated from equation (35) instead of equation (33), by substituting the maximum value of the current instead of the effective value. Substituting the effective value of the current in this equation would still give the average force.

When we consider forces due to short circuit currents, the initial rush of current may, in cases where a short circuit is produced mechanically, reach values much higher than the values obtained from the impedances involved, due to making the circuits at a part of the cycle when the resulting magnetic fields would, in their normal state, have considerable value—possibly maximum value—while in reality they must start from zero at the instant of short circuit. This would probably never occur unless the short circuit were produced mechanically, as by the swinging of wires, or the closing of a switch. If it were to occur by the breaking down of insulation, it would probably be at a time when the applied voltage was maximum, which corresponds to zero flux. If the initial rush of current at short circuit should be double the final value which might occur as a maximum (considering inductance only; i.e., neglecting resistance), the resulting mechanical force is, of course, multiplied by four.

A large majority of the transformers now in service would not withstand the shock of a short circuit directly at the low tension terminals, with full voltage maintained on the primary. In most cases there is little reason to desire that they should be able to withstand such a shock, since the conditions necessary to produce it are a practical impossibility.

If the short circuit occurs on the secondary line, the current will be limited by the combined impedance of the transformer and the line to the point of short circuit, and if some auxiliary apparatus, as a reactance coil, is connected in series with the transformer, this must also be included in the impedance. If the generating capacity back of the transformer is not large as compared with the transformers, the synchronous impedance of the generators must also be included as a part of the total impedance limiting the current, or else the transformer must be considered in connection with the reduced voltage applied.

High reactance within the transformer has been recommended as a measure of safety where severe conditions may be met. The advantage derived from increasing reactance depends, however, upon the way in which the reactance is introduced. If this is done in the way which is most economical from the standpoint of the cost of the transformer; namely, by decreasing the number of primary-secondary groups of coils, the reduction in the mechanical forces would be but slight, since the resulting increase in n_G is nearly proportional to the decrease in the value of the short circuit current. This would be exactly true if the magnetic leakage were confined to the gaps between primary and secondary windings, as may be seen by supposing that the number of groups be reduced to one-half. The number of turns per group, n_{gmax} $(=n_G)$, will be doubled and the reactance per group multiplied by four. The total reactance, with one-half the groups, will be doubled, so that, neglecting the resistance component of the impedance, the current will be divided by two. The fact that the leakage is not entirely confined to the gaps between primary and secondary, but that some of it is found in the gaps between individual primary or secondary coils, and within the coils themselves, modifies the above conclusion somewhat, to the effect that there is a comparatively small reduction in the mechanical forces when the reactance is increased in this manner, but not enough to amount to much in the way of a factor of safety for a transformer which would otherwise be on the verge of collapse.

If the increased reactance is obtained by increasing the distance between primary and secondary groups, without changing the number of groups, or the number of turns per group, the increased reactance is proportional to the increased distances, while the factor n_{gmax} remains constant, so that, neglecting resistance, the mechanical force is inversely proportional to the square of the reactance. This method of introducing reactance into the transformer accomplishes the same result as a separate external reactance, but is likely to cost more. The relative cost must, of course, be calculated for the particular case.

Comparing high voltage transformers with low voltage transformers, it will be seen that the greater distances required between the windings of the high voltage transformers, for purposes of insulation, afford at the same time a very effective means of protection in reducing the mechanical stresses at short circuit.

Various compromises between the extreme methods of introducing reactance described above are possible, such as by increasing the total number of turns in the transformer, without changing the number of groups. This increases the reactance at a rate greater than the increase in the number of turns, but less than the square of that number, on account of the resulting changes in the dimensions. The effect of the reduction in current upon the mechanical forces more than offsets that of the increase of n_{gmax}. This method of obtaining increased reactance is not so effective in reducing the stresses as that last mentioned, and is also expensive if carried to extremes. It has the added disadvantage, in common with the first method mentioned, that eddy current losses are increased through the increase in the density of the field.

It is important to notice the great disadvantage, from the standpoint of mechanical stresses, of unsymmetrical grouping; that is, of making the number of turns in one group greater than that in another. This is seen at once, since the factor n_{gmax} for calculating the maximum stresses, and the forces acting upon the coil retaining clamps, is the maximum number of turns in any group, while the current is proportional inversely to the average of the squares of the numbers of turns for all the groups.

It has become a regular part of the design of transformers to calculate the mechanical stresses, so as to provide the necessary strength of parts to resist these stresses for any condition of short circuit to which the transformers may be subjected, and, if necessary, to modify the design so as to reduce these stresses.

The fundamental principles given above apply equally to the core type transformer as to the shell type. In the core type transformers of ordinary construction, with primary and secondary windings concentric with each other and symmetrically placed in an axial direction, the resultant mechanical forces in this direction are zero. The only forces which are effective in this case are radial in direction, tending to expand the external winding and to compress, or buckle inward, the internal winding. These forces ordinarily give no trouble. If, however, the active parts of the windings are not symmetrically placed in an axial direction, as is liable to be the case when taps are used for changing the voltage ratio, severe stresses may be set up in an axial direction at short circuit, which may injure the transformer unless ample provision is made to resist them.

DR. STEINMETZ'S PAGE IN THE REVIEW

Dr. C. P. Steinmetz, Chief Consulting Engineer of the General Electric Company, has requested that a reservation of one full page in all future issues of the REVIEW be made for him, wherein notices may be made of some of the more important and interesting items of special engineering work which are being done in the department under his supervision. These Consulting Engineering Department records will be edited personally by Dr. Steinmetz, and the first of the series is due to appear in our February issue.

THE NATURE OF SURGES AND THE REQUIREMENTS PLACED THEREBY ON PROTECTIVE APPARATUS

By E. E. F. Creighton

Consulting Engineer, General Electric Company

This article is a reprint in part of Mr. Creighton's contribution to the Turin International Congress on Electrical Applications, on the subject of the Protection of Electrical Apparatus against Abnormal Surges of Potential and Current. The subject divides itself logically under four heads, as follows: (a) Nature and Probable Cause of the Disturbance; (b) Characteristics of Insulations and Constructions; (c) Characteristics of Protective Apparatus; and (d) Practical and Commercial Adaptation. The matter of the second and third sections has been pretty thoroughly covered in recent issues of the Review (June and July, 1912) and we have therefore omitted that portion of the paper from the reprint; including, however, as a convenient reference, the skeleton outline of the entire subject matter, as published in the original copy. Our article therefore has to do with sections (a) and (b); under the former of which the author has selected for discussion the more common kinds of surges, such as those resulting from lightning, arcing grounds, short circuits, etc.—obviously those that should be most assiduously guarded against. Under the section on insulation, the very important matters of spark lag and the self-repairing qualities of such insulating materials as air, oil, and porcelain are dealt with, as are also the questions of "end turn insulation" and the dimensioning of insulators.—Editor

In this brief review, it will not be possible to give a detailed analysis either of all the known subdivisions of the classes of surges which injure electrical apparatus or of the manufacturing details of the types of protective apparatus in use. There are, however, a few main divisions of electrical surges that predominate and are especially important to differentiate and there are correspondingly general types of protective apparatus that are applicable to give degrees of safety for each of these divisions.

This treatment has, somewhat, the requisite view point of the manager of an electrical power company, who has to decide how to choose the equipment and apparatus to fit his particular conditions of operation. In the absence of absolutely unbiased and authoritative statements as to what to do, it becomes just as important, in order to avoid expensive mistakes and experiments, to know some of the things not to do. Some of the things that should be avoided are represented in the history of the development of protective apparatus. Many, perhaps one might say most, of the errors have been more of omission than commission. The multiplicity of factors that enter the problems of protection were not at that time even known to exist. Even today, while the main problems of protection have a satisfactory workable solution, there are still hazy notions of certain practical points to be cleared up and there is much in the realm of theory, especially in regard to atmospheric changes, which has scarcely been touched.

It is the nature of the human mind to make things easy by generalizations and rules. In the application of the protective apparatus, this tendency ha led to misapplication of several good principles in physics. For example, an investigator or engineer in looking through the mathematical equations of electrical surges, finds that an electrical oscillation is dampened out in the shortest time possible by utilizing a value of resistance in series known in the mathematical literature on this subject, as the "critical value":

$$R = 2\sqrt{\frac{L}{C}}$$

The resulting lightning arrester involving this principle gives a high degree of protection to one class of surges and a low degree to others. The frequent failure of such an arrester was no reflection on the truth of the physical law, but the conditions in the arrester which satisfied this law did not meet the requirements of other factors and forces which existed simultaneously in the same circuit.

Again, another engineer notes that a resistance somewhat less than the "critical resistance" brings the potential of the surge to zero in a shorter interval of time than would the "critical value of resistance."

An application of this principle led to as frequent failure to protect the electrical apparatus as the greater resistance. Both principles are good for certain conditions, but they are not universally applicable. In each case a potent fact has been lost sight of: the insulation of the electrical apparatus can be punctured in an extremely short time. Although both the time to cause puncture and the period of the usual electrical oscillation are so extremely small as to readily fall under the designation *instantaneous* to our senses, yet their difference may be relatively enormous. A comparison is easier to conceive by translating the time factors into more familiar intervals. If the unit time required to puncture the insulation is designated as a *day*, then the time to dampen out the oscillation might be designated in *years*. In the life of a surge the interval of puncture is a moment and soon becomes ancient history.

Still again, another engineer has seen the objectionable nature of series resistance and has decided to use none.

Great success was obtained with arresters built on this principle until, through the natural growth of the electrical industries, the generating apparatus became so powerful as to melt, and even explode, the active parts of the arresters before the arrester could extinguish the dynamic current which naturally followed a lightning discharge to ground.

As still another example of a valuable principle that has been misapplied by attempting to use it as a universal protector against all sorts of electrical surges is the absorption of high frequency surges by an electrostatic condenser. It has its advocates both in Europe and America.

In reasonably large units the electrostatic condenser will absorb certain classes of surges admirably. Unfortunately the cost of a desirably large capacity is usually prohibitive, and furthermore such a condenser may introduce another risk by its presence in the circuit. There is always a possibility of resonance between such a condenser and a series inductance in the circuit. When the capacity of such a protector is reduced to an equivalent of two disks five centimeters in diameter separated by about 0.2 mm., as was done by one advocate, the application becomes absurd. The valuable principle of the condenser action depends on its capacity to absorb the charges of electricity in the electrical system without permitting a rise in potential. In other words, the capacity must be comparable in dimension to the quantity of electricity that it should absorb. An elementary calculation will show the impossibility of attaining this end at any reasonable cost at present on circuits of potential high enough to be considered in transmissions of power.

The fallacy in using a small condenser may be illustrated by an analogy. It corresponds to an attempt to force a room full of air into a small bottle without bursting the bottle or even increasing the internal pressure to an unsafe value.

There are several other illustrations of good principles which apply to specific conditions but which, when involved alone in a lightning arrester, limit its value. No lightning arrester involved all the good principles; therefore as the competitive manufacturing companies failed to get protection with their arresters they would adopt a new condition of design each year. It has happened that two competitive concerns actually and unwittingly exchanged their principles of designs between lightning seasons. Each realizing their own failures and short comings thought the other must have found the solution.

The problem, as already stated, is many sided. Dr. C. P. Steinmetz, by his work on Transient Phenomena, has undoubtedly done more than anyone else to bring order out of chaos. Up to a few years ago, the designer of lightning arresters labored under an unusual disadvantage. He was designing to meet an unknown condition, to absorb the effect of a phenomenon which came without warning and on one hand, provided it did no damage, disappeared in a thousandth of a second; or on the other hand, it started a small fault which resulted in a gradual destruction of the apparatus.

Subsequently it was found that lightning was not the only cause for electrical surges, and these other sources, not being distinguished from lightning, caused a confusion which put the design out of the realm of engineering.

Still further, insulating materials were employed with but little knowledge of their characteristics or their proper location.

Discussion took place on the design of arresters without distinguishing the factors due to the voltage of the system or the nature of the service, such as trunk lines, overhead or cable distributions for lighting, power, or railways. Not half the chaotic requirements of design have been mentioned, but contrast these, for example, with the problems of design of a motor. Although such a design may be difficult and complicated there was always the definite aim of torque, speed, and heating to be reached. While the variable permeability of iron always caused a degree of uncertainty it could be met by a change in the mechanical dimensions.

It is the object then of this paper to describe, as best one can briefly, the progress that has been made in putting this branch of electrical engineering on a solid foundation.

To do this will require several kinds of classifications.

Since these classifications will be made from different points of view they must necessarily overlap.

To begin the classification, the problems in protective apparatus engineering involve such factors as may be classified under the general headings:

(*a*) Nature and source of electrical surges.

(*b*) Characteristics of insulations and constructions.

(*c*) Characteristics of protective apparatus.

(*d*) Practical and commercial adaptation.

(*a*) Nature and Sources of Electrical Surges

The first subdivision of surges is the separation of *potential surges* from *dynamic current surges*. Although a surge of potential naturally involves a movement of a charge of electricity, and therefore an electrical current, it is convenient to distinguish this surge current from the heavy dynamic currents which take place on a constant potential system when an accidental short-circuit occurs. Although either may involve the larger value of current and power, there is always a greater energy in the surge of dynamic current. The abnormal dynamic current frequently involves dangerous mechanical strains and heating.

The oscillating currents of abnormal potential surges rarely do any harm in themselves; it is the abnormal value of potential involved which does the damage.

The damage is confined to the dielectric. As a distinguishing mark the subdivision will be designated as A_1 and A^1, and further subdivision by the corresponding small letters. Thus:

(A_1) Abnormal Potential Surges.

(A^1) Abnormal Dynamic Current Surges.

(A_1) Abnormal Potential Surges

The subdivision of this classification will be made with the type of apparatus in view that should be used to give protection.

The subdivisions are, consequently, not entirely distinct phenomena.

(a_1) Lightning.

(a_2) Accidental arcing grounds.

(a_3) Resonance.

(a_4) Cross-dynamic circuits.

(a_5) Continuous induction.

(a_1) *Lightning*

The nature of the accumulations of static electricity in the atmosphere which cause lightning is still a matter of speculation. Such speculations are outside the scope of this review. There are, however, some observations on lightning which are valuable in explaining resultant phenomena and there are a number of *effects* of lightning which are important to note.

The accumulations of static charges in a thunder storm are rapid. It usually happens that a discharge which appears to the eye as a single discharge is composed of a succession of discharges. The usual number recorded is from three to seven, although in rare instances more than a dozen distinct successive discharges have been photographed. These separate discharges are due apparently to a readjustment of the charges in adjacent clouds which produce an accumulation of sufficient potential to discharge into the path formed by the initial discharge. A number of successive discharges have been noted which had an interval of one-quarter second; usually, however, the interval is much shorter and, consequently, cannot be seen with the naked eye but must be photographed by a special photographic apparatus. The importance of these observations on multiple strokes lies in designing an arrester which always maintains a complete circuit to ground and which has an endurance to discharge sufficient to take several discharges without overheating.

Individual lightning strokes are of very short duration. Whether they are oscillating in character is still a mooted question. At any rate, the suddenness of discharge gives the effect of a high frequency discharge. Dr. C. P. Steinmetz's calculations place the possible frequency between one half million and a million cycles per second and the current of discharge of the average lightning stroke at about 10,000 amperes.

Operators of transmission circuits have often noted that the apparent severity of a storm has little to do with the damage it may do to the transmission line. This is a matter of chance location of the strokes near or far away from the line. By timing the interval between the flash and the thunder all strokes that take place within a radius of 6 kilometers can, in any storm, be counted. This includes an area of over 100 sq. km. If, for example, there were twenty strokes, it would give an average of only $^1/_5$ stroke per sq. km. The danger zone on each side of a transmission line is still an unknown quantity, but if it is taken as ½ km., then the danger zone of a transmission line passing through this lightning territory would include 12 sq. km. By the law of averages the line might, by this approximate method of reasoning, be seriously affected by an average of 2 strokes during a storm of twenty strokes total.

As a matter of fact, the number of near strokes to the line in any single storm may be either zero or nearly the total number of strokes, according to the character and location of the storm. The writer has noted two distinct formations of thunder storms and although it happens usually that both formations are more or less mixed, still it is a convenience to differentiate between them. There is the inverted cone formation of clouds and the progressive storm. In the inverted cone formation of clouds the lightning strokes all take place around the apex of the cone. If the apex of the cloud cone happens to fall over a transmission line the effects are numerous and disastrous, although the storm may not appear severe to an observer located at some distance. If, however, a storm moves progressively the number of strokes in the danger zone along the line will depend on the direction of the path of the storm and the nearness to the line.

The effect of electrostatic induction on the line from lightning is to concentrate a potential at a local point called the *bolt-peak*. The nearer the line the lightning bolt strikes, the greater the concentration at the bolt-peak. If the potential of the freed charge of electricity on the line is not sufficient to spark over an insulator to ground it will spread in waves in both directions over the line. As it travels along the transmission line it will lose more or less of its destructive power according to the conditions of protection along the line. If a station is near a bolt-peak it will naturally receive a more dangerous blow than if it is far away.

If the induction from lightning is electromagnetic, as happens rarely, due to horizontal discharges of lightning between clouds, the potential of the induced charge will be greatest at the ends of the line.

(a_2) *Accidental Arcing Grounds*

The usual location of an accidental arcing ground is at an insulator, a cable joint, transformer bushing, or a generator coil. When one phase of a non-grounded neutral three-phase system is grounded at the peak potential of its wave, the other phases rise from the value of Y potential above ground to delta potential. Since this change is sudden the potential will overshoot its normal value and may rise easily to a value of the delta plus Y potential. This is about 1.6 times delta potential and 2.5 times Y potential. This is not a dangerous potential on a normally insulated system. However, it frequently happens that the sudden adjustment of the electrostatic charges involve frequencies which find a responsive resonance in some part of the electrical system. The potentials then mount to values dangerous to the insulation. There is a natural tendency in arcs of certain lengths and certain currents to magnify every harmonic or other superimposed frequency, such as, for example, the natural frequency of some part of the system. It has been repeatedly noted that an accidental arc may be sustained for a long time at one part of a system without causing any visible damage to the insulation elsewhere, but during some other trouble when the accidental arc occurs at some other place on the system it results in the immediate destruction of the insulation on one of the other phases and a consequent short-circuit. In brief, more or less resonance is caused according to the particular location of the arcing ground. Some electrical systems are very much more sensitive to arcing grounds than others.

(a_3) *Resonance*

Since energy combination of capacity and inductance in series has its definite frequency of natural oscillation, it sometimes happens in a circuit that damage to the insulation occurs due to the impression of the corresponding frequency. The harmonics in a generator wave are, apparently, seldom strong enough or of high enough frequency to be the source of the electrical energy for resonance. The most prolific source is an arc of any kind in the circuit, such as an accidental arcing ground in a non-grounded neutral circuit, a broken line wire in an open delta circuit, and an electric arc furnace. The conditions of resonance in a transformer or generator where there is both distributed and concentrated inductance and capacity are too complicated to analyze mathematically, but it can easily be done experimentally. Mr. E. F. W. Alexanderson has designed a generator to give 200,000 cycles. By rectifying the current by means of a mercury arc and passing it through a transformer it is possible to obtain 400,000 cycles. The writer investigated the cause of numerous failures in a 350 kw. 11,000 volt transformer with a 100,000 cycle machine and found a dangerous condition of resonance at 90,000 cycles per second. With three flat coils side by side in series, the potential would not only rise to a high value on the middle coil but would also concentrate locally at certain points of the winding. At these high frequencies ratios of transformation are no longer proportional to the number of turns on the primary and secondary. A standard lighting transformer with a ratio of 20 to 1 in the winding gave a ratio of potential of 80 to 1 at the resonant frequency. Another transformer with a ratio of 1 to 10 gave a ratio of 1 to 1. This transformer had ten coils on the secondary. Each coil had induced in it a different value of potential. In one case a single coil had more than ten times the voltage it should have had according to the ratio of turns on the primary and secondary. In figures, the ratio of turns was 1 to 1 while the ratio of potentials was about 1 to 10.

(a_4) *Cross-dynamic Circuits*

Illustrations of cross-dynamic circuits are given in the following list: a metallic contact between a high potential series arc-lighting circuit and a distribution circuit for incandescent lamps; a cross between a telephone circuit and either a trolley circuit or a series arc-light circuit; a 2300 volt circuit and 110 volt circuit; a 100 kv. circuit and a 13 kv. circuit beneath it, and so on.

(a_5) *Continuous Induction*

Cases of continuous induction are found in the operation of wireless transmitters and in telephone lines situated under or near electric power lines of high potentials. The wireless transmitter may put surges in a power transmission system either by backing up through the transformer which furnishes power to the oscillating circuit, or by the influence of the emanated Hertzian waves on the connecting wires of transformers and meters. Resonance of the power circuit with the wireless waves is usually necessary to cause destructive potentials. An investigation illustrates this fact. An insulated wire 10 meters long was placed in the neighborhood of a wireless antennae. When one end of this wire was touched directly to an earthed conductor a faint spark could be seen, when the wireless antennae was alive. With this same insulated wire connected to earth through a helix of 30 turns, 30 cm. in diameter, the potential across the helix sparked viciously over a gap 2.5 cm. long (30 kilovolts maximum value). Many motor coils and integrating meters have been damaged in the same manner.

A telephone line under a transmission line is continuously subjected to more or less potential strains through both electrostatic and electromagnetic induction. When an accident happens which causes a ground on a phase of the transmission line the induced potentials on the telephone line become destructive. In a similar manner, when any kind of ground takes place on a high tension transformer, dangerous potentials can be produced on the low voltage side of such a transformer, unless the secondary is grounded or connected to an electrostatic condenser of much greater capacity than exists between primary and secondary coils of the transformer.

(A^1) Abnormal Current Surges and Short Circuit Effects

1. *Interruption of Service*

Since a short circuit shunts the power from some electrical translating device, it necessarily involves an interruption in the flow of either part or all the energy to the device. Usually it causes an interruption of service.

2. *Mechanical Strains*

The next effect is a mechanical strain on the electrical apparatus which, in a modern power station of large capacity, becomes destructive to coils and generator shafts unless protective devices are used. In the early days of steam turbines the generators were designed with unusually good regulation; consequently the values of short-circuit currents were many times greater than had previously been known. Until precautions were taken the damage caused by an accidental short-circuit was appalling. With a capacity of turbines of several thousand kilowatts back of it, a short-circuit in a 100 kw. transformer resulted in a maze of tangled wires where the turns of the coils were forcibly torn from their supports and thrown apart.

3. *Overheating of Insulation*

The third effect of a short circuit has its danger in the heat liberated. Insulation of coils is quickly damaged by the ohmic loss. Live wires are burned in two by the heat of the arcs. In a cable system all the cables in a manhole may be destroyed from a short-circuit on a single cable.

4. *Electromagnetic Impulse of Potential*

The fourth effect of a short circuit sometimes occurs when the short circuit arc is suddenly extinguished. Under certain unknown conditions heavy current arcs seem to explode. The sudden cessation of the current results in an electromagnetic impulse which raises the potential to abnormal values. These electromagnetic "kicks" have been measured with the oscillograph on direct current systems.

5. *Abnormal Generator Potentials due to Short Circuits not involving all the phases*

When, for example, a single phase of a multi-phase generator is short circuited the current in the coils of this phase causes a distortion of the magnetic field toward the non-shorted phase or phases and an actual increase in the field flux in these phases. The result is that for a short time an abnormally high voltage is generated in the phases that are not short circuited. If there is no load on the generator these dynamic potentials reach dangerous values. If there is a closed circuit on the phases not short circuited the increase in potential causes an increase in the current of these phases and thus gives a counter-magnetomotive-force to the distorting flux in the generator. The voltage is thereby limited. In considering a protective device it is well to note that any such surge is at generator frequency and has an energy limited only by the conditions of generation. The energy in such a surge is incomparably greater than that of an induced lightning stroke. Its power may be equally as great as that of a lightning stroke.

Such a trouble results in the loss of incandescent lamps, lightning arresters, etc.

(*B*) Characteristics of Insulations

It is quite as important to study the characteristics of insulating materials as to study the nature of the potentials which cause their failure. While it is impossible here to treat in detail the analysis of the many kinds of insulation in current use, it is, however, feasible to point out briefly certain general characteristics which are important from the standpoint of protection. The most important factor to note is the dielectric-spark-lag. Perhaps next in importance is the self-repairing quality. The dielectric-spark-lag is the interval which elapses between the application of the potential and the actual puncture of the dielectric. For the convenience of the present analysis insulating materials are divided into four classes, viz., (b_1) air, (b_2) oil (liquid), (b_3) porcelain (solid), and (b_4) other solids.

The dielectric-spark-lag of air is very much less than oil, the former being of the order of micro-seconds and the latter milli-seconds. This relatively high value of dielectric-spark-lag gives oil a predominant value in insulating against lightning strokes which are of short duration. This characteristic of oil makes it an objectionable material to use in the discharge path of a lightning arrester.

Both oil and air are self-repairing after a dangerous potential strain is removed. Free air recovers its insulating properties almost immediately, while oil may require a second or more. A number of rapid electrostatic discharges on a film of oil will cause a puncture where the same discharges with a greater interval of time between them will not.

None of the solid insulations has the quality of self-repair. They are all more or less subject to what may be called *cumulative damage*. In other words these insulations are damaged by transitory discharges which are insufficient to puncture in one stroke. The damage done by a stroke is cumulatively carried into the successive strokes. The condition is somewhat analogous to the mechanical operation of driving a nail through a board by a number of successive strokes. Good porcelain, glass, and like substances, seem to be very slightly subject to *cumulative damage*, either they puncture or retain their dielectric strength. On account of the fact that "singing insulators" (that is, insulators having a heavy static leak which shows itself in brush discharge) would remain on a line for years without failing, it was concluded that these materials had no "fatigue." However, where the potential gradients become excessive, as occur in line potentials above 100 kv., even porcelain shows a condition of gradual deterioration. A number of pressboards, varnishes, paints, and the like, all show gradual deterioration under static strains sufficiently high to cause brush discharge. It may require months or years, according to the conditions, to cause a noticeable weakening. In high altitudes the rarefied atmosphere permits of so much brush discharge that the use of generators wound for even 13,000 volts becomes problematical. There is a growing tendency to recommend in general a lower limit of potentials for generators and obtain higher potentials by transformation. From a protective standpoint this is to be highly recommended. Transformers can be more easily and better insulated than generators.

There is much of value in considering the nature of the various grades of porcelain and also in avoiding air pockets in all insulating materials. In many cases impregnation becomes of extreme value not only on account of the dielectric strength but also on account of firmness of mechanical structure. A modern generator coil of good design is a work of art and it requires several months to complete it.

(B^1) Distribution of Insulation

Only two features of design will be here considered, viz., "end turn insulation" and the dimensional relations of the parts of an insulator.

As an aid to protective devices it has been the practice for a number of years to place extra insulation on the turns of the coils nearest the terminals of high tension transformers. Even with ordinary switching nearly full potential of the terminals may exist momentarily on the end turns of a coil. Since this is an internal effect and does not involve a rise of potential at the transformer terminals above normal operating voltage, it is beyond the province of a lightning arrester to give any protection against such a condition. On the other hand, when abnormal potentials of lightning strike the end turns of a coil, the extra insulation placed there relieves the lightning arrester of a duty which would be nearly beyond it. Generator design does not lend itself to reinforcement of insulation on the end turns and the generators are, consequently, more difficult to protect against lightning than transformers.

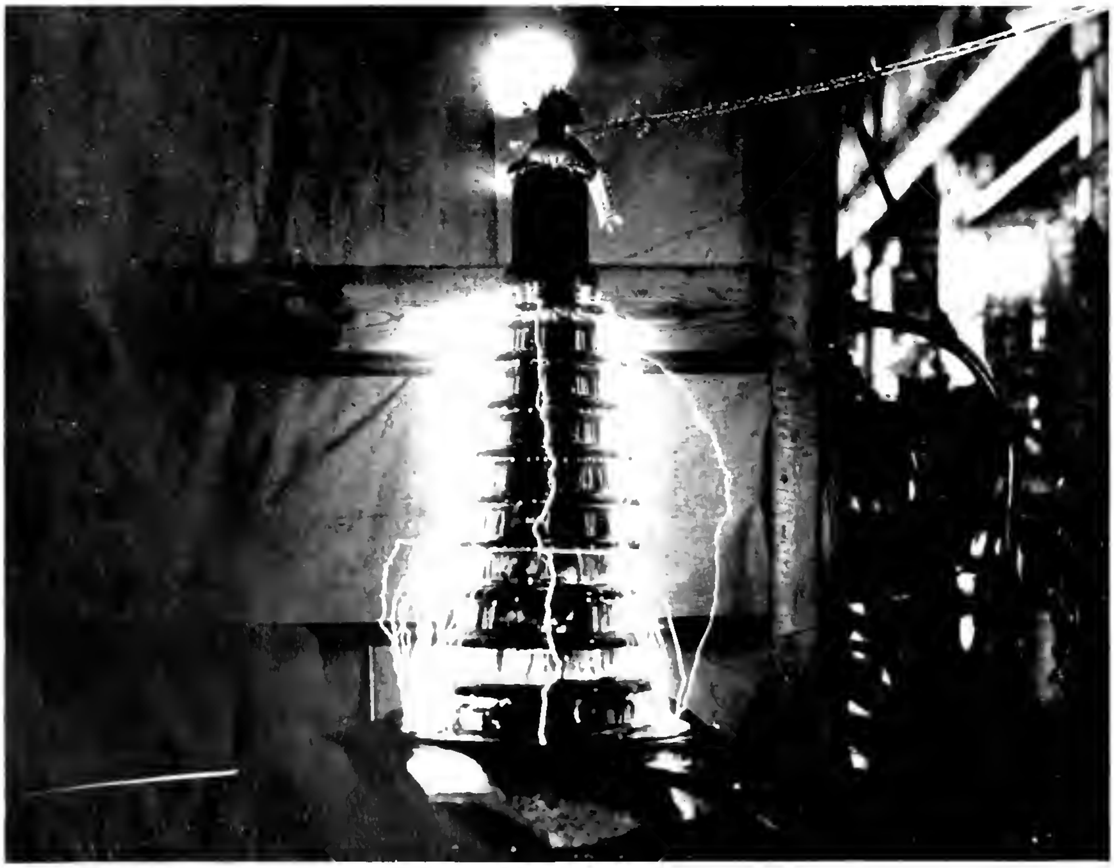
In the design of an insulator the dimensions should be made such that a failure due to the application of high potentials will result in a flash around the porcelain rather than through it. It is not sufficient to determine this condition by test with gradually applied potentials, because corona streamers give a shorter path around the insulator than exists when the potential is suddenly applied as in the case of lightning. Tests should be made with disruptive discharges.

SKELETON OUTLINE OF SUBJECT MATTER OF ORIGINAL PAPER

- **A — Nature and Source of Electrical Surges**
  - A_1 Abnormal Potential Surges
    - a_1 Lightning
    - a_2 Arcing Ground
    - a_3 Resonance
    - a_4 Cross-dynamic Circuits
    - a_5 Continuous Induction
  - A^1 Abnormal Current Surges or Short Circuit Effects
    1. Interruption of Service
    2. Mechanical Strain
    3. Overheating of Insulation
    4. Electromagnetic Impulse of Potential
    5. Abnormal Generator Potential due to a partial short-circuit
- **B — Characteristics of insulation (dielectric-spark and self-repairing quality)**
  - B_1 Materials
    - b_1 Air
    - b_2 Oil (liquid)
    - b_3 Porcelain (solid)
    - b_4 Other Solid Materials
  - B^1 Distribution of Insulation
    - End Turns
      - Air Pockets
      - Impregnation
    - Insulator Design
- **C — Characteristics of Some Protective Apparatus**
  - C^1 Multigap Lightning Arrester
  - C^2 Aluminum Lightning Arrester
  - C^3 Vacuum Lightning Arrester
  - C^4 Choke Coils
  - C^5 Arcing Ground Suppressor
  - C^6 Low Voltage Grounded Secondary
  - C^7 Overhead Grounded Wire
  - C^8 Grounded Neutral
  - C^9 High Insulation, High Voltage, and Corona
  - C^{10} Horn-Gap-Resistance-in-Series
  - C' Switches (Oil Break and Air Break)
  - C'' Fuses (Bare, Surrounded, and Expulsion)
  - C''' Choke Coils to limit Dynamic Current

SKELETON OUTLINE OF SUBJECT MATTER OF ORIGINAL PAPER (Continued)

D Practical and Commercial Adaptation	Protection	of service of apparatus of human life against fire
	Cost of Protection versus	1. Cost of power apparatus to be protected 2. " repair parts 3. " reconstruction of damaged apparatus 4. " removal and reinstallation 5. Interest on extra number of spare parts and spare apparatus 6. Partial damage to insulation 7. Loss of revenue during interruption 8. Loss of prestige and public sympathy, due to the interruption 9. Loss of prospective customers on account of unreliability of service
	Protection of some specific conditions	Transformers at 30 kv. and up Transmission transformers at less than 30 kv. Distribution transformers 2300 volts, etc. Power house and station apparatus 110-250-volt service circuits Direct current railways Various very low voltage apparatus Transmission lines



200,000 Volt Rain Test on High Tension Oil filled Lead. An article on the subject of Oil-filled Leads, by Mr. E. B. Merriam, appeared in the Review for September, 1912.

THE CONSTRUCTION, INSTALLATION AND MAINTENANCE OF ALUMINUM ARRESTERS AND THEIR AUXILIARIES

PART I

By R. T. WAGNER

SUPPLY DEPARTMENT, GENERAL ELECTRIC COMPANY

The first aluminum arrester designed for use on a large transmission system in this country was put in service about seven years ago. Since that time hundreds of installations have been made under varied conditions in all parts of the world. While essentially unchanged, the later designs naturally embody certain improvements resulting from both laboratory work and a careful study of installations. Any article intended to cover some of these improvements and to illustrate the modern style of aluminum arrester installation must necessarily traverse some ground which has already been covered in papers written during the earlier stages of its development. Several such papers have already appeared in the REVIEW (E. E. F. Creighton, June, 1908; V. E. Goodwin, June, 1908; the late Caryl D. Haskins, January, 1911; E. E. F. Creighton, June, 1912). In the present article by Mr. Wagner, the first instalment of which appears this month, unnecessary repetition has been avoided, but the paper constitutes a complete treatment in itself of this class of apparatus. In this regard the author's section on Auxiliaries (in a later installment) will be found of particular value, since it is in this respect that the most notable changes have during the last few years been made in arrester apparatus.—EDITOR.

Aluminum arresters are designed to protect alternating current electrical systems from all potential surges and lightning disturbances. They have an enormous discharge capacity and their design and construction enable them not only to discharge large quantities of lightning, but also to safely take care of both continuous and recurrent discharges lasting for long periods. They can be adjusted to discharge at only a small percentage above the normal operating voltage of a system. The design of the aluminum arrester is based on the characteristics of the aluminum cell consisting of two aluminum plates, on which has been formed a film of hydroxide of aluminum, immersed in a suitable electrolyte.

Formation of Film

The most important characteristic of the aluminum cell is its critical * voltage, which depends upon the hydroxide film of aluminum formed on the surface of the aluminium plates by putting them though chemical and electro-chemical treatments. Up to a certain voltage the cell allows an exceedingly low current to flow, but at a higher voltage the current flow is limited only by the internal resistance of the cell, which is very low. A close analogy to this action is found in the well-known safety valve of the steam boiler, by which the steam is confined until the pressure rises above a given value, when it is released.

On the aluminum plates there are myriads of minute safety valves, so that, if the electric pressure rises above the critical voltage, the discharge takes place equally over the entire surface.

*The particular voltage at which the current begins to flow freely is known as the critical voltage of the cell.

It is important to distinguish between the valve action of this hydroxide film and the failure of any di-electric substance such as mica, for example. The internal action of the cell closely resembles that of a storage battery on direct current, in which up to about 2 volts per cell impressed the storage battery gives an equal counter e.m.f., but above this value the current that flows is limited only by the internal resistance of the cell.

The volt-ampere-characteristic-curve of the aluminum cell will vary somewhat according to whether direct currents or alternating currents are used. If direct current is used, there will be no current passing through the circuit except the small leakage current through the film; whereas, if alternating current is used, the aluminum cell acts as a fairly good condenser, and there is not only the leakage through the film, but also a capacity current flowing into the cell. The phase of this current, then, is nearly 90 degrees ahead of the potential and represents a very low energy factor.

A volt-ampere-characteristic-curve of the aluminum cell on direct current is shown in Fig. 1 in which the permanent critical voltage is 420. This voltage will, however, vary considerably with the nature of the electrolyte. A curve of the current discharging above the critical voltage is shown in Fig. 2. The data for this curve were taken from oscillograph records.

The volt-ampere-characteristics of an aluminum cell on alternating current are shown in Fig. 3. The permanent critical voltage is between 335 and 360 volts, and indicates a less definite value of the critical voltage than the direct current curve.

When a cell is connected *permanently* to the circuit, two conditions are involved which may be distinguished as the temporary critical voltage, and the permanent critical voltage. For example, if the cell has 300 volts applied to it constantly, and the voltage is suddenly increased to, say 325 volts, there will be a considerable rush of current until the film thickness has been increased to withstand the extra 25 volts; this usually requires several seconds. In this case 325 volts is the temporary critical value of the cell. Similar action will occur at any potential up to about the permanent critical voltage, or the voltage at which the film cannot further thicken and therefore allows a free flow of current.

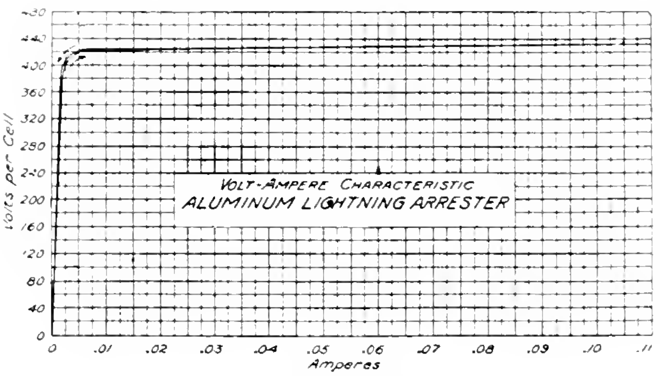


Fig. 1. Volt-ampere Characteristic Curve of an Aluminum Cell on Direct Current

If the voltage is again reduced to 300 the excess thickness of film will be gradually dissolved, and if it varies periodically between two values, each of which is less than the permanent critical value, the temporary critical voltage will be the higher value. This feature is of great importance as it provides a means of discharging abnormal surges, the instant the pressure rises above the impressed value.

The number of cells for a circuit is so chosen that the average dynamic voltage per cell will be approximately 300 volts, or always less than the permanent critical voltage.

The foregoing shows that the arrester will discharge a large amount of dynamic current for a brief interval, and lightning, being of a similar nature, will be discharged with equal facility.

Besides the valve action already described there is another characteristic of the cell of great importance. The thin insulating film of aluminum hydroxide between the conducting aluminum and the conducting electrolyte acts as a dielectric, and the cell, therefore, is an electrostatic condenser. A condenser of this type makes an ideal path for high frequency lightning discharges. Due to this capacity these aluminum arresters can not be connected permanently across alternating voltage. The charging current at a frequency of 60 cycles (about 0.40 amperes) would in time heat the electrolyte. In every case, therefore, spark gaps set to arc over at slight increase of voltage, insulate the arrester from the line.

Film Dissolution

Another characteristic of the aluminum cell is the dissolution of a part of the film when the plates stand in the electrolyte and the cell is disconnected from the circuit. The film is composed of two parts: one part is hard and insoluble, and apparently acts as a skeleton to hold the more soluble part. The action of the cell seems to indicate that the soluble part of the film is composed of gases in a liquid form. When a cell which has stood for some time disconnected is reconnected to the circuit, there is a momentary rush of current which reforms the part of the film which has dissolved. This current rush will have increasing values as the intervals of rest of the cell are made greater.

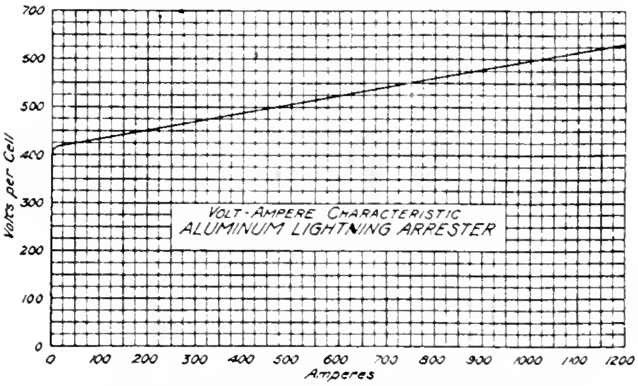


Fig. 2. Volt-ampere Characteristic Curve of an Aluminum Cell on Direct Current Showing the Rate of Discharge above the Critical Film Voltage

Many electrolytes have been studied, but none has been found which does not show this dissolution effect to a greater or less extent. If the cell has stood disconnected from the circuit for some time, especially in a warm climate, there is a possibility that the initial current rush will be sufficient to open the circuit breakers or oil switches. This current rush also raises the temperature of the cell, and if this temperature rise is great it is objectionable. When the cells do not stand for more than a day, however, the film dissolution and initial current rush are negligible. Suitable means are provided with the arresters for throwing them directly on the line by a very simple operation, and thus the film may be always kept in good condition.

Construction of Arresters

In the following paragraphs, arresters for three-phase circuits will be described, but arresters for other circuits of 1000 or more volts have the same general construction. The form of the arrester varies somewhat according to the voltage, grounding of the neutral and conditions of operation. In general, the arresters vary in the construction of the series gaps and in the grouping and spacing of the cells.

The differences in the arrangement of the cells will be described first; then the differences in the construction of the horn gaps.

Cells

The arresters consist of a series of concentric inverted cones, the number depending upon the voltage, placed one above the other with a vertical spacing of about 0.3 inch in arresters up to and including 27,000 volts and 0.42 inch in arresters above that voltage.

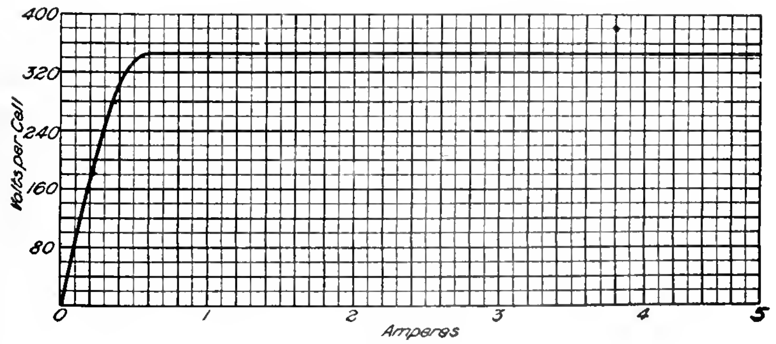


Fig. 3. Volt-ampere Characteristic Curve of an Aluminum Cell on Alternating Current

The electrolyte is poured into the cones and partly fills the space between adjacent ones. The stack of cones with the electrolyte between them is then immersed in a tank of oil. The tanks are steel with welded seams and are provided with metal covers. The cones are insulated from each other except for the electrolyte. The oil improves this insulation as well as prevents the evaporation of the solution. A cylinder of insulating material concentric with the cone stack is placed between the latter and the steel tank. This improves the circulation of the oil and increases the insulation between the tank and the cone stack.

The utilization of the heat-absorbing capacity of the oil is of great value, since it enables the arrester to discharge continuously for long periods.

There is a stack of cones for each phase, and for non-grounded neutral circuits and for circuits grounded through resistance there is an additional stack for the ground leg. The necessity of the fourth stack is given under "Differences in Arresters for Grounded and Non-Grounded Circuits."

1000 to 7250 Volts. In these arresters the radiating and insulating qualities are such that all of the cones may be placed in a single tank. This effects a saving in space without sacrifice in the features of endurance and insulation. (Fig. 4.)

Above 7250 Volts each stack of cones is placed in a separate tank. (Fig. 5.)

A larger spacing between cones has been adopted for the arresters above 27,000 volts because in general they are used on long distance transmission lines where rises in voltage at substations when load is suddenly removed from the line at the power house are especially severe on the arresters. The larger spacing increases the factor of safety and the length of time the arrester can take a discharge without overheating due to the larger amount of electrolyte to be heated and the larger radiating surface of electrolyte in contact with the oil. The size of the tanks and amount of oil have also been made larger thus adding to the heat storage and radiating surface of the arresters. On account of the increased height of tanks, on the 60,000 and 70,000 volt arresters tie rods are provided from the tops of the tanks to the supporting racks. These hold the tanks securely in place and prevent the danger of overturned tanks should they be subjected to an external force or blow.

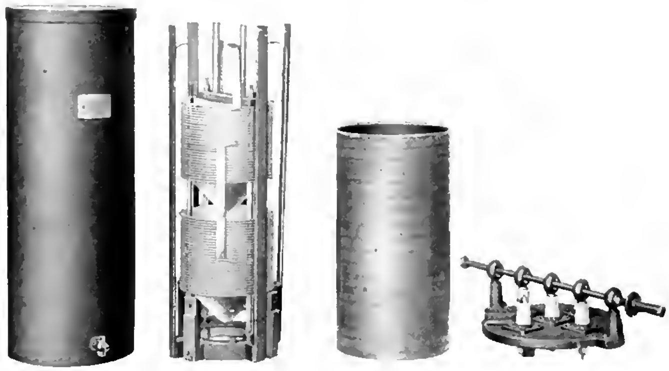


Fig. 4. Elements Less Horn Gaps, etc., of 6600 Volt, Three-phase Aluminum Lightning Arrester for Non grounded Neutral Circuit

Horn Gaps

The arresters are not designed to be connected permanently between the line and the ground. A gap set at a suitable value above the line potential is inserted in series, and prevents the arrester from being subjected continuously to the line voltage. In this way leakage is prevented at normal voltage and longer life is insured for the aluminum cones.

The horn gaps placed between the aluminum cells and the line serve a triple function. First. As fixed gaps in series with the cells, they prevent the arresters from being subjected continually to the normal line voltage which would result ultimately in overheating the cells; Second. They act as a disconnecting switch to disconnect the arrester from the line for repairs, inspection, etc.; Third. They can be used as a connecting switch for daily testing. As described above, the film, if allowed to stand in the electrolyte without any current flowing, gradually dissolves, so that after a period of inactivity there might be a considerable flow of dynamic current following a lightning discharge. For this reason the gaps are designed so that they may be closed for a few seconds and thus keep the film in normal condition.

Two main types of horn gaps are used, one type having a resistance through which the arresters are charged and one having no charging resistances.

In arresters up to 7250 volts, the type of horn gaps used is shown in Fig. 6. These horn gaps have the charging resistances.

The closing of the horn gaps for charging is effected by a rotating shaft of insulating material carrying three metallic projectors, which, when the shaft is rotated, bridge the three gaps and allow the necessary charging current to flow through the cells. The disconnecting feature is provided by separate detachable fuses. The horn gaps, fuses and transfer device are mounted on a pipe framework. (See Fig. 7.)

Above 7250 volts, the horn gaps consist of three sets of horns mounted on a common framework of iron pipe. Horn gaps with or without charging resistance can be supplied. Each pair of horns is clamped firmly to petticoat insulators, one insulator being fixed rigidly to the frame while the insulator carrying the other side of the horn can be turned, using its pin as an axis. There is a gap for each phase and all three of the movable insulators are joined by a connecting rod so that they move simultaneously. In the normal position of the gap the movable

Fig. 5. One Leg, Less Horn Gaps, etc., of 15,000 Volt Aluminum Lightning Arrester

horn is turned sufficiently to give the required spark gap. When the horn gaps are in normal position they are held firmly by a latch.

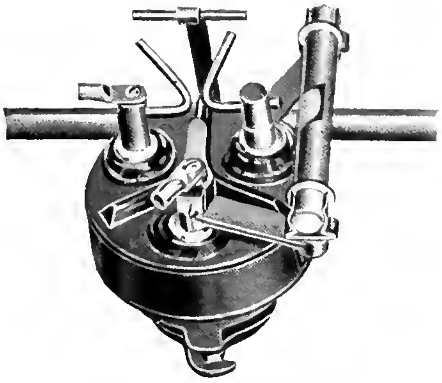


Fig. 6. Horn Gap for 6600 Volt Aluminum Arrester Showing Charging Resistance and Short-circuiting Contact

The type used from 7250 to 27,000 volts inclusive is shown in Figs. 8 and 9. In this type the movable insulators are held in position against the latch by heavy coiled springs. The short-circuiting operation is performed by pulling one rope until the horn gaps are closed. When this rope is released, coiled springs return the horn gaps to the normal position. Disconnecting is accomplished by pulling the other rope, which releases the latch, thus allowing the coiled springs to turn the movable horns through a large and amply safe angle. The gaps are put in the normal position by pulling the first rope, until the latch resets.

To facilitate the setting of the horn gaps an adjustable latch block is provided by which all the gap spaces may be changed uniformly and simultaneously without taking the voltage off the horns.

In the type used with arresters above 27,000 volts, one of the supporting pins of one of the revolving insulators is extended to a point within easy reach of the operator, and is fitted with an operating lever and latch. It will be remembered that the movable insulators are joined, so that by turning this lever all three horns are moved. When the latch has been released, the operator can turn the movable horn into either the short-circuiting or the disconnecting position. (Fig. 10.)

Provision is made for locking the horn gaps in either the normal or the disconnecting position and for adjusting the horn gap setting.

All horn gaps have copper strips which short circuit the gaps during charging. The short circuiting contact for the higher voltages is shown in Figs. 10, 12 and 13.

Charging Resistances

The charging resistance shown in some of the accompanying figures and described more fully below are recommended for use with all aluminum arrester installations. Their use is imperative when arresters are connected to cable systems, directly to busbars, or to lines running directly from generators with no intervening transformers.

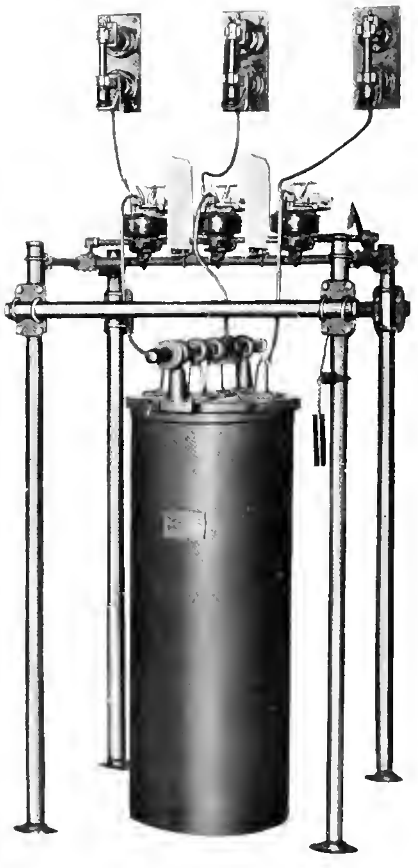


Fig. 7. Aluminum Lightning Arrester for 6600 Volt, Three-phase Non-grounded Neutral Circuit

The addition of the charging resistance to an arrester will insure a material improvement in its operation, as well as increased life of cones and electrolyte. The charging current is limited, and its wave form is so modified that, even with such a delicate test as a parallel telephone circuit, it is impossible to detect any action of the charging on resonant parts of the circuit.

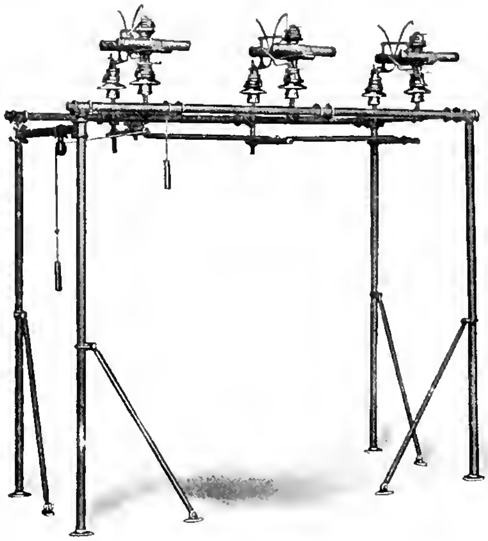


Fig. 8. Horn Gaps, Pipe Framework and Charging Resistance of Aluminum Arrester for 12,500 Volt Circuit

The horn gap with charging resistance has an auxiliary horn mounted above and insulated from the regular horn in such a manner as to intercept the arc if it arises on the regular horns. (Fig. 13.) Enough resistance is connected in series with this auxiliary horn so that the current flow and arc across this gap are always limited to a moderate value. Such a device has several advantages. Since the mechanism is so arranged that the charging is always done through the auxiliary horn the current-rush is limited during the charging and thus troubles from carelessness or ignorance are avoided. It also gives a more uniform charging current.

In the use of this auxiliary horn gap and resistance there are three successive stages which will be described in their order as follows:

1st. Light discharges will pass across the auxiliary gap through the series resistance to the cells.

2nd. If the discharge is heavy, the resistance offers sufficient impedance to cause the spark to pass to the main horn. This is accomplished with only a slight increase in potential because the gap is already ionized. If the cells are in normal condition the spark at the gap is immediately extinguished without any flow of dynamic current.

3rd. If the cells through either negligence or some untoward condition are in poor form, the dynamic current may follow the discharge across the main gap and the arc will rise to the safety horn and be extinguished through a resistance.

Difference Between Arresters for Grounded and Non-Grounded Neutral Circuits

It is important to avoid the mistake of choosing an arrester for a thoroughly grounded neutral when the neutral is only partly grounded, that is to say, grounded through an appreciable resistance. Careful consideration of this condition will make the above statement clear. In an arrester for a grounded neutral circuit, each stack of cones normally receives the neutral potential when the arrester discharges; but if a phase becomes accidentally grounded the line voltage is

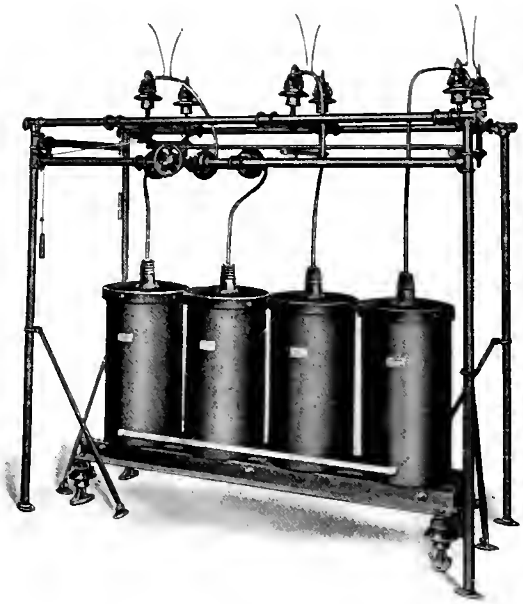


Fig. 9. Aluminum Lightning Arrester for Three-phase Non-grounded Neutral Circuit

thrown across each of the other stacks of cones until the circuit breaker opens the circuit. Line voltage is 173 per cent of the neutral or normal operating voltage of the cells and therefore about 150 per cent of the permanent critical voltage of each cell. This means that when a grounded phase occurs this 50 per cent excess dynamic potential is short-circuited through the cells until the circuit breaker opens. The amount of energy to be dissipated in the arrester depends upon the kilowatt capacity of the generator, the internal resistance of the cells, and the time required to operate the circuit breakers. It is evident that the greater the amount of resistance in the neutral, the longer will be the time required for the circuit breakers to operate. *Therefore, in cases when the earthing resistance in the neutral is great enough to prevent the automatic circuit breakers from opening practically instantaneously, an arrester for a non-grounded neutral system should be installed.*

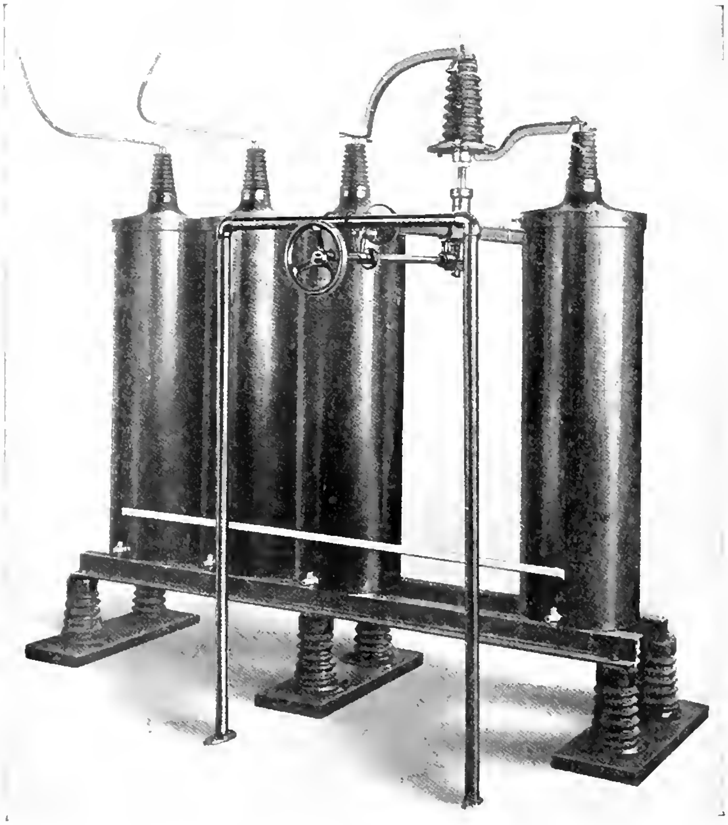


Fig. 11. Tanks, Transfer Device and Rack of a 35,000 Volt Aluminum Lightning Arrester for Non-grounded Neutral Circuit

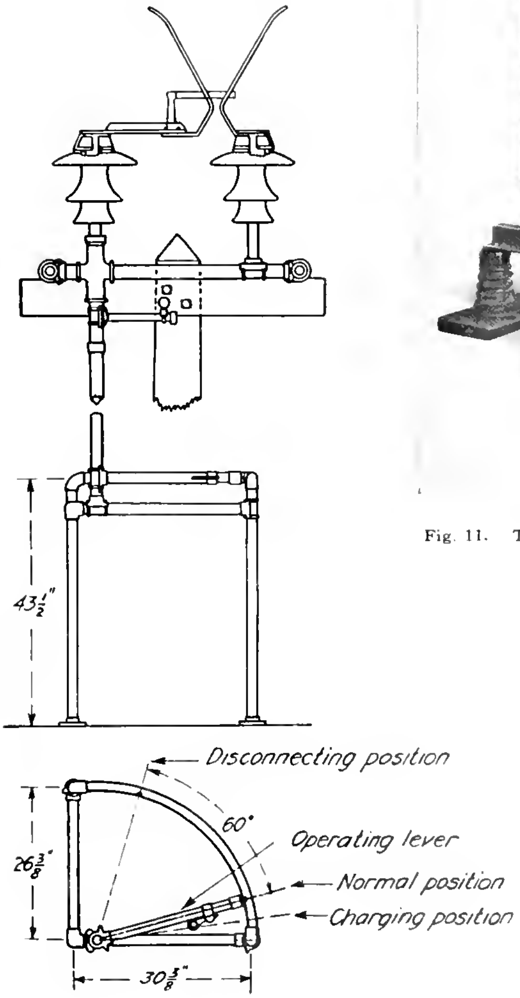


Fig. 10. Horn Gap and Operating Stand for High Voltage Arresters

It is difficult to determine these factors of ground resistance and time elements in the operation of switches and therefore no mistake can be made by adopting the four tank arrester even on grounded Y circuits.

Arresters for circuits with thoroughly grounded neutrals have three stacks of cones. The bases of the stacks of cones are connected to the tanks and grounded. For arresters up to 7250 volts, inclusive, all the cones are mounted in a single tank, but for higher voltages each stack is mounted in a separate tank. (Fig. 5.) The top cone of each stack is connected to the line through a horn gap. Insulating supporting racks are not necessary with arresters for grounded neutral circuits.

For non-grounded circuits the arresters have four stacks of cones, the bases of which are connected together by a multiplex connection. The fourth stack is thus between the multiplex connection and the ground, the object being to give the same

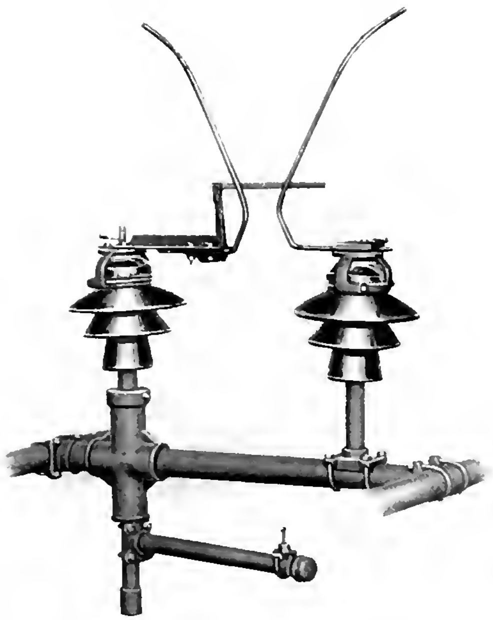


Fig. 12 Horn Gap, Showing Short-circuiting Contact for 40,000 Volt Aluminum Arrester

protection between the line and line as between line and ground. This insures proper distribution of voltage in the cells during the conditions incident to an accidentally grounded phase. The fourth stack is called the ground leg of the arrester. Below 7250 volts all of the cones are installed in a single tank, but for higher voltages each stack is installed in its own tank. The tanks are mounted on insulating racks. Two of the stacks are connected directly to the line, each through a horn gap; the third is connected to the line through the transfer device and horn gap. The fourth stack is connected to the ground through the transfer device.

Transfer Device

The object of the transfer device is to provide a means for interchanging the ground stacks with one of the line stacks of cones during the charging operation so that the films of all the cells will be formed to the same value.

For arresters up to 7250 volts the transfer device consists of a plug switch (Fig. 7). For higher voltages the transfer device consists of a rotating switch which may be turned 180 degrees, thus interchanging the connections of the ground stack and one of the line stacks. For arresters up to 27,000 volts the device is mounted with three insulators on the pipe framework, and

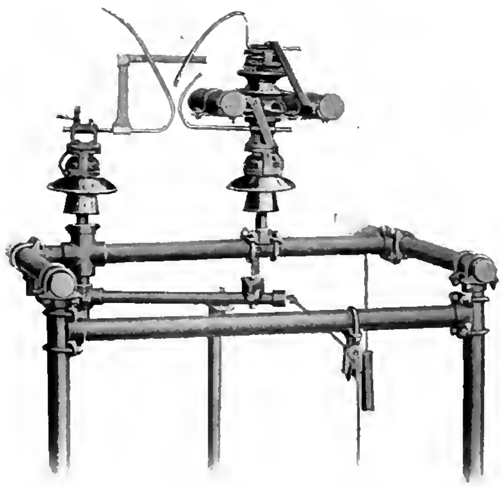


Fig. 13. Horn Gap, with Charging Resistance for 15,000 Volt Aluminum Arrester

is operated by a handwheel. (Fig. 9.) For arresters above 27,000 volts the transfer device is mounted directly over the tanks (Fig. 11), and is operated by bevel gears and handwheel.

STORAGE BATTERIES IN MODERN ELECTRICAL ENGINEERING

Part III

By D. Basch

Switchboard Engineering Department, General Electric Company

The first part of this paper was devoted to the lead battery; and the second to the Edison nickel-iron battery, charging sources and oil-switch circuit breaker batteries. In this month's installment the author goes on to consider storage battery installations for isolated lighting plants, with reference to ratio of generator and battery, and charging and lighting requirements of different installations; private and public garages for charging the batteries of electric vehicles, with reference to the various kinds of charging source; ignition battery outfits; and automatic cutouts for battery charging. Next month's installment will conclude Mr. Basch's paper, and will deal with boosters and various booster arrangements for battery charging.—Editor

BATTERIES IN SMALL ISOLATED LIGHTING PLANTS

General

At the present time less than one-half of the population of this country can be supplied with electricity from central stations. Where such electric supply is not available, and where uninterrupted 24-hour service in the most economical form is desired, as in the case of factories, institutions, residences, etc., situated outside of any electrical distribution network, storage batteries are recognized to be an absolute necessity. If in isolated plants engine and generator capacity, in the absence of storage batteries, is selected sufficient for the total number of lamps connected, the plant will normally operate at but partial load with low efficiency, poor regulation and high fuel costs, as the lamps are seldom in use. The installation of a storage battery will permit the operation of the generator at full or the most economical load; the generator and battery in parallel on special occasions when a large amount of lighting is required; and the battery alone during the balance of the time, generally during the night, when only a few lamps are turned on and when the noises of the engine are objectionable. The generator in such plants is generally compound wound so as to give the best voltage regulations on the line when running alone.

Ratio of Battery and Generator

No fixed rule can be given as to the ratio between generator and battery. The size of the battery depends on the number of lamps, etc., to be run from it, and the length of time during which it must supply the load alone. The generator, besides being able to carry the average day load, when not charging, must be of such size that it can carry the charging current, which may be varied according to the length of time available for charging *plus* the current for any other loads, etc., to be supplied during charge.

Frequently the battery is made somewhat larger than required in order to give it considerable reserve capacity. In this case the battery will not be completely exhausted in a day's run, and the capacity to be restored in an everyday charge is below the rated capacity; so that, with lower charging current, the battery can be fully charged in the time which it would otherwise take to charge with normal current, thus decreasing the required generator capacity. Generally, however, this feature is utilized to increase the intervals between charges, so that the generator again must be large enough to take care of the full charging current. It may be said that where batteries are simply used as auxiliaries, the normal eight-hour charging rate does not exceed 10 per cent of the normal ampere rating of the generator.

Batteries for isolated plant service are generally furnished for either 110 volts or for 32 volts (mostly with metallic filament lamps). In view of the fact that every isolated plant may some day come within the range of a central station, it is advisable to use wherever possible 110 volts.

Various Systems

There is a very wide variation in the requirements to be met, but in general the following sub-division can be made: (a) According to whether lights are to be supplied during the charge of the battery or not; (b) according to whether regulation of electric supply must be constant at all times, or whether it is desired merely to have current available during the night when the battery runs alone, so that a lamp may be turned on for a short time if needed with no particular consideration for voltage regulation.

In most cases the batteries are charged in two parallel sections, each section containing one-half of the total number of cells, and discharged in series. This puts a load on the generator during charge equal to double the normal charging rate of the battery. Sometimes the battery is divided into three sections for the purpose of charging, say A, B and C. A and B are first charged in series for one-half the time necessary for the full charge; then B and C for the same length of time; and finally A and C. This method takes longer to charge the battery, but the load imposed on the generator is less, and less energy is lost in the resistance.

The differentiating features of the various sub-divisions mentioned above are then as follows: When light is to be furnished during the charge, the generator runs at normal voltage while charging, and suitable resistances are introduced between generator and battery so as to limit the voltage impressed on the battery. These resistances may be variable, when the battery is charged with constant current; or fixed, when it is charged with tapering current. Sometimes only one resistance is furnished between generator and the two combined sections, carrying a current equal to double that of the normal charge rate. At other times one separate resistance is arranged in each section carrying a current equal to the normal charge rate of the battery.

When it is not necessary to supply any lights during charge, it is satisfactory to omit the resistances and to vary the charging voltage by manipulation of the field rheostat of the charging generator. With this arrangement the battery is sometimes charged in one series and the voltage raised through the field rheostat; or, if the generator field does not give a sufficient voltage range, through field rheostat and raised speed pulley. This method admits of reducing the capacity of the charging generator, as the load imposed on the generator is equal to (instead of double) the normal battery current.

The individual advantages of a 110-volt generator and a 32-volt battery are combined in a system which has been installed for private residences, and which has proven very satisfactory. This system consists of a three-wire installation, the outside wires of which supply current from the 110-volt generator; the center wire and one of the outside wires supply current from the 32-volt battery. The main lights are connected to the 110-volt source. Each group of lights contains one or more 32-volt lamps, and the switch controlling each group is made up with three throws—the first for 110-volt, the second for 32-volt and the third for open circuit.

The second sub-heading (*b*) refers to the relative importance of maintaining constant voltage at all times, while load is supplied. If close regulation is required, especially during the discharge of the battery, three methods may be used; metallic resistance, end cell switches and counter cells. A metallic resistance will represent a loss of power, and is therefore not recommended on any but small installations. The charging resistance, if variable, can be utilized to regulate the voltage while discharging. End-cell switches permit of regulating the number of cells in circuit, so as to keep the supply voltage constant; beginning with the smallest number of cells when the e.m.f. of the cells is highest and gradually cutting in additional cells as the voltage goes down; until finally all cells are in circuit. Counter cells require a counter cell switch, similar to an end-cell switch, which regulates the number of counter cells connected in circuit, as the discharge goes on. At the beginning of the charge, all counter cells are in; as the discharge voltage of the battery decreases, the number of counter cells is cut down; until finally, with cell voltage down to 1.80 volts, all counter cells are out. Counter cells, with about 2½ volts per cell e.m.f. have an advantage over end cell switch regulation, as with them all cells are discharged equally, while with end cell switches the end cells are not worked the same as the other cells. However, as the use of counter cells does not reduce the number of cells required in the battery and a counter cell switch is necessary, the expense of the equipment is increased and additional complications are introduced. Counter cells represent a loss of power, and in general they are not used for larger batteries. For small batteries counter cells are considered preferable to end cells. When no close voltage regulation is required, all auxiliaries for discharging may be omitted.

The consideration of voltage regulation has a direct bearing on the number of cells required. For close regulation, the number of cells must be such that with 1.80 volts per cell the full voltage is available. In the other case the number of cells is such that when the battery is fully charged, the voltage is somewhat above normal; and, when discharged, an equal amount below normal. Figs. 10 and 11 show some switchboard panels for this class of work.

VEHICLE BATTERY SWITCHBOARDS

The various types of vehicle battery charging panels are based on the nature of the service which they have to perform, and the nature of the charging source available.

With regard to the service, they may be divided into panels for public and for private garages, a public garage panel being arranged to charge a greater number of vehicle batteries simultaneously, a private garage panel having provision for only one or two batteries. With regard to the nature of the charging source, where the charging station (garage) is supplied with 125 volts or 250/125 volts direct current, the batteries are charged through resistances from the source. Where the supply is 600 volts direct current a small motor-generator set is generally provided, in addition to the 125 and 250 volt panel, to produce a lower charging voltage and to prevent waste of power in the charging rheostat. Where only alternating current is available, usually a mercury-arc rectifier is employed to transform alternating current into direct current. In some instances an alternating current motor, direct current generator set (125 volts direct current) is used, in addition to the regular 125 and 250-volt panel.

PUBLIC GARAGE PANELS

(See Fig. 12)

These panels are built on the unit system, the standard unit being equipped to take care of two, four or six circuits, for either 125 volts two-wire, or 125/250 volts three-wire

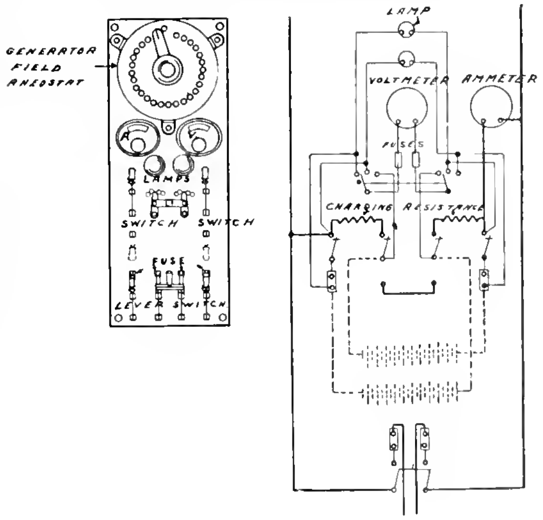


Fig. 10. Switchboard Panels for Batteries in Small Isolated Lighting Plants

direct current. These standard unit panels are furnished with ammeter and voltmeter; but two circuit sections without instruments can be furnished when more batteries are to be provided for than intended in the original installation. Sub-bases may be furnished with fuses for the incoming line, when further protection is desired than that afforded by the circuit fuses. Instead of fuses, circuit-

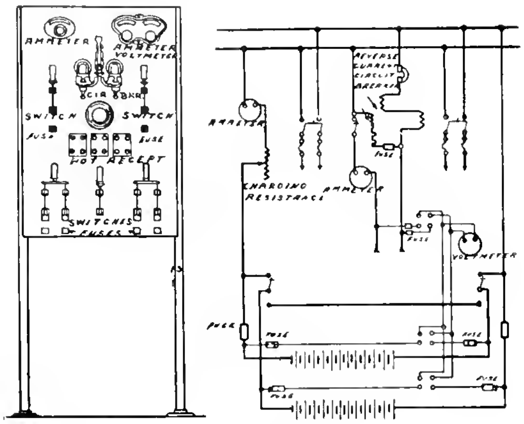


Fig. 11. Switchboard Panels for Batteries in Small Isolated Lighting Plants

breakers with overload, underload or reverse current attachments, may be supplied.

Frequently a separate single-pole double-throw switch on the sub-base is desired in order to discharge a battery. The circuit switches are made double-throw, permitting the use of a single ammeter to read the current on any one of the circuits. Each circuit switch is fused to take care of trouble in the individual feeders. A separate fuse is provided on the back of the panel in the ammeter circuit to protect the instrument in case two or more feeders are unintentionally thrown in on it simultaneously. The charging rheostats are mounted compactly above the panels; and where the floor space is limited the rheostats are arranged in two tiers, with the upper tier operated by means of a rod. Each rheostat consists of two parts. The one mounted above the panel contains the variable resistance; the other contains the unvarying resistance, and may be placed on the floor in a convenient location.

The voltage of the supply and the voltage actually applied to the battery inside the charging rheostat are read in a single voltmeter, which can be plugged in receptacles connected to the various circuits. It is recommended that the panel be raised at least 6 in. above the floor, to prevent injury to apparatus and panel when flushing the garage floor.

In public garages charging posts are provided in convenient locations with receptacles which are connected to the various circuits on the panel. The vehicle batteries are equipped with plugs fitting in these receptacles, so that a battery can be charged

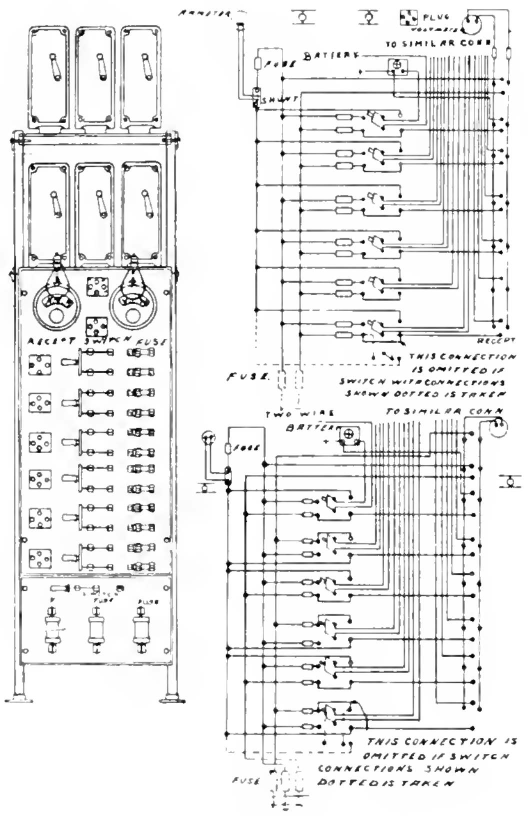


Fig. 12. Public Garage Panel

anywhere in the garage. The plugs and receptacles are so arranged that a reversal of polarity is impossible. (See Fig. 13.)

PRIVATE GARAGE PANELS

(See Fig. 14)

These panels are designed for charging one or two batteries simultaneously from a 125-volt two-wire direct current supply. They are intended to be mounted on the wall of the garage by means of flat strap iron supports. The charging rheostat may be located on the floor directly underneath. A combined ammeter and voltmeter is supplied, the ammeter being continuously in circuit in the case of the single circuit panel and arranged to be cut into either circuit in the case of two circuit panels. The voltage of the incoming line may be read, also of the charging circuits by means of plug and receptacles.

PRIVATE GARAGE PANELS WITH MERCURY ARC RECTIFIERS

(See Fig. 15)

These panels contain direct current ammeter and voltmeter, a double-pole switch for the alternating current supply, a direct current circuit-breaker for the load, and the necessary switches, etc., for starting and operating the rectifier. A starting load resistance, on which the rectifier starts before being connected to the actual or working load, is mounted on the back of the panel and is operated by a single-pole double-throw spring switch which is normally closed in the load position and must be transferred and held in the starting position by hand.

An auxiliary spring switch—the starting anode switch—is operated by the blade of the starting switch; and is connected through the starting anode resistance, in series with the starting anode circuit, for the purpose of limiting the current flowing through the starting anode when the mercury bridge is formed. When the starting switch is in the load position, the anode switch is open and closes only when the starting switch is thrown into the starting position, opening again automatically through the spring when the starting switch handle is released. Voltage control is obtained by adjustment of a regulating switch on the front of the panel, connected

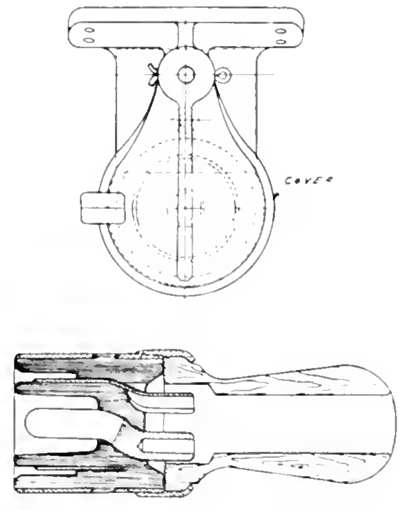
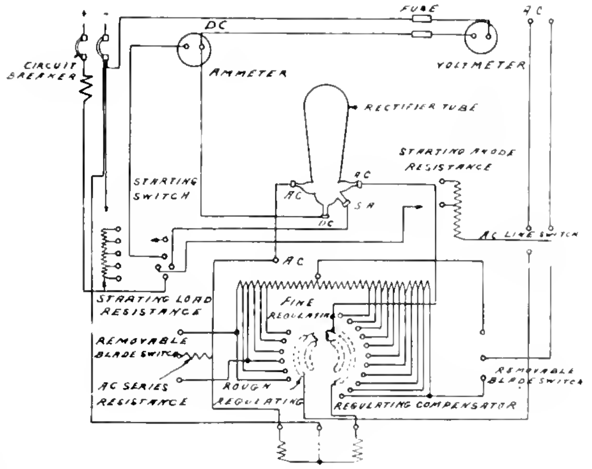


Fig 13. Charging Plug for Vehicle Batteries

to a regulating compensator which is mounted on the back of the rectifier panel on the pipe supports. An alternating current series reactance gives a drooping characteristic to the direct current voltage. The rectifier tube is mounted on a holder on the back of a panel and is shaken by means of a handwheel on a shaft, which protrudes through the front of the panel. An automatic electromagnetic starting device may be furnished with the standard supply this apparatus unless very good reasons demand it.



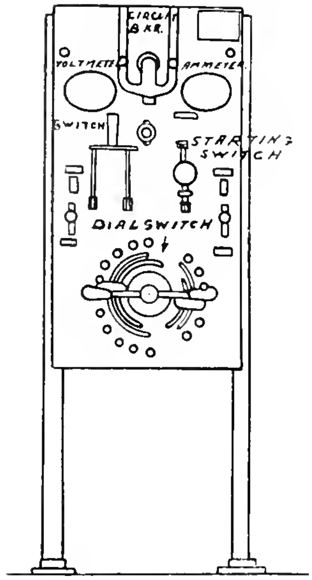


Fig. 15. Private Garage Panel With Mercury Arc Rectifier

outfits, which is particularly useful where large fluctuations or momentary interruptions sufficient to stop the arc are liable to occur in the load or supply. This device rocks the tube and starts the arc automatically. In general, it is recommended not to

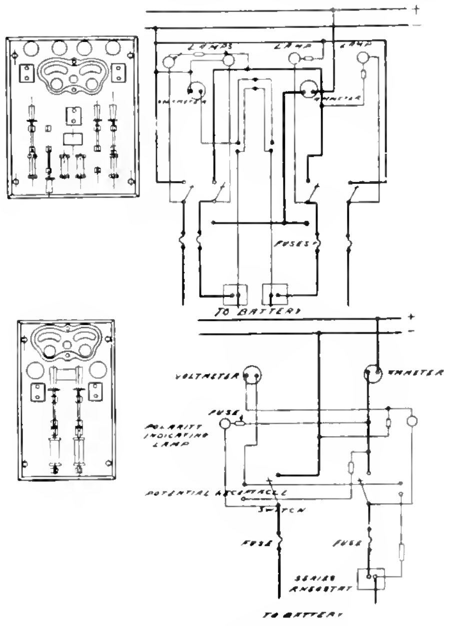


Fig. 14. Private Garage Panels

Any two or more standard rectifiers may be operated in multiple, when the desired output is above 50 amps. It is only necessary to add suitable reactances in series between the cathode of each rectifier and the positive side of the load. In general, only 30 and 40-ampere rectifiers are paralleled. Panels may be designed to operate either individually or in multiple. They are then each furnished with a double-pole double-throw switch in addition to the regular equipment.

The so-called commercial vehicle type of rectifier panel is designed particularly for use in large garages of department stores, express and delivery companies, etc., wherever a number of batteries of approximately the same voltage is to be charged. Each rectifier is a complete unit; a charging outfit generally consists of one panel with instruments, and preferably not more than the two panels without instruments. Provision is made to transfer the ammeter and voltmeter to any one of the circuits.

For small electric pleasure vehicles having a charging rate not exceeding 30 amps. a special panel without instruments has been designed, which is simpler in operation and does not have the wide voltage range of the standard outfit. The voltage range is 34-82 volts with 110 volt alternating current supply; and 34-120 volts direct current with 220 volt alternating current supply. (See Fig. 16.)

PUBLIC GARAGE PANELS WITH MERCURY ARC RECTIFIERS

(See Fig. 17)

A public garage rectifier outfit consists of two panels. One is used for controlling the rectifier tube and for adjusting current and

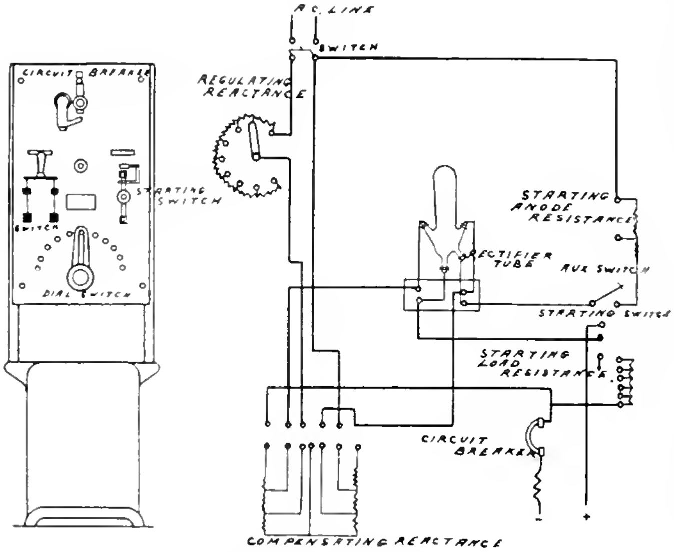


Fig. 16. Private Garage Panel with Mercury Arc Rectifiers for Small Electric Vehicles

voltage; the other one contains the starting switches and two ammeters. The rectifier panel is equipped with the necessary load circuit-breakers, supply switch, starting switch, anode switch, rectifier tube and shaker, regulating switch, etc., similar to the private garage panel. The direct current voltage range is 30-230 volts with 220 volt alternating current supply. One voltmeter (350 volts) reads the voltage delivered by the rectifier; the second one (150 volts) may be switched onto any one of the individual batteries receiving a charge. On the right-hand panel six triple-pole double-throw switches, each controlling one battery, are mounted. These switches are connected in two groups of three each; by means of a double-pole double-throw switch mounted on the rectifier panel the two groups can be connected in multiple or in series across the rectifier. Forty amp. is the maximum current which the rectifier tube can deliver to the right-hand section; twenty amp. is therefore delivered to each battery when the switches are thrown in parallel, and forty amp. when in series.

In series with each group of switches is connected one of the two sixty ampere ammeters and one charging rheostat. The rheostats are set directly underneath the right-hand section, and serve to adjust the charging current individually for the two sets of batteries.

Standard sub-bases may be supplied in addition to the regular equipment. This sub-base is equipped with six non-reversible plug receptacles and six charging plugs. To these plugs are attached six charging cables leading to various convenient points, for charging, in the station. Each receptacle is connected to one of the six triple-pole double-throw

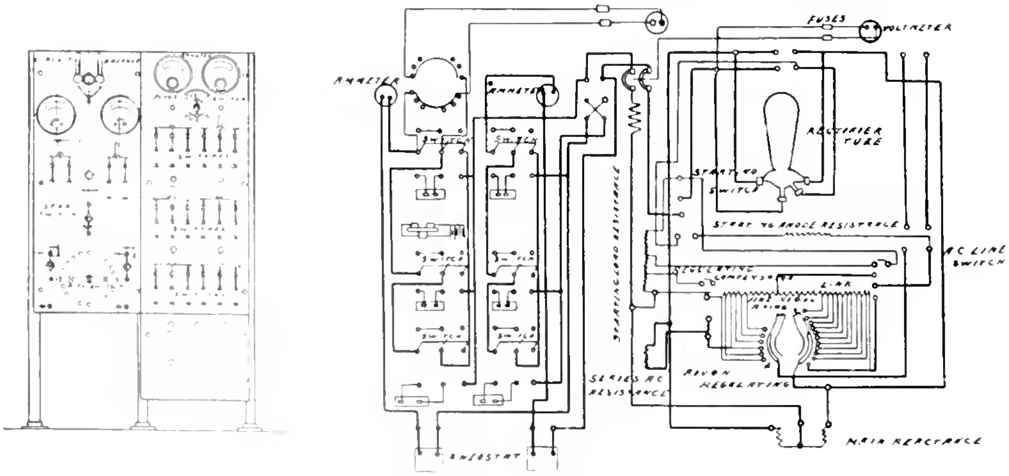


Fig. 17. Public Garage Panel with Mercury Arc Rectifier

charging switches on the upper panel. This arrangement permits of readily changing the distribution of the various batteries under charge from one circuit to the other, in order to produce the most efficient combination without moving the vehicles from place to place.

IGNITION BATTERY OUTFITS WITH MERCURY ARC RECTIFIERS

Ignition sparking batteries, for gas and gasolene engines and gasolene automobiles, are ordinarily about six volts, equal to three lead and five Edison cells. Standard panels have been designed for the control of two, four and six ignition batteries, with a direct current rectifier voltage of 15 to 30 and 45 volts. Panels either have no instruments, one ammeter, or ammeter and voltmeter. (See Fig. 18.) The ignition battery rectifier is operated in a manner similar to other types of rectifiers; it should, however, be noted that it is designed to charge batteries in series only. The panel contains a small rheostat for rough adjustment of the charging current and voltage, double-pole supply switch, starting switch, starting anode switch, rectifier tube and shaking device.

A special feature of these panels is the so-called auxiliary load resistance, which is designed to furnish sufficient load to keep the rectifier operating during fluctuation in line voltage, and when the rectifier is to be used at a current considerably below normal. There is a relay connected in circuit so as to

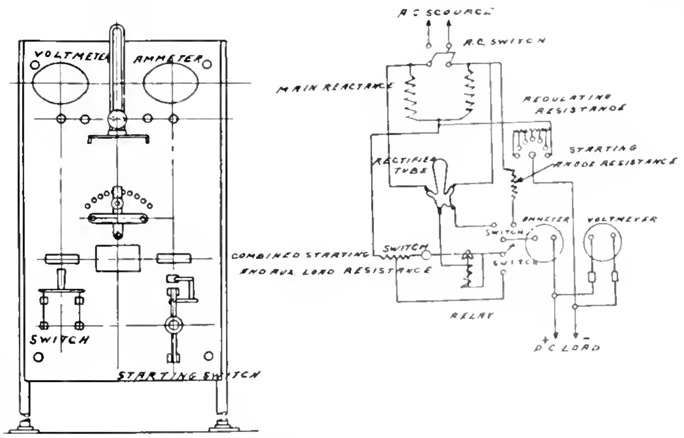


Fig. 18. Ignition Battery Panel Mercury Arc Rectifier

open the auxiliary resistanc circuit, in case the line voltage should fail and the rectifier cease to operate. Without the relay, the battery under such conditions would discharge into the auxiliary resistance. The auxiliary resistance may be cut by means of a snap switch, when the load and supply are steady and normal.

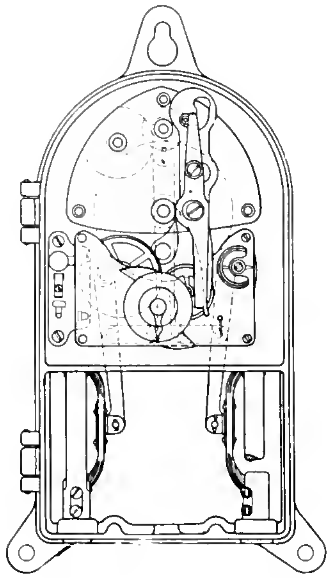


Fig. 19. Automatic Time Switch for Storage Batteries

AUTOMATIC CUTOUTS FOR BATTERY CHARGING

Frequently it is desirable to install with a storage battery outfit, especially with vehicle batteries, an automatic device which will cut out automatically when the battery has become fully charged, so as to enable charging circuits to be controlled without special attention.

Three types may be considered, as explained in the following:

1. *Voltage Cutout.* As the voltage of the cells in a vehicle battery rises, the charging current will decrease, if the voltage of the charging source is maintained constant. An underload circuit-breaker can therefore be set in such a manner as to open automatically when the current goes down to a predetermined value. There are, however, two reasons why this method is apt to be unreliable and should not be recommended. First there is no definite end voltage of a battery in charge that can be fixed beforehand. In charging, it is always necessary to work towards a maximum voltage rather than a definite end voltage, as brought out before.

As the maximum voltage actually reached by a battery is above or below the estimated value, the magnitude of the charging current at the end of the charge will vary, and either open the breaker before the charge is completed, or hold it in when the charge is finished. Secondly, the line voltage or the voltage of the charging source is apt to vary considerably, adding another factor of unsafety. The mercury arc rectifier acts in some respects like a voltage cutout, as the arc in the tube goes out when current drops to a certain point. The objections are the same as with the underload breaker.

2. *Time Switch* (See Fig. 19). The automatic time switch is somewhat more reliable than the voltage cutout. It requires considerable experience on the part of the operator, who sets the time switch, to foretell with any degree of accuracy how long it will take to charge a battery. The setting will depend on how much of the capacity of the battery has been exhausted; it will always be an estimate and consequently more or less inaccurate. This inaccuracy of estimate is furthermore apt to be increased by the variation in line voltage and battery characteristics. Its advantage over the voltage cutout is the certainty that after a predetermined time it will positively interrupt the charge, whereas under certain conditions the voltage cutout will stay in, until opened up by hand.

3. *Ampere Hour Cutout.* This cutout, which, in principle, is a contact-making integrating ampere-hour meter, will stop the charging of a battery when a number of ampere-hours, equal to the previous ampere-hour discharge *plus* the battery losses, has been delivered to the battery. As the battery losses are not constant, the condition of the battery should be checked with the regular overcharge. The meter should be connected in during discharge as well as charge. In general, the ampere-hour cutout is the best solution of the problem.

LIGHTNING PROTECTION OF BUILDINGS

By Ernst J. Berg

Professor of Electrical Engineering, University of Illinois

This article was written as the result of numerous inquiries that have come to the attention of the author as to the best means of protecting buildings and other structures from lightning strokes. Following an interesting discussion of the somewhat uncertain characteristics of lightning and the electrical constants of lightning rods, answers are given to such questions as: How much protection does a rod afford? How many rods should be used? How should the rods be placed? What should be the material, shape and size of the rods, and how should the ground connection be made? etc., etc.—Editor.

In looking over recent articles dealing with lightning and lightning protection one is struck by the prominence given to protection of electric transmission lines and electric apparatus, while practically no contributions have been made to the subject of protection of buildings since the famous work by Sir Oliver Lodge years ago. Yet the protection of buildings unquestionably is as important as the protection of transmission lines and there are thousands of people interested in protecting their homes to every one interested in a transmission line.

To people living in cities the subject is, however, of little or no interest. Experience has shown that the extensive networks of wires, metal roofs, etc., are usually ample for protection. The man living in the country, however, is very much concerned, as experience has shown that in certain localities at least it is indeed tempting providence not to have some lightning rod scheme.

The lack of literature might be assumed as indicative of either lack of interest on the part of the public or as evidence that any kind of lightning rod installation is good enough. Neither conclusion is correct. There is very much interest in this subject, as is evidenced from letters received by the few people who are supposed to know something about it, and a scheme of lightning protection may well be and is often installed so as to actually endanger the buildings.

The questions usually asked are: Is there any real advantage in the installation of lightning rods, or do they "draw" lightning and thereby add to the danger? Can a building be perfectly protected from lightning? How much protection does a lightning rod afford? How many rods should be used? How should they be placed? What kind of material should be used? What should be the size and shape of the rods? How should the ground connection be made? Should the water pipes, steam pipes, and other metallic conductors be connected together and to ground? Is it dangerous to stand in a draught during a thunderstorm? Is it safe to stand near a lightning conductor? Should persons be careful about avoiding large metal objects, such as kitchen ranges, etc., during storms?

Undoubtedly lightning has been a cause of wonder and speculation since the very earliest days and many eminent scientists have devoted their time and energy to its study, but it is still to a considerable extent a mystery. Indeed, there seems to be no satisfactory explanation of the source of the energy which as electric field is often very rapidly stored between clouds and clouds and between clouds and earth. This fact, however, is undisputable. Electric energy is frequently stored around us, and this energy is converted to heat and electric radiations, in the lightning stroke, often with serious consequences to man.

However, while little is known about the source of the electric energy, fortunately, due mainly to the researches of Sir Oliver Lodge, a fair amount of knowledge exists about the nature of its discharge—of lightning itself. Lodge first suggested that there are at least two distinct kinds of discharges: one which is relatively quiet and which results from the gradual breaking down of the air between the object struck and the charged cloud; the other which is a violent secondary discharge caused by a primary discharge in the vicinity.

The first kind follows the well known laws familiar to the electrical engineer—laws that deal with more or less permanent conditions. The nature of the discharge is governed by the resistance, inductance and capacity of the path. The path itself is almost certain to be the rod on account of the conducting streamers above it.

The second kind is more complex and the laws that it follows are less thoroughly understood. There is no conducting path above the rods because there may have been no potential difference between them and the surrounding air before the discharge. Thus the rods may well be missed and the discharge enter any portion of the roof and find its way to ground through the building. To guard against these it would seem that the entire roof should be of metal, or at least largely covered by a metal network.

Prof. Fleming has compared the first with the slow combustion of gun powder placed in a room and carefully lighted, the second with detonating powder. In the first case the heated air and gases of combustion are readily guided through the chimney and do no harm; in the second case no matter how large the chimney is, enormous pressures will exist in all directions. The reason for this is that, while the inertia of the air normally is very small and it can readily be displaced, it becomes tremendous when sudden forces are applied; in fact, during the very first instant the air acts as a solid.

Electrical Constants of Lightning Rods

It is generally recognized that a lightning discharge is oscillating and that the oscillations are of high frequency, perhaps from 100,000 to several million cycles per second. At these frequencies the electric constants of conductors are very different from those normally.

In the passing of high frequency currents, energy is expended as heat at the surface of the conductor and as electric radiations in the surrounding space. The ohmic resistance, which depends upon the conductivity and the cross section of the rod, is of practically no importance: even the shape of the conductor, which is of much importance with frequencies from 100 to 100,000 cycles, is of relatively little importance at frequencies from a million to ten million cycles.

The same applies to the inductance of the conductor—it is also practically independent of the kind of material or its section. It is evident from this that, provided the lightning discharge in the rod is a high frequency oscillation, from an electrical point of view it matters really very little whether copper or iron, flat or round, stranded or solid conductors are used; though to be sure there is a slight advantage in flat ribbons at all but the highest frequencies.

The object of the lightning rod is to form a path for the discharge, a path offering much less obstruction than any path through the building. If the ohmic resistance were all important this could well be done by using a very large copper rod, but at these very high frequencies the obstruction or impedance is measured in tens or even hundreds of ohms, whereas the ohmic resistance may be but a small fraction of an ohm.

Electric Characteristics of Lightning Itself

The greatest number of lightning discharges takes place inside of clouds or between adjacent clouds. These discharges involve usually rather moderate voltages, as has been shown by Steinmetz, but while very interesting are hardly within the scope of this paper. The knowledge of the nature of lightning discharges from cloud to earth is, however, of greatest importance in studying the efficiency of lightning rods.

Unquestionably such discharges take place not only at moderate voltages, but also at voltages which are exceedingly high; this latter being the case when the charged cloud is separated from earth by a layer of more or less dry, moisture free air.

Under these conditions the distribution of potential may be quite uniform, and the air as a limiting case may be charged to its breakdown point all through its mass, when the potential difference may be exceedingly great, perhaps hundreds of millions of volts. The maximum value of the discharge current may also be very great, reaching several thousand if not hundreds of thousands of amperes, as may be judged from the consideration of the following simple and apparently conservative case. An area on the surface of the earth 100 feet square is subjected to the discharge of a cloud or part of a cloud, also 100 feet square, at a distance of 1000 feet. In this case the capacity is approximately 0.000027 microfarads, a very small capacity indeed, something like that of the smallest Leyden jar. If the electric stress as assumed were uniformly distributed throughout the air space separating cloud and earth, and if the disruptive strength of air is 30,000 volts per cm., a potential of 912 million volts would exist between cloud and earth just before the stroke. The electric charge, that is, the amount of electricity stored, would be 0.025 coulombs, a very small value when considered by itself. The energy stored would, however, be great on account of the high difference of potential. It would be 11,200 kw-secs., corresponding to the energy of almost a pound of dynamite. This energy is expended in heat and electric radiation, partly in the stroke before it reaches the rod, partly in the circuit of the rod. The higher the frequency the greater is the relative amount radiated. With a small copper rod the energy radiated at one million cycles is perhaps 50 times as great as that converted to heat in the rod. With a small iron rod, however, the two quantities are not much different. Thus the iron rod will convert more energy to heat and yet only slightly more impede the discharge. The number of oscillations of the current in the iron rod is therefore less than with copper, and the discharge less violent. Whether, however, the energy is radiated or directly converted to heat is not so material. In either case the maximum current in the rod may be enormous and depends upon the frequency of the discharge. With an average lightning discharge this may be from 100,000 to perhaps 5 millions per second, in which case the maximum value of the current is from 15,000 to 750,000 amperes, it being proportional to the frequency. Steinmetz has shown that the impedance or total obstruction of the high frequency conductor is about 0.1 ohm per foot at 100,000 cycles, 0.5 ohms per foot at 500,000 cycles, 1 ohm per foot at 1,000,000 cycles, and 2.5 ohms per foot at 5,000,000 cycles. Thus the maximum drop of potential per foot of lightning rod would be 1.5 volts at 100,000 cycles, 9.0 volts at 250,000 cycles, 37.0 volts at 500,000 cycles, 150.0 volts at 1,000,000 cycles and 1,880,000 volts at 5,000,000 cycles.

While in every discharge almost an infinite number of frequencies undoubtedly are represented, it is probable that one is preponderating. Were it permissible to consider that the frequency in the discharge after it reaches the rod is governed only by the electrical constants of the rod, the wave length would be somewhat more than four times the height of the rod. This would mean with an ordinary dwelling, with a rod of say 50 ft., about 5,000,000 cycles. If on the other hand the effect of the rod is hardly noticeable and the frequency is governed by the distance between cloud and earth, the frequency will be much lower, say 250,000 cycles, with a distance of 2000 ft. between the cloud and earth.

In the first case the drop in potential per foot is about two million volts, in the second case only nine thousand volts. The first case, I believe, gives an idea of the conditions of a secondary stroke. It is of very high frequency and may be the result of the discharge of the air immediately surrounding the rod rather than the entire air between cloud and earth. The discharge area is in this case difficult to estimate; it may be quite limited or it may be quite great.

Assuming again an area of 100 ft. square and calculating the voltage and capacity, it is found that the capacity is increased in the same proportion as the voltage is decreased; therefore the charge and maximum value of the current remains unchanged. The maximum value of the current would be, say 750,000 amperes, and the drop per foot of rod about 2,000,000 volts.

It is evident that such discharge would jump several feet in the air rather than travel one foot in the conductor. (The drop in potential of 2 million volts per foot corresponds to 2 ft. striking distance between parallel planes and perhaps 10 feet distance between projecting masses of metal.)

The second case, I believe, is approached when a lightning discharge takes place from cloud to rod after a conducting path has been prepared by means of streamers. It is the first, the quiet type of lightning mentioned in the beginning of the paper.

Thus is seen how a single lightning rod may be expected to take care of low frequency discharge from cloud to earth but is entirely inadequate to cope with a violent secondary discharge, even if perchance it hit the rod instead of the building proper.

Were this illustration then at all representative it would mean that one lightning rod, while offering some protection, is entirely inadequate to cope with the situation. If the building were grounded by ten rods the condition would be much improved The maximum drop per foot would then correspond to a moderate air space and the lightning discharge would probably be confined to the system of rods.

Before discussing the approximations involved in this elementary discussion it may be well to see the effect of a larger cloud, or perhaps better a larger section of a cloud discharging through the rods. If the areas were doubled, twice as many rods would be required for the same amount of protection. If the areas were the same but the cloud were only one-half as far above the building, the voltage would be lower but the capacity greater, and the conditions in the original assumption would apply.

Principal Uncertainties in the Theory

The principal uncertainty of this theory lies in the estimate of voltage and frequency. Regarding the voltage, it is not likely that even in perfectly dry air the electric stress is uniformly distributed throughout the space; it is probably higher at the cloud and at the building than in the column of air separating them. The effect of this would be to lower the potential and therefore the charge and energy involved. It is probable that, as stated previously, in discharges in clouds and between clouds the potential may be only moderate because it is likely that the discharge takes place from drop to drop at rather low values. In the case of the discharge to ground, however, this suggestion does not seem reasonable, when the lightning strikes through clear air. Furthermore, unless the voltage is extremely high the energy discharged could not be great enough to do what is frequently done.

Regarding the frequency, a great deal has already been said. It seems reasonable that discharges take place at frequencies as low as 100,000 cycles and as high as several millions. While with the former considerably more energy is likely to be involved, it seems reasonable to expect that a rod is of very considerable protection, whereas with the latter a very large number of rods would be required.

What conclusions can then be drawn regarding the best method of protection; what answers can be given to the questions asked in the first part of this paper? Is there any real advantage in the installation of lightning rods or do they draw lightning and thereby add to the danger? Experience seems to have settled beyond reasonable doubt that if properly installed, lightning rods afford considerable protection. A large number of instances might be quoted, but suffice it here to mention only one near at hand. Before equipping the University buildings with rods three fires were caused by lightning; since that time, though the number of buildings has been greatly increased, there has been no damage from lightning. Any lightning rod "draws" lightning if by that expression is meant that it prepares under certain conditions an easier path for the lightning discharge than would be the case if it were not there. The conducting streamers issuing from the rod tend to equalize the potential between earth and cloud and thus diminish the severity of a stroke and possibly prevent it altogether. Yet it may also be argued that unless there are many such streamers the rod cannot always cope with the situation and a stroke may result from them. This feature is dealt with later under another heading.

Can a building be perfectly protected from lightning? The answer must be no, except perhaps in the case of a thoroughly grounded all-metal building.

How much protection does a lightning rod afford? Unquestionably some if properly installed, but it may make matters worse in some cases. Assume for instance that a large building is equipped with a high but broken rod or a rod having poor joints or a high resistance to ground, say several hundred ohms, which undoubtedly sometimes is the case. Such a rod could serve the function of equalizing the potential between cloud and earth almost as effectively as a good rod, and were there only a sufficient number of them it is conceivable that the neutralization of potential would be so complete as to make a flash discharge practically impossible. A building having one rod only, however, is considered at present. The rod is assumed as projecting considerably above the building. If the electric tension is great, unquestionably streamers are emitted, the air above the rod is made fairly conductive and thus the discharge is invited. The question is then: How can such a rod take care of a discharge? It has been shown how the discharge current frequently is very large and while the ohmic resistance of the rod is practically immaterial as long as it is at all reasonable, it must not approach or exceed the normal value of the impedance. In a rod, say 30 feet long, the ohmic resistance of even the smallest practical iron conductor is a fraction of an ohm only and the impedance is perhaps 30 to 75 ohms, depending upon the height and frequency of the discharge. It is easily seen that a poor joint may have many times this resistance; therefore, when the discharge encouraged by the streamers from the defective rod strikes the building it finds the rod entirely inadequate to cope with the situation. The voltage drop in the rod is so great that it is far easier for the current to split up in a number of paths and enter through the building than to confine itself to the rod. An apparent paradox thus exists. The rod should have good joints, should have good ground connection, and should be mechanically secure against breaking; although the shape of the rod, its metal or general dimensions, are rather immaterial.

How many rods should be used? The answer is, the more the better. The protection afforded ought to be, roughly speaking, proportional to the number of earthed rods. Half a dozen ground connections to a house 100 ft. by 50 ft. seems nothing out of the way.

How should they be placed? They should always be placed outside of the building and it is indeed a question whether the vertical part of the system, that is the rod proper, should not be some little distance from the wall and possibly even insulated therefrom. The rods should be a considerable distance from gas pipes, stove pipes, water pipes and balconies or places where persons might be during a storm. A small house might be protected as shown in Fig. 1.

There are five ground connections, one at each corner and one from the chimney. A horizontal rod follows the ridge of the roof and is connected to earth by the five ground connections. Heated gases coming from a chimney are apparently themselves good conductors, or more probable are instrumental in collecting and forming a path of charged particles constituting good conductor for lightning discharges. It seems conservative, therefore, to have a metal conductor crossing over the chimney opening. Such a conductor should be made of copper on account of the chemical effect of fuel gases on iron. Two small spires each having many points are shown. These are unquestionably of some advantage in that through them there is a continuous equalization of the potential between cloud and earth. It seems, however, as if their height should be conservative. A projection of a few feet seems quite enough. To be effective in their office these spires should have several points; but the expense of using platinum or something similar seems hardly warranted, because the amount of current radiated from the points is insignificant before the "brush discharge" begins, and when such discharge takes place it matters little whether the points are rough or sharp. Each tower or other projection of a building should have direct ground connection, though connected with the other lightning rod system. In Fig. 2 is shown what in my opinion is an unsatisfactory arrangement of rods. A small dormer is supposedly protected by an independent short rod connected by a long wire to the main system.

It seems unlikely that the discharge would travel many feet to reach the main rod when by striking through the building it can reach ground in most cases with greater ease.

The attic room, supposedly protected, is in my opinion endangered by the rod. Protection would, however, result if the dormer rod were directly grounded. Metal gutters should be connected to the lightning rod system and should be connected at their lower extreme to ground. A high factory or power plant chimney needs good protection: two or three rods does not seem too much and the opening of the chimney should be crowned by some simple copper rod construction.

What kind of material should be used? In cities, where after all the damage by lightning is small, there is always more or less fuel gases and soot in the air, copper seems best. But I can see no electrical advantage in having a stranded cable—a solid rod is as efficient.

There is a very slight advantage in a flat ribbon, but the advantage is very small and the mechanical difficulties with a ribbon are greater than with a rod. In the country, galvanized iron rods seem best for two reasons: first, they are cheaper; second, their electrical constants are if anything better than those of copper. Again an apparent paradox is met. It has been said that the material, size and shape of the rod was rather immaterial and yet now iron rods are recommended. The reason is that the first statement applied to the ability of the rod to discharge the current with the least drop of potential, whereas other factors also enter; factors which, to be sure, are of a secondary importance.

The old idea that the rod carries the electric charge to earth and that that is the end of it is fallacious. The earth is one plate of the condenser, the cloud the other, and whatever energy is stored between them has to be consumed in some way. It is done by heating the rod and by sending out electric radiations. The higher the resistance of the rod the greater is the energy converted to heat, and thus the smaller the number of oscillations of the discharge current necessary to dissipate the energy. Iron has considerably higher effective resistance than copper, and thus has an advantage. Perhaps the point will be clearer by stating that as far as impeding the flow of the current is concerned the ohmic resistance of the rod is immaterial as long as it is at all reasonable. As far as affecting the duration of the discharge is concerned, however, the higher the resistance the shorter is the time and the less violent is the disturbance.

Lodge's experiments and theory show conclusively that there is no advantage in copper over iron. Copper may have mechanical advantages under certain conditions, for instance in cities where the atmosphere is charged with soot and a variety of fumes. Galvanized iron has the advantage of cheapness, with a possible electrical superiority.

What should be the shape and size of the rods? While flat conductors have a very slight advantage, it appears too small to be considered seriously. A round wire or a pipe can conveniently be handled and seems therefore preferable. In the installation of the rods, sharp bends should be avoided as much as possible. There is little or no advantage in using large expensive copper conductors or cables; a size mechanically satisfactory is likely to serve all electrical purposes. Expensive sharp points offer little advantage over ordinary rather blunt points. The rods may advantageously terminate in a number of points projecting only a short distance above the part to be protected.

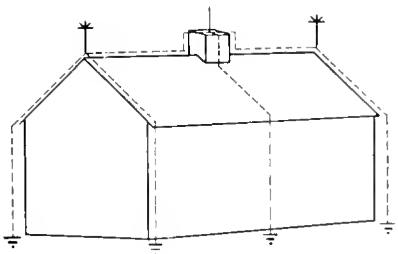


Fig. 1

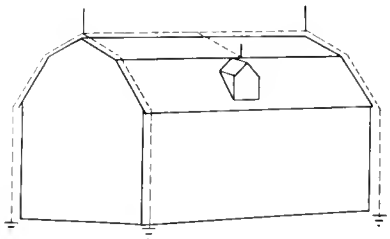


Fig. 2

How should ground connections be made? They should be of low resistance, and therefore the rods should preferably terminate in moist soil. "Salting" the ground may be an advantage, but the experience with such grounds is not sufficient to warrant its adoption unless an occasional inspection is made. In many cases excellent connection can be made by driving a galvanized gas pipe a few feet in the ground.

Should water, steam and gas pipes in the building be connected to the rods and grounded? This is debatable. On the whole it would seem most conservative to leave them alone, especially the gas pipes. The water pipes, which are always grounded, may, however, advantageously be connected to the lightning rod system under ground.

Is it dangerous to stand in a draught during a thunderstorm? Certainly a building having its windows and doors open affords a chance for the entrance of air, perhaps ionized air made conducting by a previous discharge. It is, therefore, safer to keep the house closed during a violent storm.

Is it safe to stand near a lightning rod? From the preceding discussion this seems hardly safe. It is well to keep away not only from the rod but from chimneys, kitchen ranges, metal pipes, etc.

It is finally of interest to draw attention to the fact that the damage by lightning in cities is relatively small and that so far the modern sky scraper with its vast amount of steel appears to be lightning proof.

In conclusion, I wish to emphasize the fact that after all we know little about lightning. I have tried to incorporate the experience of many investigators and observers and am particularly indebted to Sir Oliver Lodge's numerous writings and experiments on this subject.

DIRECT CURRENT LOCOMOTIVES FOR INTERURBAN AND MAIN LINE SERVICE

By S. T. Dodd

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The electric locomotive while not necessarily confined to one class of service is generally designed with the idea of meeting certain definite requirements; and the varied needs of present-day railway traction demand various types of locomotives. This article describes the more important features of construction embodied separately in four sizes of locomotive for 600-volt direct current operation. These are, broadly classified, the 25-ton, 50-ton, 75-ton and 100-ton units; and, while no well defined line of demarcation exists between them, they may be taken as illustrating the changes in construction necessitated by the increased service conditions. After a general discussion of the four types as to their approximate field of application, the paper takes up their design in some detail under the headings of motor equipment, truck design, platform framing, and superstructure; and will conclude next month with sections on methods of control, location of apparatus in cab, and operation.—Editor.

The design and construction of electric locomotives, covering as they do a distinctive engineering field of their own, require the collaboration of several different departments of engineering to produce a successful unit. Each part of the locomotive must be designed with reference to its effect upon the whole; and among the many important features which must be kept constantly in mind are the following. The motors and gearing must have ample capacity to perform the specified service, and must also be capable of producing a maximum drawbar pull up to the slipping point of the driving wheels. The control must be designed so that, when passing from one step to another, the variation in torque and speed is a minimum. The cab must be of such a design that the apparatus can be conveniently located, and must provide for easily dismounting the apparatus if it should become necessary. The trucks and platform must be of such mechanical design as to combine ample strength and rigidity, and, at the same time, be capable of withstanding the shock and wear incident to the service conditions. Finally, all of the above features and many others must be combined in such a relationship to one another as will result in a compact and homogeneous operating unit.

To meet the varied requirements of modern traction service several types of locomotive are necessary, from the relatively light machine used by some of our interurban roads to the heavy locomotives used in the exacting service of steam trunk lines. It is proposed in this article to review the principal sizes of 600 volt direct current electric locomotives, with particular regard to the fields of service for which they are fitted and the features of construction which engineering practice and experience have determined for each. The endless variation demanded by special locomotives and varying voltages from 250 volts to 2400 volts are beyond the limits of this article.

For the purpose of discussion we will refer to four different sizes, calling them the 25-ton, 50-ton, 75-ton and 100-ton types; but it is to be understood that these weights are to be taken in a very general sense as representing types of locomotives. As a matter of fact the classes of service which are presented for electric operation may generally be roughly divided into four groups which correspond to the four weights above, although in any particular case the standard locomotive may vary widely in weight to meet special conditions. For example the design of locomotive which we refer to as the 50-ton may on one road be used in service which only requires 40 tons on drivers and on another road be used where it has to have 60 tons on drivers.

Locomotive Weights and Service

Almost every interurban road will find an electric locomotive a useful adjunct to its regular equipment. Two advantages are to be obtained by reserving a separate unit of this kind to switch freight at terminals, and to haul trains of either freight or construction cars over the road. In the first place, the regular motor cars are relieved from this class of duty; and in the second, the equipment of the locomotive, being especially designed for freight service, is capable of performing it in a more satisfactory and economical manner than any equipment that is primarily designed for passenger service.

Where the grades are low and the weight of trains is not excessive a light locomotive may be used. The 25-ton electric locomotive meets the service conditions where trains of medium weight have to be hauled over tracks which do not include excessive grades. This locomotive has been extensively used as a switching unit in large industrial plants and for switching service in the terminals of interurban roads. Such conditions require a locomotive with an electrical equipment of medium capacity, arranged for slow speeds: and it is essential that the design should be as simple as possible and that all parts should be readily accessible. Fig. 1 gives a general view of a locomotive of this type.

Fig. 1. 25-Ton Electric Locomotive, Nashville Interurban Railway

Fig. 2. 50-Ton Locomotive, Oregon Electric Railway Company

For heavy interurban service with trains weighing from 300 to 500 tons, and when heavy grades have to be encountered, a locomotive weighing approximately 50 tons is frequently desirable. The 50-ton locomotive embodies features of construction which make it suitable for the requirements of the heaviest interurban roads. Fig. 2 shows a 50-ton locomotive.

The next heavier size of locomotive is the 75-ton type. This is suitable in general for the switching service of steam roads or for the heavier service on the few interurban roads which do a regular freight service, hauling freight trains over regular long runs. Fig. 3 shows such a locomotive.

The 100-ton type locomotives have a weight on drivers varying between 90 and 110 tons and are suitable for the heaviest steam railroad service. To obtain some idea of their service capacity a comparison may be made with some well known types of steam locomotives. Among road engines in steam service, 90 to 100 tons on drivers is found only on heavy freight locomotives such as the Consolidation (2-8-0) and the Mikado (2-8-2) types. on drivers, a weight which can be varied from 180,000 lb. to 220,000 lb., depending upon the equipment and the demands of the service.

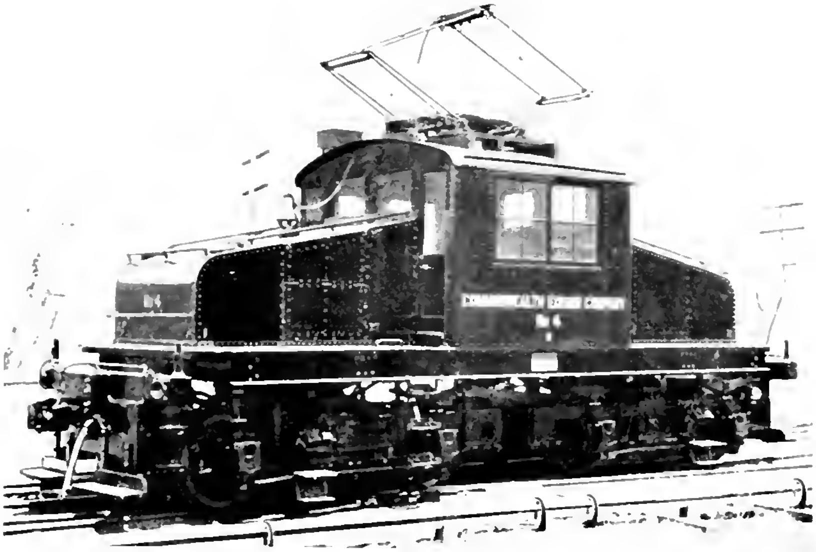

Fig. 3. 75-Ton Locomotive, Commonwealth Edison Company

Motor Equipment

The capacity of motor equipment for any locomotive will vary not only with the weight but with the characteristics of service; for while the weight of the locomotive is determined by the weight of train it has to haul, the horse power of the motors depends on this and also on the speed at which this load has to be handled and the continuity of the service. However, the following equipments are approximately those which practice has shown are generally required by the four types of locomotives mentioned above.

For a 25-ton locomotive the equipment which usually has been furnished consists of four 50-h.p. motors with cast steel gears having 71 teeth, and forged steel pinions having 16 teeth, giving a ratio of 4.43 to 1. The motors are capable of developing a tractive effort of 9500 lb., at their rated one hour load with a speed of 6.8 miles per hour, and all parts of the equipment are proportioned for taking an instantaneous current sufficient to

The Pacific (4-6-0) type, which is used principally for the heaviest passenger service, has a weight of about 75 tons on drivers. Some of the Mallet types (0-6-6-0 or 2-8-8-2) have a weight as high as 200 tons on drivers, but these are practically two engines with one boiler, and their use is generally confined to pusher service. From this comparison it will be seen that an electric locomotive of 90 to 100 tons is a unit comparable with the heaviest types of steam locomotives. This type of electric locomotive shows the latest development in electric locomotives for heavy traction service. The locomotives furnished for operating the Detroit River Tunnel and the new type of unit furnished for operating the Baltimore & Ohio Tunnel can be taken as examples of the type here referred to. These locomotives are of an articulated 0-4-4-0 type weighing nominally 200,000 lb.

Fig. 4. 100-Ton Locomotive, Baltimore & Ohio

slip the driving wheels without dangerous overload.

A locomotive of 50 tons is frequently equipped with four GE-55 motors rated at 90 h.p. each. The gear ratio is 3.53, there being 60 teeth on the gear and 17 on the pinion. The full load tractive effort at the one hour rating of the motors is 16,800 lb., at a speed of 8 miles per hour. The motors are capable of exerting a momentary tractive effort sufficient to slip the driving wheels, which under normal track conditions (or at a tractive coefficient of 25 per cent) is equivalent to a drawbar pull of 25,000 lb.

As an alternative to this an equipment frequently demanded consists of four GE-207 motors. For slow speed service the motors are connected permanently two in series and at the one hour rating of the motors the locomotive will develop a tractive effort of about 13,500 lb. at a speed of 8 m.p.h. For high speed the motors are connected in parallel pairs and the locomotive will develop a tractive effort of 13,500 lb. at 17 m.p.h. The overload capacity of this equipment also is sufficient to slip the driving wheels under starting conditions.

As a usual thing for a 100-ton freight locomotive the motor equipment consists of four 300 h.p. standard box frame motors of the commutating pole type. At its one hour rating this motor will develop a torque of 4000 lb. at a one foot radius. The gearing between the motor and driving axle has a 4.37 reduction and the driving wheels are 48 in. in diameter. With this reduction each motor will develop a tractive effort of 8750 lb. at the rail head, which gives a total tractive effort for the four motors of 35,000 lb. This tractive effort will be developed at a speed of 12 miles per hour. The four motors have an overload capacity sufficient to slip the driving wheels and can develop under maximum conditions a momentary tractive effort of 50,000 lb. to 60,000 lb.

For a locomotive of this weight the gears are shrunk on to an extension of the driving wheel hub and there are two gears and two pinions per motor, one at each end of the armature shaft. This form of construction is adopted on account of the unusually heavy torque and the excessive overloads to which the motors are liable to be subjected in heavy railway service. It has often been suggested that where the motors are fitted with only one gear and pinion a portion of the wear and breakage of pinions is due to the tilting of the motors under heavy loads concentrating the driving pressure at one end of the tooth.

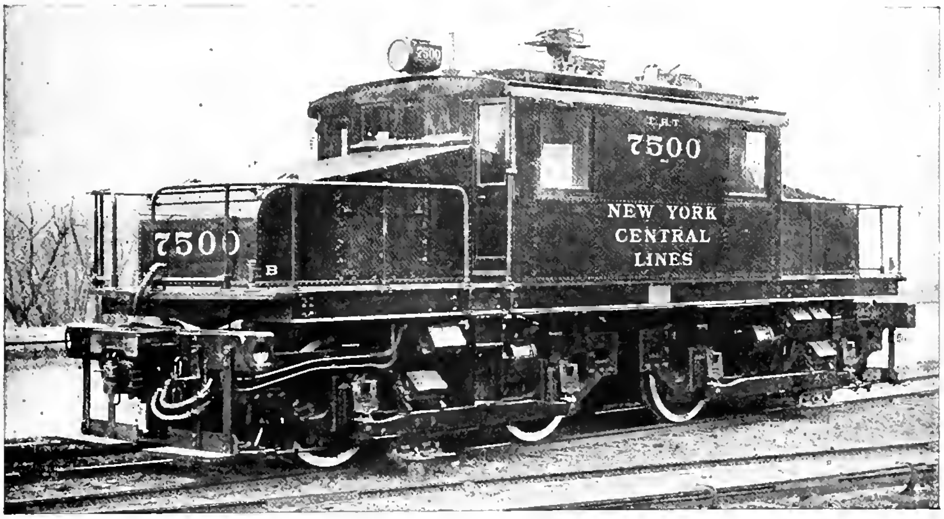

Fig. 5. 100-Ton Locomotive, New York Central

Trucks

The most acceptable design of trucks will vary with the weight of the locomotive and the service to which it is subjected, but Figs. 6, 7 and 8 show the types of trucks which are used for the various weights of locomotives.

The arch bar or diamond truck has been used for a number of years as a freight car truck on steam railroads, and, on account of its simplicity, strength and low maintenance cost, has attained a wide popularity for such service. In the present case such modifications have been made in the arrangement of brake rigging and other minor details as are necessary to accommodate the motors and to furnish the strength required for a motor-driven truck. The members of the truck side frames are forged bars, 4 in. wide, and of weights so proportioned as to meet the requirements of the service. The journal boxes consist of steel castings carried between the top bar and tie bar by $1\frac{1}{4}$ in. pedestal bolts; they are fitted with $4\frac{1}{4}$ in. by 8 in. MCB bronze bearings and wedges. Heavy malleable iron bolster guides are bolted between the top bar and arch bar with $1\frac{1}{2}$ in. bolts; and a spring plank, consisting of a 12 in. steel channel, is riveted to these bolster guides. The bolster itself is a steel casting, of a box girder design, approximately 8 in. wide by 10 in. deep. The lower center pin is formed in the upper surface of this casting. Cast iron side bearings are bolted to the outer ends of the bolster and the bolster and center pin load is carried on full elliptic springs built up of $\frac{3}{8}$ in. plates, 6 in. wide.

The brake rigging is inside hung, the brake hangers being carried on the bolster guides. Cast steel brake heads and cast iron shoes are furnished. The brake levers are so proportioned as to develop a braking pressure of 85 per cent of the weight on drivers with 50 lb. pressure in the brake cylinder. A 12 in. by 12 in. brake cylinder is located midway between the trucks and attached to the center platform sills. The brake [illegible] is attached to the truck levers through a system of floating levers arranged symmetrically on both sides of the locomotive, an arrangement clearly shown in Fig. 9. This arrangement offers the advantage of distributing the pressure uniformly over the brake shoes independently of any unsymmetrical position of the trucks assumed in taking curves.

For a locomotive of 50 tons, it is advisable to use an equalized type of truck, in order to distribute the weight more uniformly over the various driving wheels. Fig. 6 shows the truck which has been adopted for the 50-ton unit. This is a rigid bolster, equalized type, especially designed for locomotive service. The object of this design has been to produce a powerful, simple truck of an equalized type but with a small number of parts and low repair costs as compared with the ordinary MCB equalized, swing bolster truck which is ordinarily used for passenger service.

The weight of the locomotive is carried on a double equalizer yoke, resting upon the journal boxes. A heavy semi-elliptic spring under the side frames on each side of the truck carries the weight of the truck, and transmits it through suitable links to the corresponding pair of equalizers. The truck bolster is a heavy steel casting with T-shaped ends reinforced with webs through which it is bolted rigidly to the middle of the truck side frames. The pedestals in turn are bolted to the outer ends of these frames. The weight of the body resting on the center pin is transmitted through the bolster directly to the semi-elliptic side springs described above, and the whole truck is squared by the T-shaped ends of the bolster casting above and by tie-rods spreading out from it below.

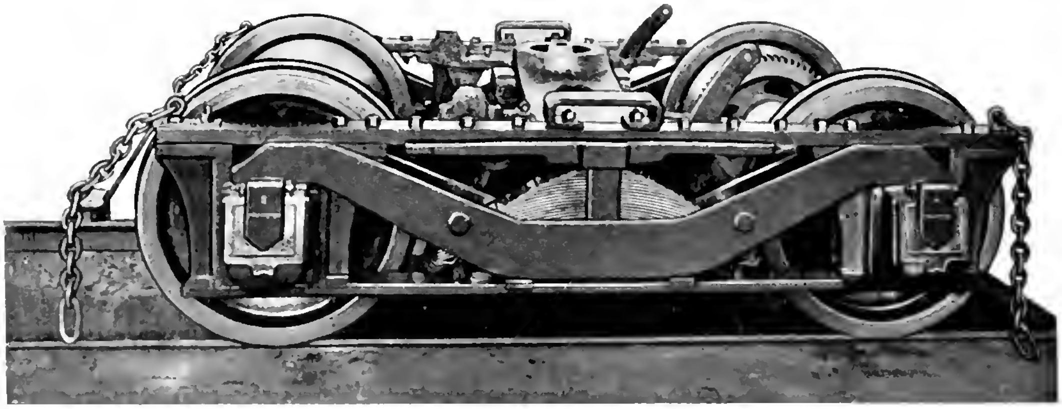

Fig. 6. 50-Ton Locomotive Truck

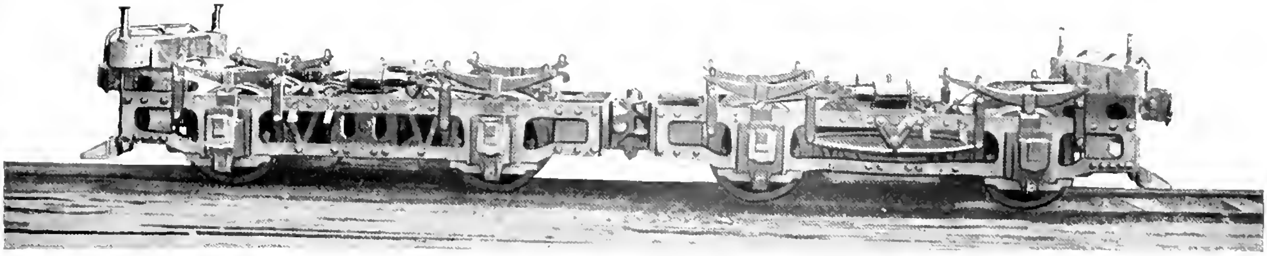

Fig. 7. 75-Ton Locomotive Truck

These details are very clearly shown in the truck photographs referred to. A wide experience with this truck on a number of roads has shown it to be a very satisfactory type for heavy locomotive service. The brake rigging for the 50-ton locomotive is arranged approximately the same as for the 25-ton locomotive illustrated in Fig. 9.

When we come to weights of locomotives heavier than 50 tons, it is advisable to adopt a different design. In the trucks described above, it will be noted that the pull of the draft rigging is transmitted to the driving wheels, through the truck center pins; and, for weights heavier than 50 tons, it has been found advisable to eliminate this by putting the draft rigging directly on the trucks, and coupling the two trucks together—in other words, furnishing an articulated running gear. The type of truck used for the 75-ton and 100-ton locomotives is shown in Figs. 7 and 8. The details below refer to the 100-ton type of truck, and the 75-ton type differs from it only in the sections and weights of the framing.

The articulated running gear may, broadly speaking, be considered as consisting of two four-wheeled trucks coupled together; but the method of coupling and the plan of equalization upon the two trucks makes it impossible to consider one truck independently of the other, so the whole must be looked on as a single running gear, hinged or articulated in the middle.

The truck side frames are heavy steel castings of a truss pattern. To get the necessary weight on drivers, the members of this frame are made heavier than actually required for strength, the top member having a section of 5 in. by 7 in. while the other members are proportionally heavy. This gives a peculiarly massive and substantial appearance to the whole under frame. The end frames and bolsters are steel castings of a heavy box girder design, rigidly bolted to the side frames and fitted in such a manner as to relieve the bolts of shearing stresses. The draft gear, buffers, and all truck frame members are designed for buffing stresses of 500,000 lb. and hauling stresses in proportion.

The suspension is of the locomotive type, the weight being carried on semi-elliptical springs restings on the journal box saddles. The system of equalization by which these springs are connected together is of such an interesting character that it demands a detailed description. The No. 1 end of the running gear, or what may be called the forward truck, is shown on the right-hand side in Fig. 8. This truck is side equalized, the two springs on each side being connected together through an equalizer beam. This equalizes the distribution of weight between the two wheels on one side, giving to this truck a two-point support and consequently leaving it in a condition of unstable equilibrium as regards tilting stresses—that is, stresses tending to tip the truck backward or forward. The No. 2 end of the running

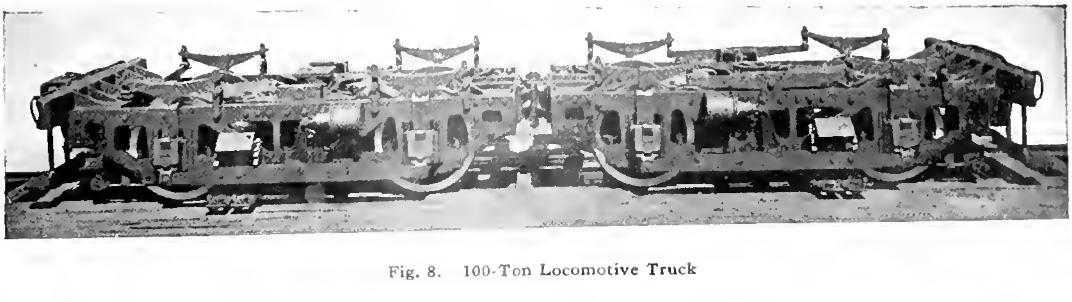

Fig. 8. 100-Ton Locomotive Truck

gear shown at the left-hand side in Fig. 7 is cross-equalized, the two springs on the rear axle being connected together through an equalizer beam while the other two springs are independent and are connected directly to the truck frame. This results in a three-point suspension on the rear truck, leaving it in a condition of stable equilibrium capable of resisting stresses in any direction, whether rolling or tilting. The two trucks are coupled together by a massive hinge so designed as to enable the rear truck to resist any tilting tendency of the forward truck. The two trucks are thus combined in a single articulated running gear, having lateral flexibility with vertical rigidity. Therefore, the running gear as a whole has what may be called a compound three-point suspension. The rear truck has in itself a three-point suspension while the forward and rear trucks taken together form an articulated frame having a three-point suspension composed of the two-point supports of the forward truck and the independent equalization of the rear truck.

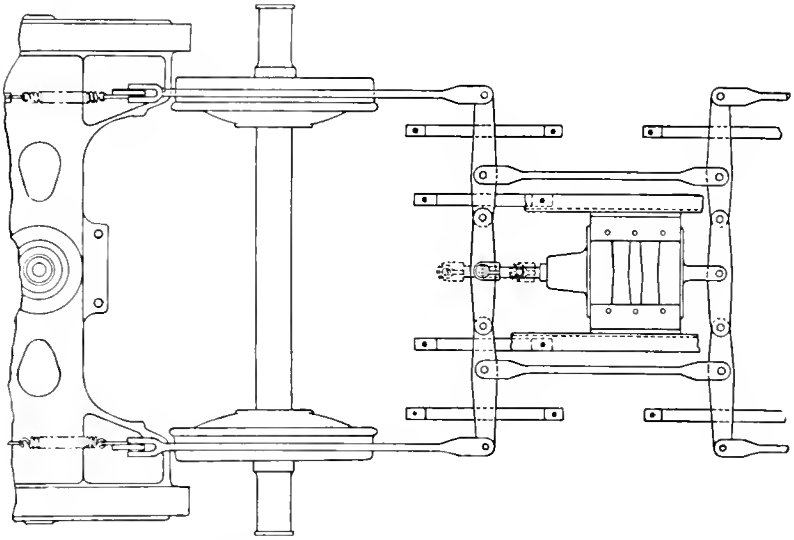

Fig. 9. Arrangement of Brake Levers, 25-Ton Locomotive

The braking equipment on each truck is mechanically independent. A pair of 12 in. brake cylinders applies the brakes on each truck and separate valves and cut-out cocks are supplied so that the pair of cylinders controlling either truck may be cut out without affecting the other cylinders.

The draft rigging consists of a standard MCB vertical plane coupler with yoke, springs and follower plates suitable for the heaviest freight service. This draft rigging as well as the spring buffer is mounted upon the outer end frame of the truck, an arrangement which insures that all hauling and buffing stresses are transmitted on the same horizontal plane through the draft rigging, side frames and hinge pin of the locomotive. As a consequence the center pins and platform framing are entirely relieved of all stresses except those due to the weight of the cab, platform and equipment.

Platform Framing

The general arrangement of platform framing is substantially the same for each type of locomotive, except for the variations required by varying weights and size. The

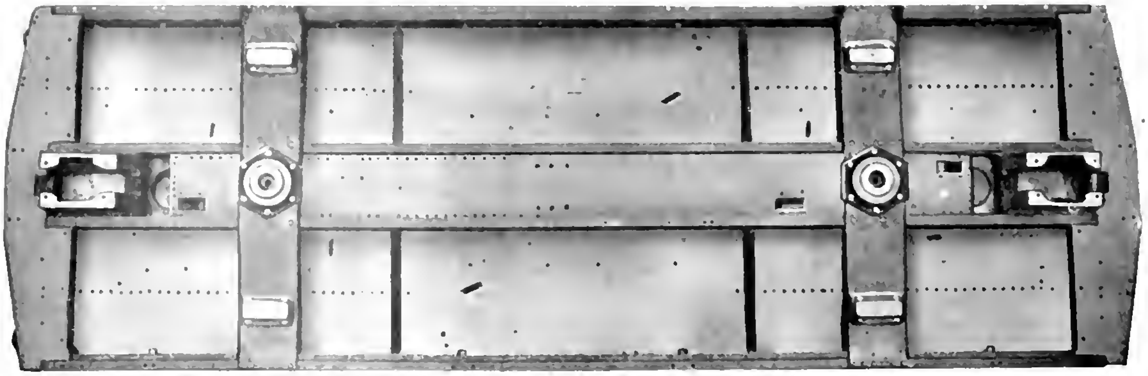

Fig. 10. Platform of 50-Ton Locomotive

only fundamental distinction between various types lies in the fact that, in the 25-ton and 50-ton sizes, the platform framing has to carry the draft rigging and is built to withstand the hauling and buffing stresses resulting from it. In the 75-ton and 100-ton sizes the draft rigging is carried directly on the trucks, and the strength and weight of the platform framing are consequently reduced. Fig. 10 is a cut showing the platform of a 50-ton locomotive. The platform framing of this locomotive consists of four 10 in. steel channels weighing 30 lb. per foot, each 27 ft. long and extending from one end of the platform to the other. These channels are tied together by the end frame castings and bolster plates, each channel being riveted to the webs of the end frame castings and riveted to the top and bottom bolster plates. The end frame consists of a heavy cast iron box girder, stiffened by webs, the various members of the casting being approximately 1¾ in. thick. The bolsters are built up of 18 in. by 1 in. plates. The lower plate is carried directly across the locomotive and is riveted to all four longitudinal sills; while the upper plate is carried under the two center sills, passing between them and the lower plate. It then turns sharply upward and is separated from the lower bolster plate by a piece of 9 in. channel 37 in. from the center line of the locomotive. From this point it continues in a horizontal direction immediately under the floor plate and butts against the outside frame.

The locomotive is equipped with an MCB coupler with a No. 3 shank and standard yoke, springs and follower plates. The draft springs are of the double coiled helical type 6¼ in. in diameter and 8 in. long. The two springs between the follower plates are in parallel and are carried in the drawbar yoke. The yoke and springs are held by guide plates in a cast iron drawhead casting which is bolted to the center sills of the locomotive. The coupler is also supported by a forged stirrup bolted to the platform end frame.

For the 75-ton and 100-ton types, the platform is also built of channels and plates, but a light end channel is used instead of the heavy end casting which is demanded upon the smaller type of locomotives. This construction is permissible on account of the fact that the draft gear and coupler are carried upon the truck frame instead of the platform frame. As a consequence, the hauling and buffing strains are not transmitted through the platform, and a light end construction can be used.

On any of the types of locomotives, where the service is continuous enough to require forced ventilation of the motors, the space between the two center channels can be used as a compression chamber to distribute the air from the blower to the outlets leading to the motors. This construction will be noted in several of the detailed views of the platform construction presented.

Superstructure

It will be noted from the photographs that the general arrangement of cabs is similar for all standard types of locomotives.

The cab consists of three sections, a main operating cab in the center of the platform and two auxiliary cabs running from it to the ends of the platform. Each of these three cabs is built up separately and attached to the floor independently of the others. They are all built of sheet steel plates supported and stiffened by structural steel shapes, and are riveted to floor angles, through which they are bolted to the platform.

The sides of the main cab are supported by upright angles having a section of 2 in. by 2 in. by ¼ in. These extend from the floor angles and are cross-connected at the top and center by angles of a similar section which serve as stiffening angles for the window space. The roof is curved, rising 8 in. from the top of the cab sides to the crown of the roof. The ends of the main cab are supported by a framework of 4 in. channels with a center cross channel and a top angle. All openings for the doors and windows are framed by small stiffening angles.

The auxiliary cabs are built up in a similar manner of sheet steel stiffened by vertical and cross angles and are riveted to heavy floor angles. The floor angles of the auxiliary cabs are on the outer side and lighter angles are riveted to the floor on the inner side of the cab to make the joint waterproof.

Hinged, perforated doors in the sides of the auxiliary cabs give access to the rheostats and to the connections at the back of the contactors, while folding doors between the auxiliary and main cabs allow the inspection of the contactors. The auxiliary cabs are bolted to the platform and main cab so that they can be readily removed when it is necessary to make more serious repairs.

The width of the auxiliary cabs allows room for a narrow platform or running board extending from the main cab, along the sides of the auxiliary cab, to the front of the locomotive. This running board is protected by hand rails running clear around the outside of the locomotive from one side of the main cab to the other. The doors of the main cab open on to this platform, and steps reaching to the ground are located near the doors. One marked advantage of this construction is that the entire absence of cab directly in front of him, combined with the low roof of the auxiliary cab, gives him a clear view of practically the entire right-of-way ahead or of the train behind him, or of the switchman at the coupling.

(To be Continued)

GENERAL DIMENSIONS AND SPECIFICATIONS

	25-Ton Locomotive	50-Ton Locomotive	75-Ton Locomotive	100-Ton Locomotive
Length inside of knuckles	26 ft. 0 in.	34 ft. 7 in.	33 ft. 10 in.	39 ft. 10 in.
Length over cab	22 ft. 6 in.	29 ft. 10½ in.	26 ft. 6 in.	33 ft. 6 in.
Height over cab	10 ft. 9 in.	12 ft. 0 in.	12 ft. 6 in.	12 ft. 4 in.
Height with trolley down	12 ft. 0 in.	13 ft. 0 in.	13 ft. 6 in.	14 ft. 9 in.
Width over all	8 ft. 6 in.	9 ft. 6 in.	10 ft. 0 in.	10 ft. 1 in.
Total wheel base	18 ft. 0 in.	24 ft. 4 in.	24 ft. 0 in.	27 ft. 6 in.
Rigid wheel base	6 ft. 0 in.	6 ft. 10 in.	8 ft. 0 in.	9 ft. 6 in.
Track gauge	4 ft. 8½ in.	4 ft. 8½ in.	4 ft. 8½ in.	4 ft. 8½ in.
Weight electrical equipment	16,000 lb.	28,000 lb.	37,000 lb.	60,000 lb.
Weight mechanical equipment	34,000 lb.	72,000 lb.	113,000 lb.	140,000 lb.
Weight total	50,000 lb.	100,000 lb.	150,000 lb.	200,000 lb.
Under frame	8 in. and 7 in. channels	10 in. channels	12 in. channels	10 in. channels
Body bolster	17¾ in. by ¾ in. plate	18 in. by 1 in. plate	3 pl. 12 in. by 1 in.	3 pl. 12 in. by 1 in.
Trucks	Arch bar	Equalized type	Locomotive type frames	with cast side
Wheels	33 in. rolled steel	36 in. rolled steel	36 in. rolled steel	48 in. steel tired
Truck bolsters	Steel castings	Built up	Steel castings	Steel castings
Springs	24 in. elliptic 6 in. by ⅜ in plates	42 in. half elliptic 4 in by $\frac{7}{16}$ in. plates	36 in. half elliptic 5 in. by ⅜ in. plates	42 in. half elliptic 5 in. by $\frac{7}{16}$ in. plates
Journals	4¼ in. by 8 in.	5½ in. by 10 in.	6 in. by 13 in.	7½ in. by 14 in.
Motors	4 GE-57	4 GE-207	4 GE-212	4 GE-209
Gears	71 tooth cast steel	64 tooth cast steel	65 tooth cast steel	83 tooth forged rim
Pinions	16 tooth forged	17 tooth forged	18 tooth forged	19 tooth forged
Number of steps	6 ser. par. 4 par.	7 ser. par. 5 par.	8 S. 7 S.P. and 5 P.	9 S. 8 S.P. and 7 P.
Maximum tractive effort (with sand)	15,000 lb.	30,000 lb.	45,000 lb.	60,000 lb.
Corresponding tractive coefficient	30%	30%	30%	30%
Tractive eff. at 1 hr. motor rating	9500 lb.	13,500 lb.	18,000 lb.	36,000 lb.
Corresponding tractive coefficient	19%	13.5%	12%	18%
Tractive eff. at 3 hr. motor rating	5600 lb.	7500 lb.	11,000 lb.	16,000 lb.
Corresponding tractive coefficient	11%	7.5%	7.5%	8%
Tractive effort 3 hr. rating (blown)	. . . .	11,000 lb.	15,200 lb.	30,000 lb.
Corresponding tractive coefficient	. . .	11%	10%	15%
Air compressor	CP-28	2 CP-28	2 CP-30	CP-26
Compressor capacity	25 cu. ft. per minute	50 cu. ft. per minute	70 cu. ft. per minute	100 cu. ft. per minute
Couplers	MCB 5 in. shank	MCB 5 in. shank	MCB 5 in. by 7 in. shank	MCB 7 in. shank
Headlights	Luminous arc	Luminous arc	Incandescent elec.	Incandescent elec.
Sanders	Double pneumatic	Double pneumatic	Double pneumatic	Double pneumatic
Collecting device	U.S.-13 trolley	U.S.-6 trolley	3rd rail shoe and trolley	3rd rail shoe 7 U.S.-119
Bell	Composition casting 50 lb.	Composition casting 50 lb.	Composition casting 75 lb.	Composition casting 80 lb.
Whistle	Air-operated	Air-operated	Air-operated	Air-operated

ELECTRIC LIGHTING OF RAILWAY CARS

By A. L. Broe

Edison Lamp Works, Harrison, N. J.

Apart from its many other advantages, the absolute safety of electric lighting by incandescent lamps would account for its rapidly increasing substitution on railway passenger coaches for the oil and gas burners that have until recently been almost universally used in such service; for statistics show that in cases of serious accident the latter systems almost invariably add to the loss of life and property by setting fire to the wreckage. A portion of the article is devoted to an enumeration of the special advantages of the high efficiency tungsten lamp for train lighting, over the old style carbon filament lamp; the major portion, however, being given to a discussion of the best arrangement of the lighting fixtures for the several types of cars and a description of the three systems of electric energy supply in most common use, viz., the head-end, straight storage battery, and axle generator systems; the last of which it would seem is the most satisfactory, all things considered.—Editor.

On the steam railroads of this country there are at present 50,000 passenger cars, of which about 11,000 are electrically lighted. Railroad trains were lighted by electricity as early as 1887, but only in recent years has this system come to be widely adopted; although it is now developing probably as fast as any of the other branches of lighting.

The traveling public is critical and exacting, and it is now beginning to demand electric lighting as one of the requisites of first-class, modern railway service. The introduction of the high efficiency incandescent lamp has been the biggest factor in this development, as it has made electric lighting on railway cars practical under conditions where it was formerly impossible.

Advantage of Electric Lighting

The increased use of electricity for railway car lighting has been due to several advantages that it possesses over other forms of illumination; the most important of which is safety. In almost every serious railway accident the loss of life and damage to property have been greatly increased by the burning of the cars. This frightful source of danger is minimized by the use of electric lighting, and in the case of a number of roads this point alone has been a sufficient reason for the adoption of this system. The result has been that the decrease in liability for injuries to passengers and damage to property has offset the possibly higher cost of maintaining the electrical equipment.

Two features of the incandescent lamp, viz., the small amount of heat given out and the fact that the atmosphere is not vitiated, are of particular importance in this service, where the cooling and ventilating of cars in summer are problems demanding considerable attention. The convenience of electric lighting is another important advantage; the lights may be switched on or off without delay, as when passing through tunnels, and without in any way disturbing the passengers.

The character of the lighting of the car may also be greatly improved by the use of electric lights. They can be placed so as to give the best effects, both as regards efficient distribution of the light and the general appearance of the car. Nor is their position limited to as great an extent by the construction of the car. In addition to all this, electric fixtures can be designed more readily with a view to artistic effect, as for example, in the use of candelabra lamps.

The berth light, another modern convenience that adds so much to the comfort of railway travel, is an exclusive feature of the electrical system. With the modern type of berth light fixtures, both the upper and lower berths can be lighted. Besides other obvious advantages, these lamps enable passengers to read comfortably in bed—a grateful boon to the great number of persons who either cannot sleep at all, or who sleep poorly on trains.

To the many advantages of electricity as a lighting agent may be added its broader field of usefulness. Take, for example, the electric fan with which all modern coaches and sleeping cars are equipped, or the electric cooking devices—a recent innovation on dining cars and a new type of car provided with a lounging room for ladies.

Energy Supply Systems

There are three systems in general use for supplying electric power on railway trains. They are known as the head-end, straight-storage and axle-generator systems. The two standard voltage ranges for train lighting service are 25 to 34, and 50 to 65 volts. One hundred and ten volts is also used in some cases in connection with the head-end system, but the Association of Railway Electrical Engineers has standardized the use of 60 volts for this system, and in time 110 volt systems will probably be replaced by the lower voltage. There are several reasons for the adoption of low voltages in train lighting:

(1) First cost of the storage battery is less.

(2) The maintenance of the battery is less.

(3) The low voltage tungsten lamp is stronger.

(4) Until recently a 15 watt lamp, which is used largely in train lighting, was obtainable only in the low voltage ranges.

The head-end system consists of a steam turbine and generator, situated either on top of the locomotive boiler or in the baggage car; the turbine in the latter case being connected to the locomotive by a steam line. A train-line running the entire length of the train distributes the current from the generator to the lamps. The head-end system is used with either one or more storage batteries situated at different points in the train, or in some cases without any battery, depending upon the character of the service. Where it is necessary to break up the train during the run, it is usual to provide batteries distributed throughout the train in such a way that the portions of the train which are disconnected from the engine or car containing the generator shall always be provided with a supply of current. The batteries are usually charged from the generator during the daytime, when no light is required. In cases where it is necessary to charge the battery while the lamps are in operation, the voltage of the generator must be raised a considerable amount above the normal voltage of the lamps. In order to avoid subjecting the lamps to this higher voltage, which would strain them and shorten their life, a method recently adopted on some roads has been to install a voltage regulator on each car. This regulator is a device which automatically inserts sufficient resistance between the train-line and the lamps to maintain the voltage at the lamps at normal value. The head-end system is efficient and economical, and is particularly adaptable to trains operating on long runs. However, it has the disadvantage that where a car is cut in or out of the train it must be provided with a battery, and this necessarily increases the cost and sacrifices the simplicity of the system.

In the straight storage system the current is supplied entirely by storage batteries, each car carrying its own set. With this system it is necessary to charge the batteries at intervals, this usually being done at the end of each run. For this purpose a charging equipment must be provided at the terminals of the road, and electrical connections at convenient points throughout the terminal yard.

The straight storage system has the advantage of simplicity, but on account of the limited capacity of the battery which may be conveniently carried on a car, it is adaptable only on trains of comparatively short runs.

The generating system most widely used at the present time is known as the axle-generator. There are a number of systems of this type on the market, but they all contain the following essential features.

(1) A small generator, usually from 2 to 4 kilowatts, mounted on the truck frame and driven from the axle of the car by either a belt or chain.

(2) A storage battery.

(3) An automatic pole changer.

(4) An automatic switch.

(5) A current regulator.

(6) A lamp voltage regulator.

The storage battery is provided to take care of the lamp load when the car is standing still or running at low speed. When the train reaches a certain predetermined speed (usually between 15 and 20 miles an hour), at which the voltage generated is at the normal value, the automatic switch closes and connects the generator with the battery and lamps. As the generator is used to charge the storage battery, it is necessary that the current be supplied always in the same direction, regardless of which way the train is moving. The automatic pole changer takes care of this requirement by reversing the generator leads when necessary.

The purpose of the current regulator is to limit the current supplied by the generator to the battery to the proper amount required for charging at the normal rate. This is accomplished by automatically varying the field strength of the generator, and hence the voltage. The lamp voltage regulator, as mentioned in connection with the head-end system, is a resistance in the lamp circuit which is automatically varied and maintains the voltage practically constant at the lamps at all train speeds.

The axle-generator system, although complicated in construction and requiring considerable expert attention to maintain it in proper working order, has been found to operate very successfully, as is shown by the large number of equipments in use at the present time. It has the advantage that each car is an independent unit, the lamps being always supplied with current, whether the car is standing or moving. However, it cannot be operated successfully on trains traveling at low speeds or making frequent stops.

Train Lighting by Tungsten Lamps

When electric train lighting was first introduced, the only available type of lamp was the carbon. This has been rapidly superseded in turn by the metallized carbon, the tantalum, and the tungsten lamp. The advantages of the last are so decided that it has been generally adopted as the standard for this service. In train lighting, economy of current consumption is as important as, if not more so than in any other lighting field. The maintenance of the generating system, especially the storage battery, is a big item, and any reduction in the amount of power used necessarily means a saving in the cost of maintenance. The advantages of tungsten lamps as compared with less efficient lamps are probably more obvious in connection with the straight-storage system than with the other systems. An equipment in which tungstens were used would require a storage battery of approximately one-third the size of that which would be required for an installation of carbons of the same candle-power. This would mean a big saving in the first cost and cost of maintenance; and where a great many cars of this type were used, the size of the generating equipment required at the terminals would be correspondingly decreased, or in the case of an expanding road, would permit the addition of new cars without increasing the charging facilities.

On the contrary, if it were desired to keep the same size of battery in the car (as would be the case with cars already equipped), the lamps might be operated over a much longer period of time on one charge, thus permitting the application of the straight-storage system on trains with longer runs. With the same size battery on the same length of run, the battery could be operated on a smaller charge, thus decreasing the time of charging, during which a car is obliged to lay over at the terminal and be temporarily out of commission. A storage battery gives a higher efficiency, that is, a larger ampere-hour capacity for any given charge, when discharged at a slow rate. A slow rate of discharge and less frequent charging also tends to lengthen the life of the battery. Both of these advantages are obtained with tungsten lamps, on account of the small current consumption. There is also less danger of damaging the battery by over-discnarging.

Certain of the above men'ioned advantages of the tungsten lamp, mainly the increased capacity of the equipment due to the smaller demand on the battery, are equally applicable where the axle-generator system is used. The use of tungstens also permits a more extended use of this system; as for example, when running with frequent or long stops, under which conditions, the battery is obliged to carry the bulk of the lighting load.

With the head-end system the decreased power consumption effected by using tungstens would result in a decreased steam consumption in the turbine, and consequently a saving of coal. One of the difficulties that has frequently been experienced with the head-end system is that occasioned by the locomotive's heavy demand for steam on grades, where the engineer will sometimes cut down the steam supply to the turbine. Any decrease in the steam consumption of the turbine would thus be an advantage in this respect.

One feature of this lamp that is of particular value in train lighting service is its small variation in candle-power and life with varying voltages. As is generally known, the decrease in candle-power on the tungsten lamp for a given decrease in voltage is very much less than for any other incandescent lamp. In any train lighting system, variations in voltage are very apt to occur. This is particularly the case in straight-storage systems. A battery consisting of 32 cells, when freshly charged, will have a voltage of approximately 67 volts; near the end of the discharge this voltage will be down somewhere around 57½ volts. This means a variation of approximately 14 per cent in the voltage at the lamps during the period of discharge. In the case of a carbon lamp this would cause a variation of 56 per cent candle-power; whereas for a tungsten lamp the corresponding variation in candle-power would be only 43 per cent.

The exclusive use of tungsten train lighting lamps of the 30 and 60 volt type by such of the large railroads as have adopted the electric system, has proved conclusively that the drawn wire lamp is excellently adapted for train lighting. It has been found sufficiently rugged to withstand all shocks and jars imposed upon it by this class of service. The round bulb lamps have been adopted as the standard in train lighting, because of their more ornamental appearance. The standard tungsten train lighting lamps are now the 10, 15, 20, 25 and 50 watt round bulb type, in either the 25–34 volt or the 50–65 volt range. Train lighting lamps are also made in the straight sided bulb types, but the demand for them is very limited, as practically all of the railroads have standardized the round bulb lamps for this service.

Methods of Lighting

The use of a proper reflector is a very important point in the illumination of a railway car. For reasons of economy it is essential to make the best use of all the available light. The light is used mostly for reading, and should have the intensity, color and direction most suitable for this purpose. The subject of glare is one which should be given considerable attention. The passenger is usually seated in the same position for a considerable length of time, and to have a bare lamp in the field of vision becomes very distressing. Glare is best eliminated by the use of a reflector of such a size and design as to effectively shade the lamp from the eyes. Bowl frosting or opal dipping is also used for this purpose, the latter being preferred, as the lamps can be cleaned more easily.

There are numerous methods of arranging lamps, fixtures and reflectors in the lighting of cars. For coaches the two most common arrangements are: first, with a single row of units, either clusters or single lamps, placed along the center of the ceiling from 6 ft. to 10 ft. apart; second, with two rows of units, one along each deck rail. For the former the 50 watt lamp is generally used. For the deck rail lighting any of the small round bulb lamps are more suitable.

Where gas lighted cars are changed to an electric system, the center deck arrangement is generally retained, as gas fixtures can be readily adapted for electric lighting with slight alteration. There is little to choose from between the two arrangements. Deck rail lighting has the advantage that the lamps are placed directly over the seats, where the light is desired. A disadvantage of this arrangement, however, is that where a car is equipped with baggage racks, lamps are apt to be broken by passengers in removing articles from the racks. The lamp renewal cost is also higher on account of the larger number of lamps required where the small units are used. With a properly designed reflector the center deck system gives very satisfactory results. The units should be placed so that the space directly under the side deck does not appear dark.

For the lighting of dining, buffet, parlor and observation cars the artistic effect is an important consideration, the object being to give a cheerful and attractive appearance to the car. In the dining cars a common method is to have center deck fixtures in conjunction with either wall brackets between the windows, table lamps or small lamps placed in the side deck. The small units furnish sufficient light directly on the tables, while the larger center units supply the general illumination for the car. The ornamental box type of fixture, either sunken in the ceiling or suspended, is also used in this class of lighting.

The lighting of sleeping cars is usually accomplished by the center deck arrangement, with either one 50 watt lamp or four 15 watt lamps. The upper and lower berths are lighted with small round bulb lamps in any of the standard wattages, placed in the wall at each end of the berth. These lamps also furnish light for reading during the early hours of the evening, before the berths are made up. In the past berth light fixtures were made to contain a comparatively small bulb—too small a bulb for a tungsten, on account of the greater length of filament that would be required—and therefore the metallized carbon berth lamp was developed. The modern berth light fixtures are now being made for larger bulbs, with the result that the tungsten lamp for berth lighting is rapidly succeeding the old metallized lamp. It has been found much more satisfactory for this service, as it gives twice as much light for the same wattage. In addition to this advantage the tungsten lamp has a much longer life than the metallized berth lamp, on account of the smaller bulb of the latter having a tendency to blacken more quickly.

In mail cars good illumination is of paramount importance. The light should be distributed in such a way as to properly illuminate the sorting tables and letter cases. It is essential that there be plenty of light so that the mail clerk can readily read the addresses on the letters and distribute them to the proper racks. This can be accomplished, with properly designed reflectors, by either the center deck or deck rail arrangement, or a combination of both. As the appearance of the car is of very little importance, metal reflectors are frequently used.

Passageways and platforms can be conveniently lighted by electric lighting. The smaller round bulb lamps with appropriate reflectors are best adapted to this purpose.

The tungsten lamp has proved beyond a doubt its superiority over any other lamp for train lighting service, and it is only a question of time before it will be universally adopted. As over three-quarters of the passenger cars in the United States are not equipped with electric light, it is evident that there is here a large field which has thus far been comparatively undeveloped.

General Electric Review

Published Monthly by the

GENERAL ELECTRIC COMPANY'S PUBLICATION BUREAU

Manager, M. P. RICE   Editor, D. S. MARTIN   Associate Editor, B. M. EOFF

Subscription Rates: United States and Mexico, $2.00 per year; Canada, $2.25 per year; Foreign, $2.50 a year, payable in advance. Remit by post-office or express money orders, bank checks or drafts, made payable to the *General Electric Review*, Schenectady, N. Y.

Entered as second-class matter, March 26, 1912, at the post office at Schenectady, N. Y., under the Act of March 3, 1879.

VOL. XVI., No. 2 FEBRUARY, 1913

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Anson W. Burchard
Vice-President, General Electric Company

GENERAL ELECTRIC REVIEW

THE DIFFICULTIES OF THE HIGH-SPEED-GENERATOR DESIGNER

The very valuable New Year's number of the ELECTRICAL WORLD, in which appears a broad review of electrical progress in the past twelve months, contains a chapter on recent developments in electrical machinery, in which we find the words: "It seems pathetic that the labors of the last thirty years, culminating in the development of almost perfect types of slow-speed electric generators, have not been of more permanent value."

It certainly is pathetic when we begin to realize that, in bringing up the available output of a 3600 r.p.m. turbo-generator from a maximum of, say, 400 kw. in 1904 to a maximum of, say, 5000 kw. in 1912, the designer of the high-speed generator has had to solve all his problems for himself, with but little to fall back on in the way of past experience from the men who have preceded him. It would appear that, for the largest sizes, he has by now nearly reached the end of his tether. "Not only have almost all known special alloys been called into use and taxed to the limit of their strength, but it also seems as if a further increase in speed would increase the losses and thus lead to lower efficiency." It is not that the designer, in this instance, is struggling with the unknown and groping in the dark through lack of laws and lack of data. He is all the time coming up against the physical limitations of well-understood substances. A certain structure will stand a certain centrifugal stress, and no more; a certain opening in a rotor will efficiently carry a certain quantity of cooling air and no more; and the disinterested observer will probably be able readily to realize that the advent of the steam turbine, which depends, for its successful operation, on high rotative speeds, and which presents the mechanical engineer with no problems of extraordinary magnitude so far as the mechanical design of the turbine itself is concerned, has landed his electrical *confrère* in some very tight corners, where he has necessarily spent his time in strenuous days and sleepless nights.

The matter is of great interest at the present time. Mr. Reist, the alternating current engineer of the General Electric Company, has very kindly written up for this magazine a short review of some of the salient features of recent high-speed designs; while Mr. Lamme, of the Westinghouse Company, presented his views in great detail at the January Institute Meeting in New York. The latter paper occupies some forty pages of the Proceedings, and constitutes a quite unusually frank, able and comprehensive review of the situation. His candid and detailed exposition of the designer's difficulties, and particularly his outspoken utterances on the matter of temperatures and the absurdity of classifying a piece of apparatus as *good* or *bad*, respectively, according to whether it tests possibly one or two degrees below or above a specified thermometer guarantee, compel the most genuine admiration, and the whole paper is probably destined to become a classic. If it is easy to see the pathetic side of the thirty years of unproductive labor in perfecting the low-speed generator, it is certainly easy to sympathize with the people who, starting from nothing a few years ago, were compelled to deliver the goods on short notice in the shape of high-speed turbo-generator sets. "The whole design has been carried far beyond the most economical construction, from the generator standpoint alone. In fact, the whole machine is more or less a compromise between desirable conditions as a generator, and most economical conditions as part of a combined turbine and generator unit. The ultimate limits in construction and capacity will be obtained only when steam turbine conditions are satisfied, and there are indications that possibly this result is being approached now with the present high speeds."

This looks like a rift in the clouds. Someone told us the other day that Edison's dream had come true. Why shouldn't the designer's?

EDUCATIONAL FACILITIES PROVIDED BY THE LARGE CORPORATION

The publication of a brief review, in our November, 1912, number, of the prospectus of one of the educational courses at the Harrison Lamp Works, served to call attention to an interesting phase of the life of the modern manufacturing corporation—the somewhat elaborate schemes which are now the rule for the education of the employees of the corporation, the object in view being, of course, the profits which will accrue through the placing at its disposal of a force of young engineers, or young salesmen, systematically trained in the fundamentals of the business in which they have to engage.

We noted at the time that the feature of greatest interest in a consideration of this system was the definite proof which it furnished that the more enlightened of our modern large corporations have now far outgrown their old-time limitations. Similar indications are found when we turn to welfare work and note what is being done in this direction. The coming of the iron age, with the substitution of machine work for manual labor in practically every industry has meant an accompanying tendency to regard the whole factory as a gigantic machine, some of its operating parts being of wood, iron and steel, others being of human flesh-and-blood. Successful operation of the plant can only be attained through a sympathetic knowledge of all the parts; and that implies more than mere engineering. Just as a machine requires adjustment, lubrication, overhauling, repair, and a knowledge of its loading capabilities, so the human machine requires an intimate consideration in order that it may operate efficiently, noiselessly, smoothly and without distress. The science which has, in the last ten years, sprung up around the means of producing this result from the human machine in the twentieth-century factory is called human engineering. There is in this country a journal called *Human Engineering* which is devoted to this one science. It is conducted on the broadest lines; and relegates the question of securing efficiency to a second place compared with the importance of securing the welfare of the worker, and of making sure that the mechanical age, while placing a considerably lower relative value on skilled manual labor than ever before, shall secure to the working-man greater benefits than ever before, protection of his life and limb, congenial surroundings for his daily work, provision against sickness, compensation for disability, opportunities for recreation and education, and so on.

Mr. Magnus W. Alexander's article in the REVIEW for December, 1912, consisted, for the most part, in an argument which showed that the large industrial combination, from its very nature, was capable of subserving the common good, and especially the welfare of its employees, to a far greater extent than an aggregation of individual employers. If this is true of welfare work, the results of which are mainly physical, it is equally true of educational work, the results of which are mainly intellectual. The big corporation can and does maintain educational facilities within its organization far greater than those which any collection of private employers could support, and far greater than that of which the average man can have any idea. The work is undertaken for the advantage of the corporation, in order that it may, when the need for new men arises, have a supply available, with the inefficient weeded out, and the efficient well grounded in the fundamentals of the specialized work. The corporation schooling, therefore, does not supplant the university, since it is all a specialized schooling, but is supplementary to it. The need for the specialized education is imperative. It cannot be undertaken by the universities, since, for its direction, it requires the services of men actually engaged in practice for the major portion of their time; and there is therefore a definite *raison d'être* for the corporation school. The New York Edison Company, as can be seen from a glance at their program for the present winter, have now a very highly-developed department of education, embracing all the diversified classes of work concerned with the generation, distribution and marketing of electric energy; and which results in keeping that company well supplied with men who can intelligently handle the enormous proposition of giving to the citizens of the metropolis an efficient electrical service.

The educational requirements of the manufacturer's employees are of a somewhat different nature; but, in a similar way, cover many different classes of work. Our previous notes in the REVIEW on this subject related to the education of salesmen. Even more important than this, from the standpoint of the industry generally as distinct from the immediate needs of the General Electric Company, is the purely technical instruction. Probably the most important of this class of work is the educational course which is carried on in the Consulting Engineering department under Dr. Steinmetz's direction, and in the Transformer Engineering department. The prospectus relating to this course is given on page 140, and indicates the kind of training which a man must have had before he can be of use to the department, and the kind of work which he will have to carry out while there. The prospectus says little of the advantages which he himself will gain from the educational standpoint, and from the standpoint of what he may be subsequently suited for—and may achieve—along the line of special engineering work in the organization. These possibilities can hardly be exaggerated. The Consulting Engineering department at Schenectady has done more than any other one institution in this country to bring high-voltage operation down from the clouds into a science whose laws are approximately known and understood. Other matters have, of course, been handled. Mr. Alexanderson's study of the magnetic properties of iron at very high frequencies, and his successful development of alternators to furnish current for wireless telegraphy at 100,000 and 200,000 cycles a second are well known; while greatly improved efficiency and economy in the design of various classes of electrical machines have been made possible through the studies of Mr. Hobart into these and other matters. Many very general problems encountered in the operation of large supply systems working with low and medium voltages have been studied and solved; but primarily the department will be famous for its discovery of at least some of the laws of corona, its writings on the nature of surges in transmission lines, and its pioneer work in the development of protective apparatus; in all of which work, of course, the genius of Dr. Steinmetz has been the guiding light. Upon none of these things has anything like the last word been pronounced. The work has by now only just begun, and there is a demand for help of the right kind. No finer chance for original experience and inspiring associations can ever have been offered to the student.

Some of the best articles we have had in the Review during the last few years have, as our readers will have noticed, come from Dr. Steinmetz's department, and we shall hope that he and his engineer will still give us their support with our future issues. Apart, however, from work of outstanding importance which can be discussed only with difficulty even within the limits of a seven- or eight-page article, there is a constant supply of copy being written up in the Consulting Department on some of the lesser developments, insufficient, taken singly, to warrant the preparation of a separate article, but well worthy of careful notice, if of brief mention, in the Review. We have for long wanted to get hold of some of this copy; and believe that, by the plan which Dr. Steinmetz has just inaugurated, we shall be able to keep our subscribers advised from month to month on some of the interesting things which are going on in his department. The plan, briefly, is that one full page in each issue of the Review will be placed at the disposal of the Consulting Engineering Department. Therein will be found notes upon specific lines of study which are being followed and mention of the various links in the educational chain. On page 140 will be found the first collection of news items. This month there is little of a strictly technical character, although in future issues the engineering end will probably be accorded greater prominence.

MODERN USES OF STORAGE BATTERIES

Of recent years the great improvements which have been introduced by the manufacturers into the various storage batteries on the market have made this apparatus appropriate for fields of service whose requirements it can fulfill very satisfactorily, and for which it would be difficult now to find any equally convenient substitute. Accompanying this there has been a broadening of the general understanding of this branch of engineering on the part of engineers and plant operators, and to-day the storage battery may be said to be full of interest for all electrical men. The purely power-station services which it has performed so satisfactorily in the past it will presumably continue to discharge; while the great market for electric vehicles which is now in process of being opened up presupposes, of course, a very vast supply of batteries. This month we bring to a conclusion the serial paper by Mr. Basch on the uses of the storage battery in modern electrical engineering, which has, in relatively small space and in a very practical manner, discussed the various services to which the battery is being put to-day. We regret that we have had to divide this paper over two years (November and December, 1912, and January and February, 1913); but we find that nearly all our old subscribers are staying with us, and we trust that this division will not prove of great inconvenience.

NOTES ON THE DESIGN OF STEAM TURBINE-DRIVEN ALTERNATORS

By H. G. Reist

Alternating Current Engineer, General Electric Company

This article deals briefly with recent tendencies in the design of high speed alternators. The present approximate limits of output for 25 cycle and 60 cycle designs are specified, although these may change as other methods of construction are adopted. The review touches on the following points: effect of high internal reactance on the ability of the machine to withstand short-circuit strains; methods of supporting and insulating armature coils; rotor design for providing maximum copper space; rotor coil construction, insulation and support; punchings or forgings for revolving structure; critical speed; successful schemes for ventilation.—Editor.

In designing a generator to be driven by a steam turbine, one is met with difficulties due to the high speed needed for the economic operation of the turbine. The cost of the turbine is greatly reduced as the speed is increased, while the efficiency is also greater with higher peripheral speeds.

The minimum number of poles that may be used on a generator, viz., two, determines the maximum speed of rotation, which for 25 cycles is 1500 r.p.m. and for 60 cycles 3600 r.p.m. It seems possible to build, without serious difficulty, even the largest 25-cycle machines (i.e., for 25,000 kw. and over) with only two poles. With 60 cycles we soon reach the limits of size with our usual constructions, the 3600 r.p.m. being possible only in the smaller sizes with an approximate limit of 5000 kw. Machines for this frequency may be built to run at 1800 r.p.m. in sizes up to about 20,000 kw., while larger sizes may be constructed with greater advantage to run at 1200 r.p.m.

It will be understood that the limits of sizes for a given speed are determined by a number of factors, and may change as we adopt other methods of construction such as improved methods of ventilation, the use of steel having higher tensile strength, and of insulating material that we are willing to operate at higher temperatures. A considerable reduction in the sizes of this class of machines has already been made, due to allowing poorer inherent regulation than formerly. This change is satisfactory through the use of automatic voltage regulating apparatus, and is made urgent by the need of restricting the stresses in the windings in cases of short-circuit. On large machines with a small number of poles, a very large current will flow for three or four cycles following a short-circuit. The current will then gradually decrease; and in a second or so will be of the magnitude of two to three times the normal full load current, or what is generally known as the "short-circuited current." The magnitude of the current immediately following a short-circuit is determined by many factors, chief of which are the size of the cross-section of the magnetic circuit, the leakage space between the stator and the rotor windings, and the resistance of the armature windings.

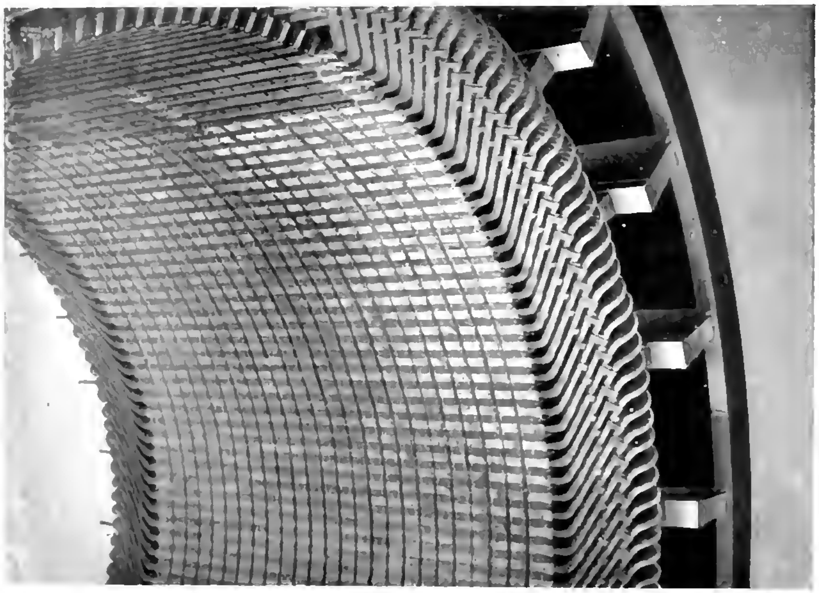

Fig. 1. Stator of Turbine Driven Alternator Showing Portion of Armature Coils Embedded in Slots

It is the instantaneous short-circuited current that makes it very difficult to support the armature windings so that they will not shift when a short-circuit takes place. The best designs employ a series of well supported rings, which form a backing for the coils to rest against, in the direction in which the greatest stress is exerted with the design of coils used on these machines. The coils are prevented from shifting sideways by a carefully planned system of blocking. The use of non-metallic lashing is a great safety factor, as it eliminates the danger of injury to the coils at the points of clamping. The insulation used on the armature coils is of a high quality; and, with a superior method of application, produces a compact covering of insulating material without break over the entire coil, including the leads coming from the coil. Fig. 1 shows a portion of the stator of a modern turbine-driven alternator, with the armature coils embedded in the slots; while Fig. 2 shows an entire stator, complete except for end shields and lagging.

In the revolving element of two- or four-pole turbo-generators the designer is handicapped in his work by the small amount of space available for copper. The limited space frequently makes it necessary to build the machines larger, that is, with more iron than would be necessary if the copper space were not so cramped. In the most approved design of generator the rotor copper is distributed in radial slots covering about two-thirds of the rotor surface. These slots are placed as closely together as the strength of the rotor iron admits. This construction gives a relatively large space for copper—probably larger than can be obtained with any other design. At the same time it allows proper conductivity for the heat from the coil to flow to the surrounding mass of metal, so that it may flow to the surface from which it may be radiated or conducted to the surrounding air. The coils are so designed that the layers of copper composing them are piled up in a radial direction, thus insuring against any tendency of the parts to slide on each other or to be supported on sharp corner or edges.

Fig. 2. Complete Stator of Turbine-Driven Alternator without End Shields or Lagging

The rotor coils are insulated with non-inflammable material, are very solidly placed in the slots so that there can be no shifting or chafing, and the ends are supported by weldless nickel-steel end-rings of high elastic limit. The copper is spaced at the ends so that there is room for a definite flow of air. This air, passing through holes in the retaining rings, mingles with the air taken into the machine by the fans mounted on the ends of the rotor. The coils are of such a construction that they are easily placed in the slots, and in case of injury, can readily be removed and replaced on site.

The rotor structures are made of punchings, wherever possible, and of forgings in the larger sizes, and for very high speeds. On smaller machines, with moderate-sized air gaps, it is very desirable that the pole-faces be laminated; on larger machines, with correspondingly large air gaps, this is not so necessary. The rotors of most medium-sized turbo-generators consist of a single forging, including one end of the shaft. The use of forgings is to be preferred to castings, because they are more homogeneous, and are free from flaws, which it is very desirable to avoid at the high speeds at which it is necessary to operate these machines. The forgings for the rotors are turned all over, the slots for the field windings are milled and the coils are held in place by metal wedges.

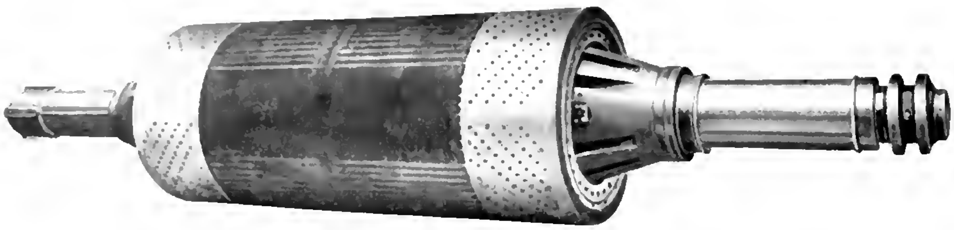

Fig. 3. Rotor of Two-Pole Turbine-Driven Alternator, Complete without Fans

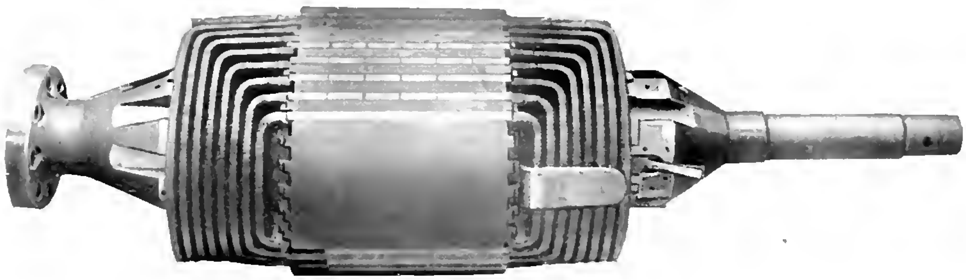

Fig. 4 Rotor of Two-Pole Turbine-Driven Alternator, Showing Field Coils Assembled in Core

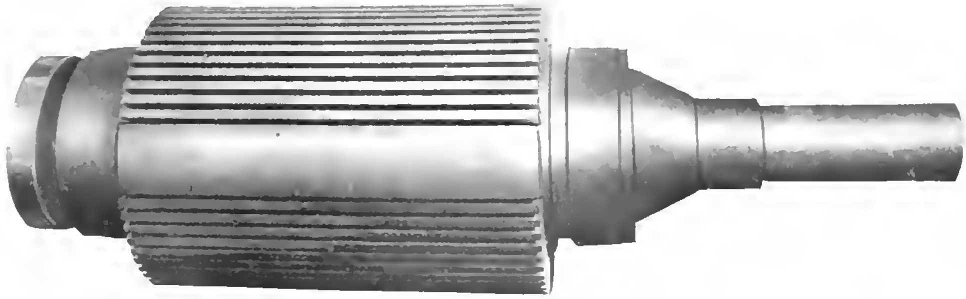

Fig. 5 Rotor of Four-Pole Turbine-Driven Alternator, Consisting of a Single Machined Forging

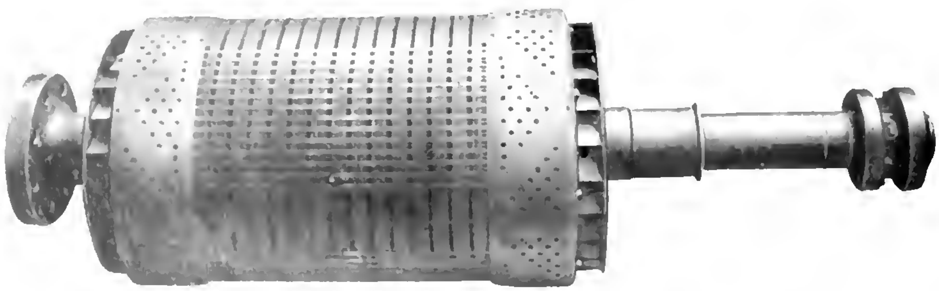

Fig. 6 Complete Rotor of Four Pole Turbine-Driven Alternator, Built up of Laminations

This construction is expensive, but so superior that most manufacturers are adopting its use. Figs. 3, 4, 5 and 6 illustrate some of the types of rotor construction employed today in the design of turbine-driven alternators.

High-speed generators may be run either above or below the critical speed. The "critical speed" is the number of revolutions which correspond to the rate of natural vibration of the rotor shaft with the structure which it is carrying. Some turbo rotors run below this speed, and others operate above; but as the design is made with this condition in view, the results are equally satisfactory. The ventilation of the generators has been worked out with considerable detail, and the methods which have been evolved have produced very satisfactory results.* The air is taken from a duct below the machine, and by means of carefully-designed centrifugal fans at each end of the rotor (Figs. 7 and 8) is forced over the end windings of the armature; then through the air gap between the stator and rotor and out through the radial ventilating ducts in the armature core. The air thus passes over the surface of the rotor in sufficient quantity to keep it cool. It also passes over the inner surface or bore of the stator, which greatly aids in removing the heat from what is usually the hottest part of the machine. After passing through the ducts in the core, the air is taken circumferentially around the outside and is expelled through a passage in the foundation or is allowed to pass into the room from the top. The latter method is used if it is not convenient to place the ducts in the floor, or if it is desired to use the warm air for the purpose of heating the room. In either case the movement of the air over the outer edge of the punchings is a valuable aid to the other cooling surfaces.

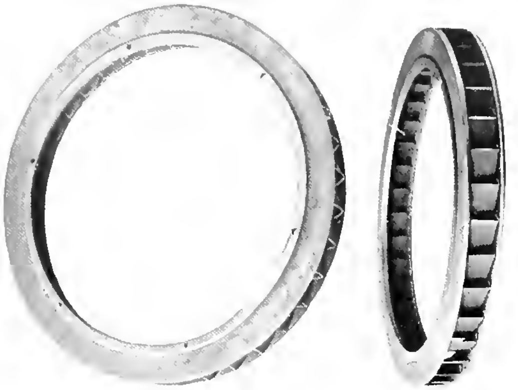

Fig. 7. Fans for Rotor of Turbine-Driven Alternator

*See also article by E. Knowlton in the October, 1912, GENERAL ELECTRIC REVIEW, on "The Ventilation of Steam Turbine-Driven Alternators."

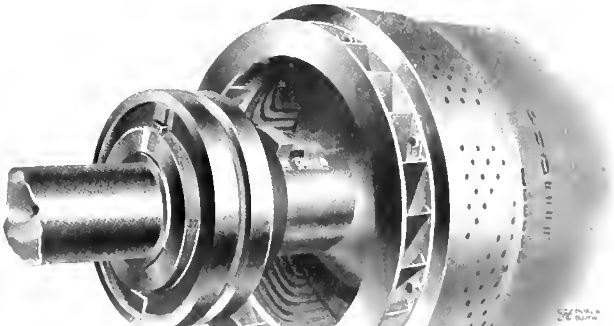

Fig. 8. End View of Rotor of Turbine-Driven Alternator, Showing Collector Rings, Fans, Field Coils and Retaining Ring

THE APPLICATION OF DIRECT CONNECTED REVERSING MOTORS TO PLANERS, SLOTTERS AND OTHER MACHINE TOOLS

By Charles Fair

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The reversing motor is applicable to the driving of planers, slotters, key-seaters, lathes, wire and tube-drawing machines, boring-mills, and other classes of reversing drive now commonly operated through belts or clutches. This article shows the large increase in production as well as the saving in power consumption which is to be achieved with this form of drive; specifies the type of motor used; and describes (with illustrations) the control method and apparatus whereby safe and economical operation of both motor and tool are ensured. The current-consumption curves for belt, clutch and reversing motor drives on slotters and planers from which our line cuts have been made, were actually drawn by a graphic recording ammeter; and as well as being representative, are therefore thoroughly reliable indications of the great economies which have been made possible in machine-tool operation.—Editor.

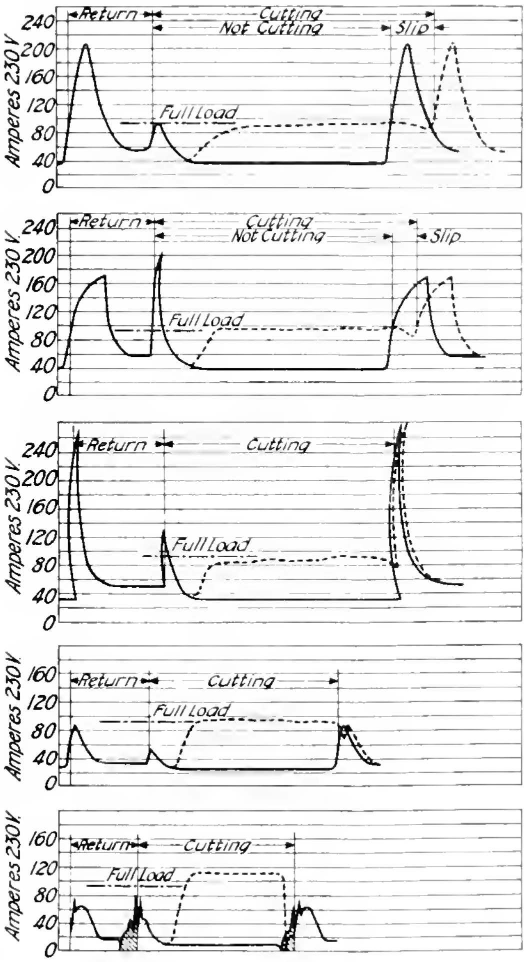
Perhaps the most interesting motor application to machine tools at the present time, both from an engineering standpoint and from the standpoint of production, is the reversing motor as applied to planers, slotters, etc. The results of this drive are being watched with the keenest interest both by tool builders and by manufacturers using these or similar machines. The idea of supplying a reversing motor for driving metal planers is not new, the writer having seen such a drive, which has been in operation for more than nine years. These drives are being manufactured by a number of the leading electrical firms both in this country and in Europe. It is only of late, however, that the advantages and the economy of the reversing motor drive have been realized, and that the increasing demands have warranted the expense necessary to perfect it for commercial purposes.

Much has been said from time to time regarding the increased production and saving of power due to direct connection to the tool; yet there are very serious doubts if the real importance of this direct application of power is realized in many cases, even by those who are advocating it. For instance, the saving of power is looked upon generally as a matter of how much of the transmission friction load can be saved; and though this saving sometimes amounts to 50 per cent and even more, yet it is in many cases only a small part of the real saving as proven by numerous tests made by the writer.

Figs. 1 to 5 inclusive show graphically the power required to drive metal planers light; and also how the required power when planing at about normal cut by the three methods commonly used today, namely: belt, clutch and reversing motor. Fig. 1 illustrates the distribution of power required and also slip, when driving planers through single belts; Fig. 2, when driving through double belts; Fig. 3, pneumatic clutch as ordinarily applied to planers; Fig. 4, pneumatic clutch when properly applied though seldom seen in practice; Fig. 5, reversing direct-connected electric motor with a cutting speed of more than two to one and with a total speed range of four to one. The cross-sectioned portion of Figs. 5, 14, 16 and 23 is not line current but that of dynamic braking. Comparison with magnetic clutches was omitted because they are not in general satisfactory for planer drives.

The above curves were plotted from numerous tests made with graphic recording ammeters and reduced to the same length of stroke, the difference in cutting speeds being taken care of in the time element. These curves are representative, though there is considerable difference in the power consumption of belt driven planers due to varying conditions, such as tightness of belt, flywheel effects, weight, size and speed of the reversing pulleys, etc. Generally speaking, tight belts give high peak loads on reversals, reverse faster, and pull heavier cuts, but wear out quicker than moderately tight belts. Loose or light belts show excessive slipping on reversals and when making average cuts. Medium or large size reversing pulleys of average speed, unless extremely light, show high power peaks, sluggish reversals and are slow in accelerating. Double belt drives show heavy power on accelerating to high speed and give high peaks on reversing to cut, not unlike those of the high speed pneumatic clutch.

Fig. 6 shows the areas of curves 1 to 5 inclusive, reduced to a more convenient form to facilitate comparison. A represents the proportion of power used to drive the planers without cut; B, the slip in transmission when cutting (driver to driven on machine only); $B+C$, the power actually used for removing the metal under average cutting conditions. Note that a comparatively small amount of power in the belt drives is available for removing the metal. In Fig. 7, D shows the power consumption per unit of time, for the belt drive illustrated in Fig. 1, and E that of the reversing motor drive Fig. 5, which, however, makes 43.2 per cent more cuts than D. The amount of metal removed per unit of time is represented graphically in Fig. 8 which compares the belt drive of Fig. 1 with the reversing motor drive of Fig. 5; F being the belt drive and G the reversing motor drive.



Planer Drives
Fig. 1. Single Belt
Fig. 2. Double Belt
Fig. 3 Pnuematic Clutch—High Speed
Fig. 4. Pnuematic Clutch—Slow Speed
Fig. 5. Reversing Direct Connected Motor

It will be seen from the above that the saving in power and in cost of belt maintenance for planers, large as it is, is small as compared with the real saving due to direct drive—increased production and decreased cost.

A table (see page 80), based on numerous tests reduced for comparative purposes to a 25 h.p. drive and an 8 ft. stroke, shows some of the figures from which the above were compiled. It will be noted that in no case were

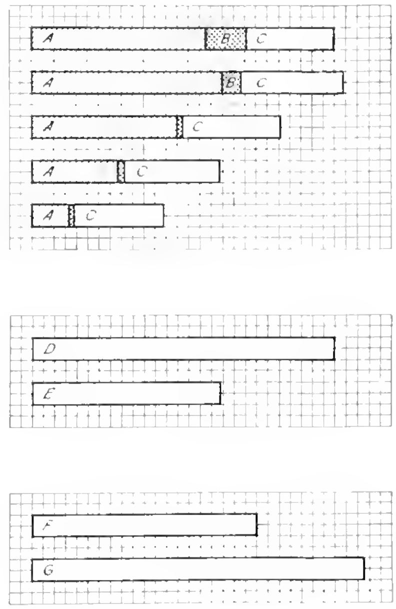


Fig. 6. Integrated areas of Figs. 1 to 5
Fig. 7. Power consumption per unit of time Figs. 1 and 5
Fig. 8. Metal removed per unit of time Figs. 1 and 5

extremes used. Comparisons in time, power and amount of metal removed, etc. vary with the different combinations of speeds, length of stroke and transmission.

The majority of planers to-day return at a speed approximately three times the cut, and therefore by far the greatest amount of time is saved when a maximum cutting speed is maintained. As an illustration, take a cutting speed of 25 ft. per min. and a return speed of 85 ft. per min. Increase the cutting speed to only 35 ft. and maintain the same return speed (85 ft.) and 22 per cent will be gained in time on the whole cycle. On the other hand with 25 ft. cutting speed and an increase in return speed to 95 ft., only 2.4 per cent will be gained on the whole cycle. With direct connected adjustable speed reversing motors not only can a maximum speed be used when cutting materials of varying degrees of hardness, but a given speed can be maintained when the cut requires heavy overloads.

The large increase in production due to this form of drive on planers is now very generally understood, but the application of the reversing motor drive in its various forms (which is almost unlimited) is not so well known. It is applicable not only to planers, new and old; but to screw, worm and rack driven slotters; key seaters, turret lathes, wire and tube drawing machinery; and to boring mills, when machining projections which are short in comparison to the total travel of the mill, or in machining surfaces whereon projections prevent a complete revolution. Reversing motors are also applicable to that class of reversing machinery which is now operated through clutches, shifting belts, etc., the maintenance of which is usually high and the efficiency low.

COMPARATIVE DATA OF VARIOUS TYPES OF PLANER DRIVE

(1) SINGLE BELT, (2) DOUBLE BELT, (3) PNEUMATIC CLUTCH, HIGH SPEED, (4) PNEUMATIC CLUTCH, SLOW SPEED, (5) REVERSING DIRECT CONNECTED MOTOR

Type of Drive	1	2	3	4	*5
Drive h.p....	25	25	25	25	25
Stroke ft....	8	8	8	8	8
Approximate cutting load h.p.	25	25	24	26	31
Peak load reverse to return h.p.	55.5	45.3	75	25	20
Peak load reverse to cut h.p.	25	55.0	36	15	20
Time return stroke, sec.	7.2	7.2	7.6	6.8	5.6
Time cut stroke, sec.	20.0	20.0	19.5	16.0	13.4
Time of cycle, sec..	27.2	27.2	27.1	22.8	19.0
Ft. per min. return stroke	66.6	66.6	63.2	70.5	85.7
Ft. per min. cut stroke	24.0	24.0	24.6	30.0	35.8
Ratio, cut to return, one to	2.78	2.78	2.57	2.35	2.4

The motors for this service are those of a standard commutating pole type having a speed range usually of 250/1000 r.p.m. and ranging in capacity up to and including 100 h.p. planer rating; also a speed range of 350/1200 r.p.m. in sizes up to 35 h.p. planer rating. These combinations of speeds allow the motor in the majority of cases to be coupled direct to the driving shaft of the machine.

Starting, stopping and reversing are accomplished with sparkless commutation. In order not to brake (dynamically) from high speed in one step [illegible], means have been taken in the control to accomplish this in three distinct steps, braking slowly from the high speed and [illegible] quickening the braking action at the lower [illegible] out the brake [illegible] completing the entire [illegible] possible time without undue shock. This feature, in addition to the quickness of the brake, will be recognized as a decided advantage in the maintenance of the machine. Incidentally, reversing is accomplished without the delay incident upon the use of sluggish relays. After failure of voltage with the master controller in the running position, and upon closing the line breaker, the motor will start up in the regular way, without additional complications in the control. This latter feature is advantageous in the event of the operator failing to return the master switch to the off position.

Cutting and return speeds are entirely independent of each other, so that it is possible to use the slowest cutting speed and the highest return speed, or vice versa, in any combination not exceeding four to one, with thirty-five to seventy cutting speeds and the same number of return speeds, depending on size of the equipment. Cases where overlapping speeds are required or where the entire range of motor speeds is to be used in both directions for cutting, as in plate planers, require special arrangement of control.

The control consists of a contactor panel, master switch and resistance. The contactor panel is made up of eight contactors similar in appearance to the series contactor, but actuated by shunt, series or differential coils in such a manner as to eliminate electrical disk interlocks. An additional precaution is taken by using mechanical interlocks to prevent the possibility of short circuits. The contactor panel and field rheostats are enclosed in a cast iron box, the cover of which

* For [illegible] per min., return stroke 55 to 92 ft. per min., the above being but one of the

is hinged, so that when swung open the contactors and wiring are readily accessible. The box itself is pivoted about liberal openings in order that the rear of the panel may be swung into view for inspection when required. The leads are carried through these same openings from either top or bottom, which prevents them from chafing when the panel is swung out. The field rheostat handles are brought out through the cover of the enclosing case and are marked, "Cut" and "Return". The pointers of these handles traverse a blank ring which can be marked or graduated for cutting and return speeds in feet per minute. The enclosing case of the contactor panel is so arranged that nearby operators do not see the arcing from any of the contactors. The master switch contains three contact fingers, two forward and two reverse, one finger being common to both directions and three segments on the drum, all of liberal proportions. The function of the master switch is to close the shunt coil circuits of the forward and reverse line contactors. The motor field is external to the master switch, the field resistance being cut in or out by a contactor on the control panel. The master switch is operated by dogs on the planer table in much the same way as is now employed for shifting belts. There is supplied with each equipment a special double-pole circuit breaker which provides for overload and minimum voltage protection. In case the breaker opens or the current fails from any cause, the breaker automatically stops the motor, which prevents the planer table from coasting.

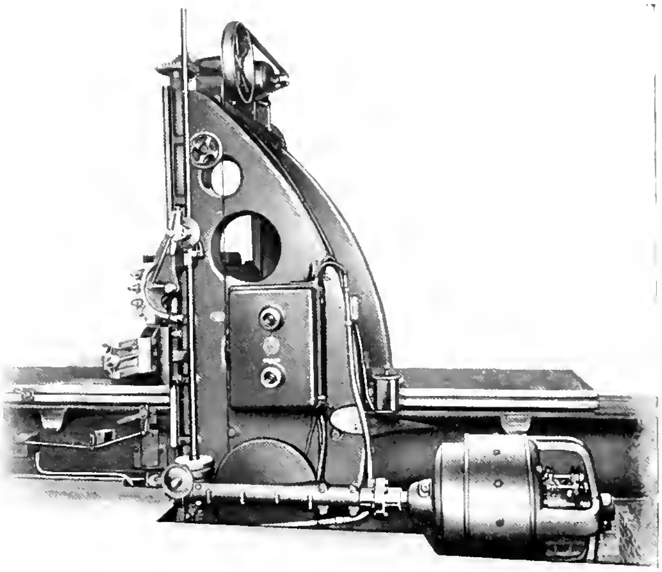


Fig. 10. Planer shown in Fig. 9 re-equipped with a 250/1000 r.p.m. Direct Connected Reversing Motor

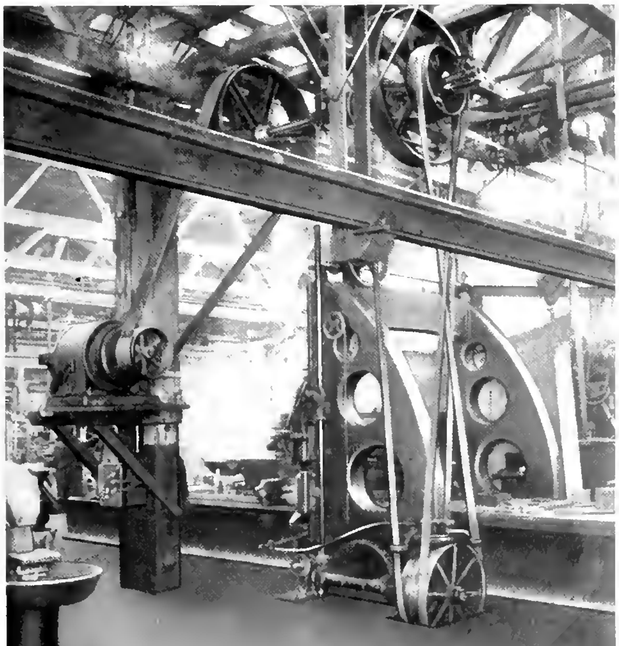


Fig. 9. Planer, 72 in. by 22 ft., belt driven, by a 40 h.p. 1060 r.p.m. Compound Wound Motor

Fig. 9 shows a 72 in. by 22 ft. Bement Miles planer driven by a direct current 35 h.p. motor through shifting belts. After being equipped with a 35 h.p., 250/1000 r.p.m. direct-connected reversing motor, the same planer has the appearance shown in Fig. 10. The master switch is shown at the extreme left of the photograph. The contactor panel is enclosed in the iron case mounted on the planer housing.

The standard type of contactor box is illustrated in Fig. 11 in which the cover of the enclosing case is swung open displaying the panel mounted in the box proper and the field rheostats fastened to the inside of cover. The master controller has the appearance given in Fig. 12.

Figs. 1 to 5, 13 to 16 and 21 to 23 inclusive

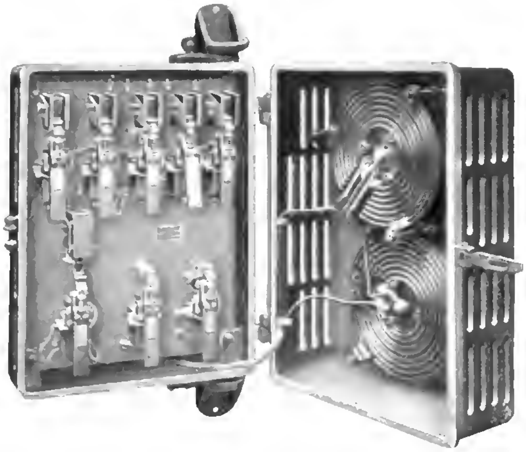


Fig. 11. Panel Case, open, showing Contactors and Adjustable Field Resistances

are curves made by a graphic recording ammeter. Curves *A*, *B*, and *C*, Fig. 13, show the ampere input of a 10 h.p. motor driving a 36 in. modern type planer, through shifting belts, the belts being in the best of condition. *A* is the return stroke of the planer table at a speed of 72.8 ft. per minute; *B*, the cutting stroke, without cut, at 31.9 ft. per minute; *C*, the same cycle but with a cut slightly less than 10 h.p. The lost time on the cutting stroke, due to the belt slipping, is plainly seen, the cutting speed falling off from 31.9 ft. per minute to 28.3 ft. per minute, or 12½ per cent. *C′* shows the result when attempting to pull a cut with the same belt as *C*, but to the value *F* shown in Fig. 14; the limit of power that the belt will transmit having been reached, the belt merely slips. This slip reaches its maximum at the point where the machine is actually stalled yet the energy input will remain approximately the same, the power being dissipated in heat. *D*, *E*, and *F*, Fig. 14, are curves made on the same machine when driven by a 10 h.p. 250/1000 r.p.m. reversing motor direct connected. No attempt was made in this set of curves to duplicate the slow cutting or return speeds of the belt-driven machine, Fig. 13, as the comparison would have shown power differences only. *D* is the return stroke of the planer table at a speed of 90 ft. per min.; *E*, the cutting stroke at 52 ft. per min. without cut; and *F*, the same cycle but with a cut of approximately 13 h.p. For comparison the speed of curve *F* was chosen as the most economical speed at which the machine could be run. The loss in time of the belt drive as compared with the direct connected reversing motor drive on the whole cycle (the depth of cut and feed being the same in both cases) is 62 per cent. If the return stroke of the belt drive 72.8 ft., had been maintained in both cases, the saving in time on the whole cycle would still have been 50 per cent. Comparing the two cycles starting to cut even, the direct connected reversing motor drive will make one cut, one return and one-third of the second cut while the belt drive is completing only one cutting stroke.

In Fig. 15 curves *A*, *B* and *C* show the ampere input on a direct current, 35 h.p. constant speed motor, driving the 72 in. by 22 ft. Bement Miles planer shown in Fig. 9. *A* is the return stroke of the planer table at a speed of 59.3 ft. per min.; *B*, the cutting stroke, without cut, at 22.9 ft. per min.; *C*, the same cycle, but with a cut of approximately 25 h.p., the speed having dropped from 22.9 ft. to 17.1 ft. Comparing curves *B* and *C* the lost time in the cutting stroke, curve *C*, due to belt slip is 34 per cent. This

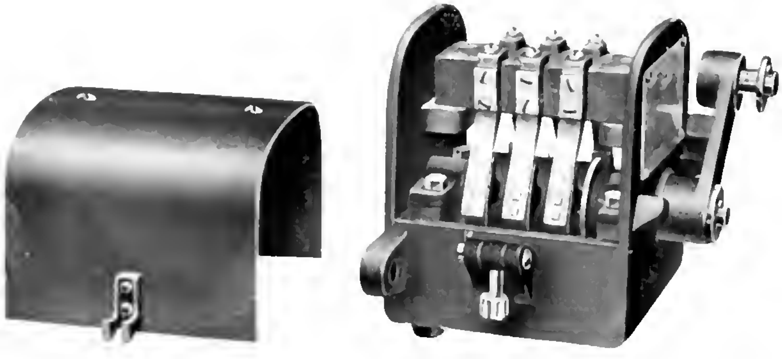


Fig. 12. Master Controller for Reversing Motor Planer Equipment, cover off

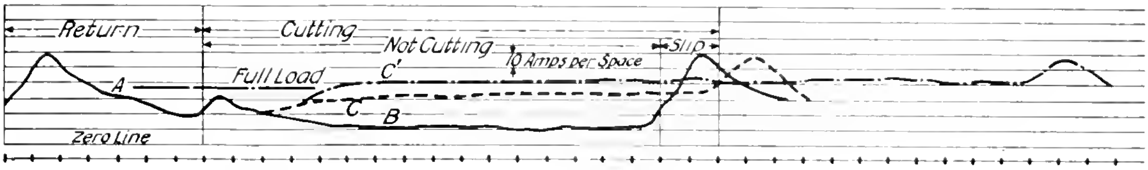
is about the maximum cut that the belts on this machine will pull without excessive slipping.

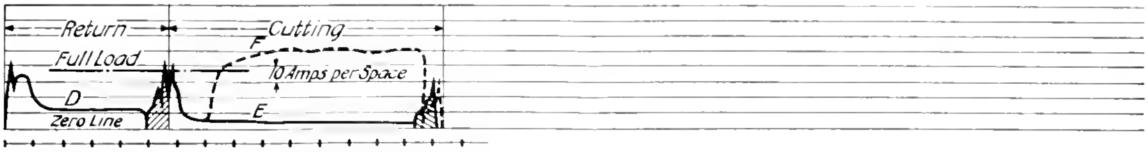
Fig. 16 shows a curve made on the same

machine as Fig. 15 but driven by a 35 h.p., 250/1000 r.p.m. direct connected reversing motor. (See Fig. 10.) *D* is the return stroke at 77 ft.; *E*, the cutting stroke without cut and *F* the cutting at 36.2 ft. Comparing the two drives on the basis of saving in time, the direct connected reversing adjustable speed drive shows a saving of 11 per cent. Note the saving in power of the direct connected drive as compared with the belt drive, even though the direct connected drive is at a much higher speed on both the cut and return strokes. The power required to drive the planer at a return speed of 77 ft. per min. by the direct connected reversing motor drive is actually less than that required to drive the belt planer on the cutting stroke without cut at a speed of only 22.9 ft. per minute.

A 48 in. by 12 ft. Pond planer equipped with a 20 h.p., 250/1000 r.p.m., 230 volt motor and control is shown in Fig. 24 (page 86). Here the contactor panel and the method of fastening it to the machine are clearly shown, as is also the master switch and resistance. The small controller just above the contactor panel is for operating the cross rail motor which is mounted on top of the planer. The main motor which is coupled to the driving shaft of the planer is just visible on the far side of the machine.

Figs. 17 and 18 illustrate a portable slotter driven by a 20 h.p., 250/1000 r.p.m. reversing

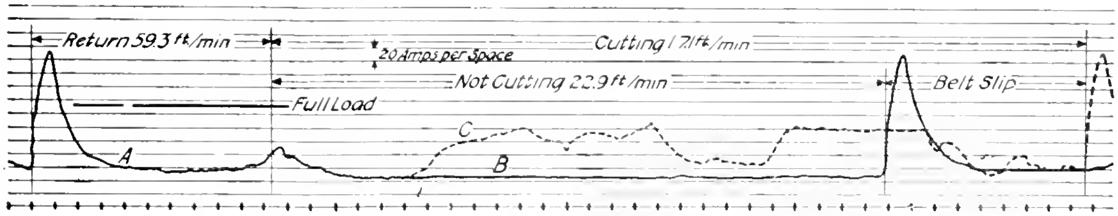




Graphic Recording Ammeter Curves

Fig. 13. 36 in. Planer, Belt Driven

Fig. 14. Planer of Fig. 13, Reversing Motor Driven



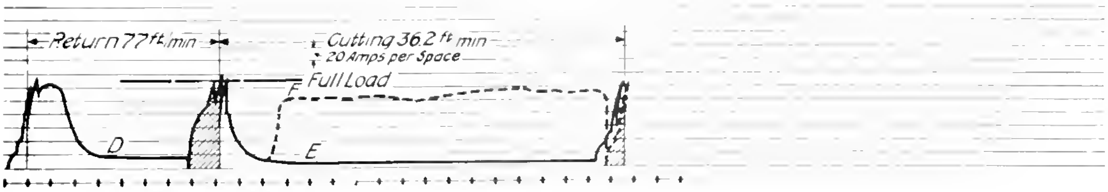


Fig. 15. 72 in. Planer, Belt Driven

Fig. 16. Planer of Fig. 15, Reversing Motor Driven

motor The special circuit breaker, control panel, resistance, master switch and operating dogs are plainly seen.

An idea of the current consumption used in driving a 60 in. portable slotter through magnetic clutches and a multiplicity of gears may be obtained from Fig. 21 (see second the magnetic clutch drive. The marked improvement when this same type of machine is driven by a direct connected reversing motor with much of the gearing omitted may be noted in Fig. 23 (see Fig. 17 and fourth machine, Fig. 20). *A* is the up stroke; *B* the cutting stroke without cut; and *C* the same

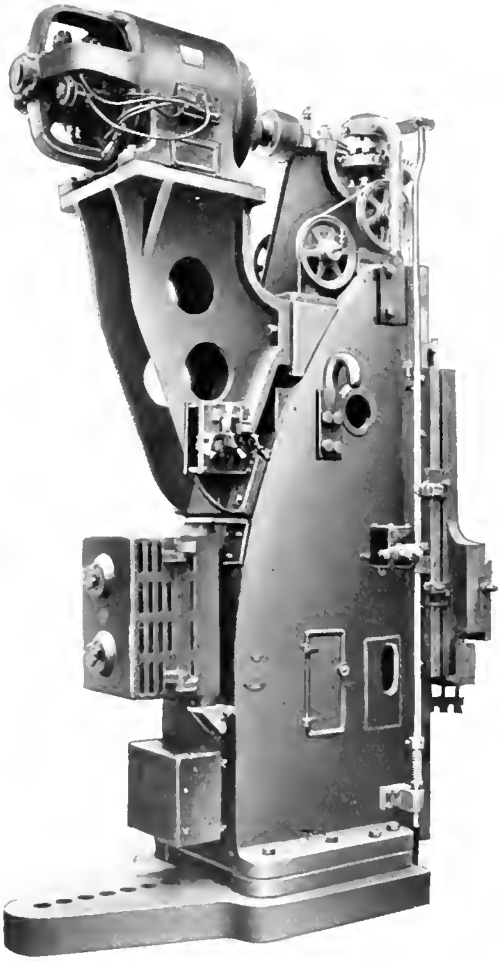


Fig. 17. 48 in. Slotter equipped with Reversing Motor Drive. Left hand side, panel cover closed

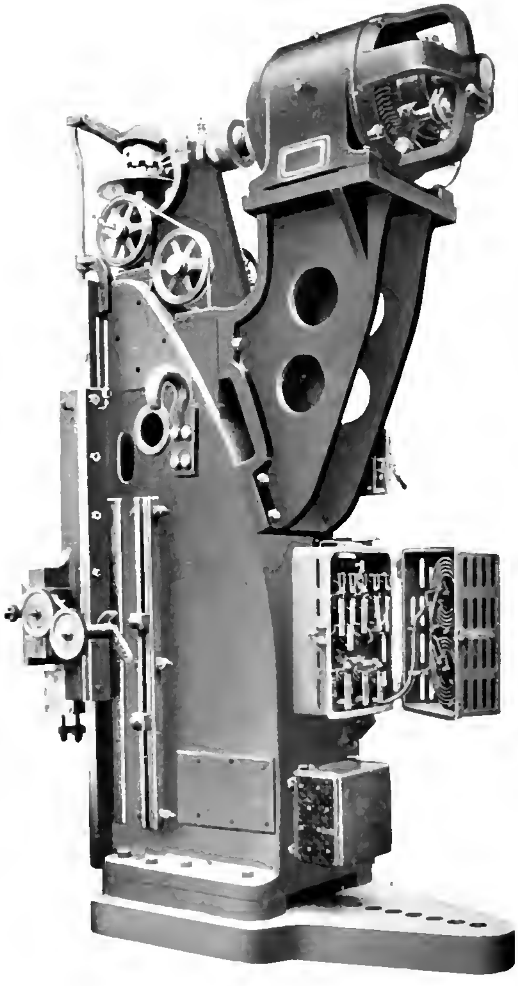


Fig. 18. 48 in. Slotter shown in Fig. 17. Right hand side, panel cover open

machine, Fig. 20), *A* being the up stroke; *B* the cutting stroke without cut; and *C* the same stroke with cut.

Fig. 22 is the curve of another 60 in. portable slotter, driven through pneumatic clutches (see third machine, Fig. 20). This one is shown by Fig. 22 to be not unlike that of stroke with cut, which curve will be noted is almost identical with the reversing motor planer curve.

Of the pair of 96 in. portable slotters, shown in Fig. 19 (one being driven through magnetic clutches, the other by reversing motor) the reversing motor drive makes 1¾ cycles while the magnetic clutch drive is making one cycle.

Fig. 20 is interesting in that it shows the evolution in the order named of the individual motor drive for portable slotters as driven through belts, magnetic clutches, pneumatic clutches and reversing motor.

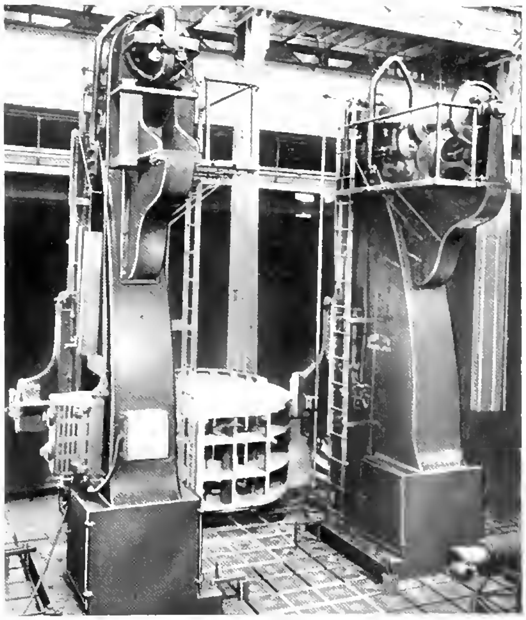
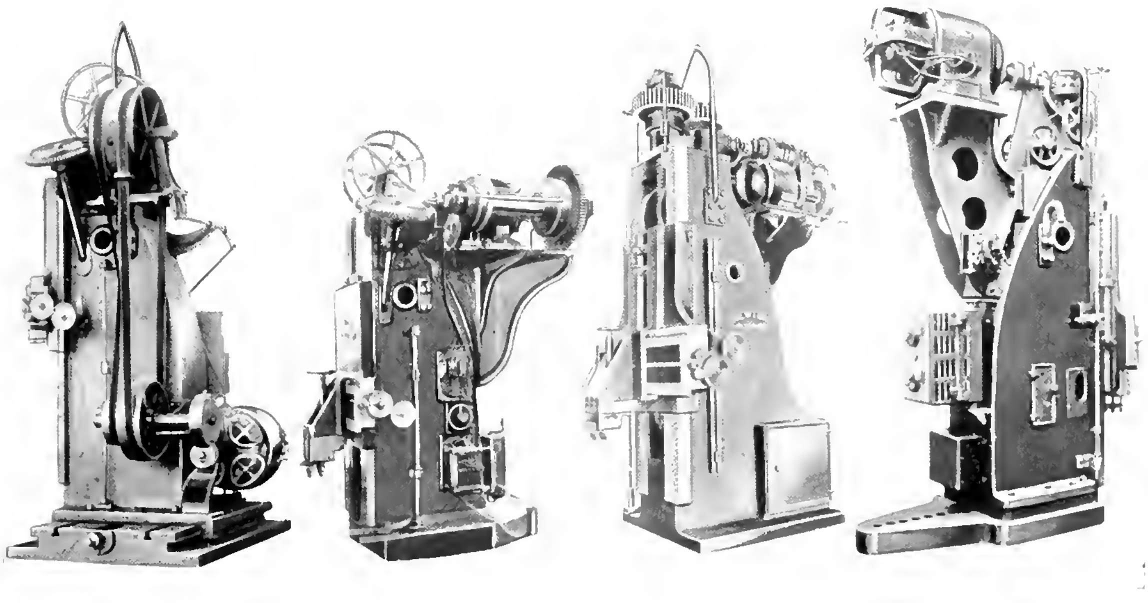


Fig. 19. Two 96 in. Slotters. Left hand machine driven by Reversing Motor, right hand through Magnetic Clutch

Attaching Reversing Motors and Control to Old Planers

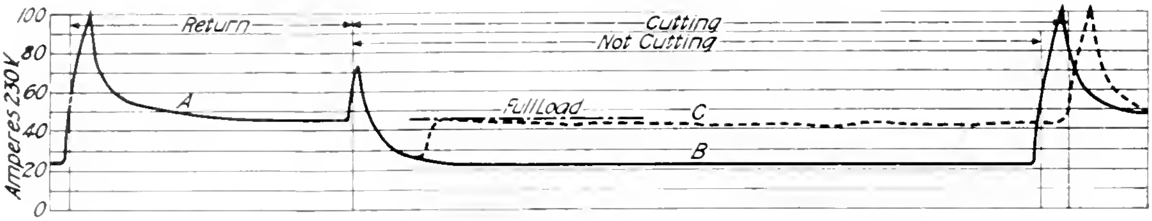
In the majority of cases the driving shaft of the planer will be slow enough in speed on the slowest cut to meet a motor speed of approximately 250 r.p.m., in which case only a coupling and the necessary motor foundation will be required, in order to attach the motor. If, however, the planer gearing is of such a ratio that the speed of the driving shaft, corresponding to the slowest cut required, is lower than the motor speed of 250 r.p.m., it will then be necessary to use a slower speed motor (usually expensive); or to provide an additional pinion and gear for the required speed reduction, in which instance an outboard bearing should be used.

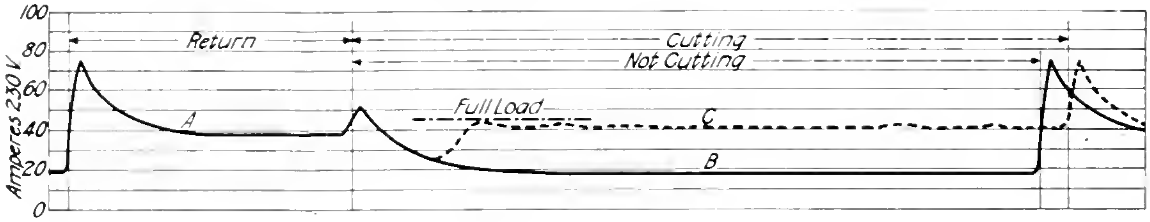


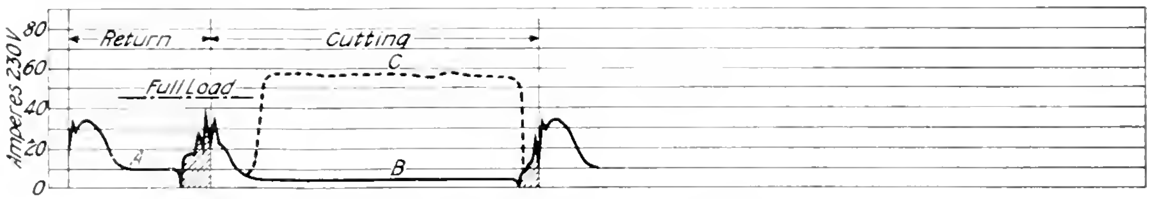
(a) (b) (c) (d)

Fig. 20. Evolution of Motor Drives applied to Portable Slotters

(a) Driven through Belts
(b) Driven through Magnetic Clutches
(c) Driven through Pneumatic Clutches
(d) Driven by Direct Connected Reversing Motor







Graphic Recording Ammeter Curves (Slotters)
Fig. 21. Magnetic Clutch Driven Fig. 22. Pneumatic Clutch Driven
Fig. 23. Reversing Motor Driven

Fig. 24. Planer, 48 in. by 12 ft. driven by a 20 h.p. 250/1000 r.p.m. Reversing Motor

THREE-PHASE TO SINGLE-PHASE TRANSFORMATION

By W. W. Lewis

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No scheme of connections can effect an exact transformation from balanced polyphase power to single-phase; but some schemes are better than others in the approximation, while some which have been seriously proposed are utterly impracticable. This article analyzes and compares some of the many which have of late been put forward; and the results of the analysis are applicable especially to the electric welding industry, in which excessively heavy single-phase loads are often placed on the system and in which therefore a close approximation to even distribution is essential to safe operation of the three-phase system. The purpose of the article is to offset the effect of some of the recommendations which have recently been put forward for this transformation; since the table on page 90, with accompanying illustrations and text, shows that there is after all only one scheme of connections which may be said to possess sufficient merit to warrant its use.—Editor.

The growth of the electric welding industry, requiring large amounts of single-phase power, has resulted in the proposal of numerous transformer connections for obtaining single-phase current from three-phase circuits. The object of most of these connections is to distribute the load among the three phases in a better manner than is possible when a single transformer is used across one phase. As these welding loads are often considerable, it is very important on some systems to thus distribute the load.

This subject was discussed by Mr. W. S. Moody in the January, 1908, issue of the General Electric Review, where it was stated that none of the combinations investigated gave better results than could be obtained by simply using a transformer across one phase. Since that time, new schemes have been proposed, and old schemes revived in the hope of accomplishing the desired result. It is the purpose of the present article to analyze and compare some of the many connections. It may not be amiss here to give the reason, as explained by Dr. Steinmetz in the Transactions of the A.I.E.E. for 1892, why none of these schemes are able to transform balanced polyphase power to single-phase power, but only to approximate such transformation. His explanation is that single-phase power changes from a maximum to zero and back to maximum every half cycle, while polyphase power is delivered at a constant rate. Therefore, any system capable of transforming from balanced polyphase current to single-phase current must be capable of storing energy during the interval of time when the power delivered to the single-phase side is less than the power received from the three-phase side. The transformer is incapable of fulfilling this requirement, and hence it fails to perform the desired operation.

The method of analysis is to assume single-phase load, EI, at unity power-factor on the secondary side and from that point work back to the generator; also assuming that there are no losses and therefore that the generator output is equal to the transformer output. For simplicity the ratio of transformation is so chosen that the primary line voltage and the secondary line voltage are equal. The diagrams represent the transformer and generator connections, and at the same time serve to represent the potentials in direction and magnitude. The isolated arrow tipped line represents the direction of current, which is assumed to be in phase with the secondary voltage.

For the first scheme the generator is shown in Fig. 1 connected both Y and delta. The sketches for the subsequent schemes show only the transformers. The sketches and the accompanying table give the essential information.

In scheme 7 (Fig. 7) it is obvious that unless the neutral of the primary Y is connected to the neutral of the generator, twice as much current as is required to balance the ampere-turns of the secondary $X'' A''$ will flow in the primary $X' A'$, with resulting distortion of the neutral. Such connection is therefore not feasible, and for the same reason a delta connected generator cannot be used with this scheme. Connecting the neutral of the transformers to the neutral of the generator, however, provides a path for the excess current, as shown. By de-

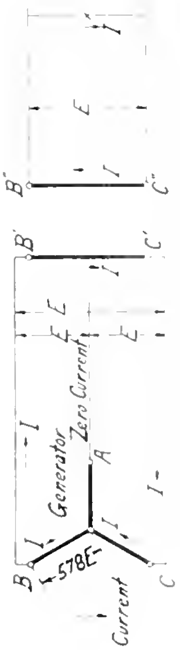

Fig. 1a. Transformer Across One Phase, Generator Y

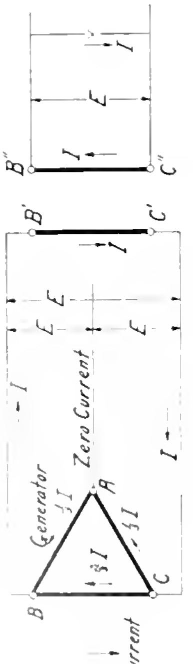

Fig. 1b. Transformer Across One Phase, Generator Delta

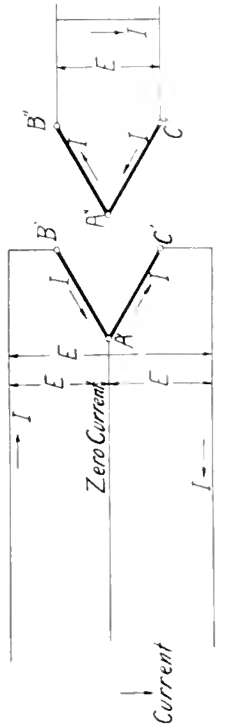

Fig. 2. Open Delta

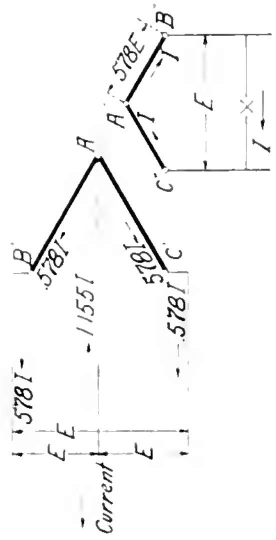

Fig. 3. Open Delta, One Leg of Secondary Reversed

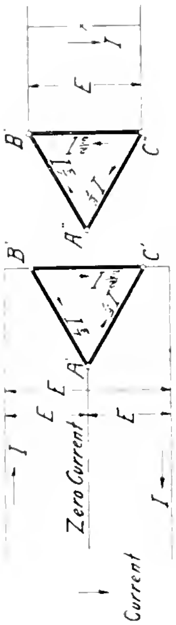

Fig. 4. Delta

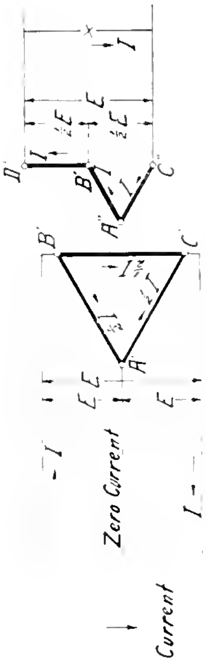

Fig. 5. Delta, One Leg of Secondary Reversed

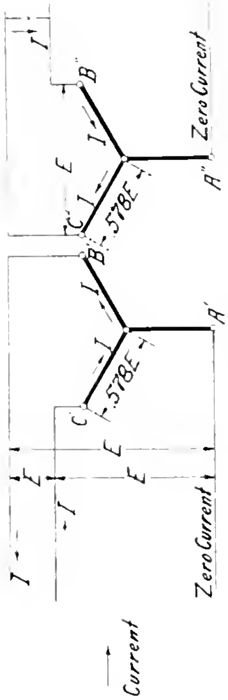

Fig. 6. Y-Connection

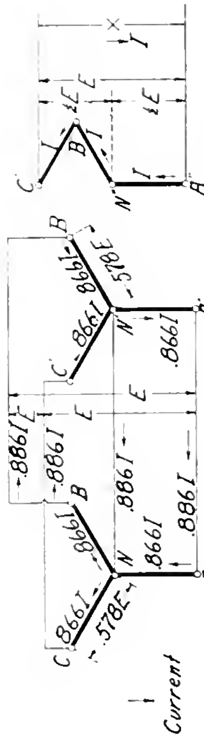

Fig. 7. Y-Connection, One Leg of Secondary Reversed, Transformer and Generator Neutrals Connected

creasing the ratio of leg NA to one-half that of the other two legs, the Y connected primary without connected neutral may be used (Fig. 8).

The various connections may be compared from the standpoint of the relative transformer power-factors, line currents, generator currents, or the division of power among the phases of the generator. By power-factor is meant the ratio of output to kilovolt-ampere rating. The power-factor is the same for both primary and secondary in all cases except the connection of Fig. 10. The power-factor here is found by taking the ratio of (input+output) to (kv-a. primary+kv-a. secondary).

Referring to the table, it may be seen that the single-phase connection (Fig. 1) is superior to all others from the consideration of power-factor. From the standpoint of even distribution of current in the lines and generator and of power in the generator, the Y-connection with neutral brought out (Fig. 7) is apparently superior. This, however, requires a four-wire system with a total current carrying capacity of $4 \times 0.866\, I = 3.464\, I$; or, if the fourth wire is omitted and the neutrals grounded, $3 \times 0.866\, I = 2.598\, I$, the transformers working at a comparatively low power-factor (0.666). In scheme 1, on the other hand, current carrying capacity of only $2\, I$ is required, and the power-factor is 1.00.

The remainder of the schemes possess no advantages. For instance, in scheme 3 the distribution of line current, 1.155 I, 0.578 I and 0.578 I, is in reality no better than the distribution I, I, O of the single-phase connection (Fig. 1), while the power-factor is only 0.866. Neither scheme has the advantage as far as the distribution of power in the phases of the generator is concerned.

With three-phase load, the voltage drops due to load are 120 degrees apart in the different phases, and the resultant potentials of the system still bear a true 120 degree relation. With single-phase load, however, all the voltage drops are in the same direction and the resultant potentials of the system

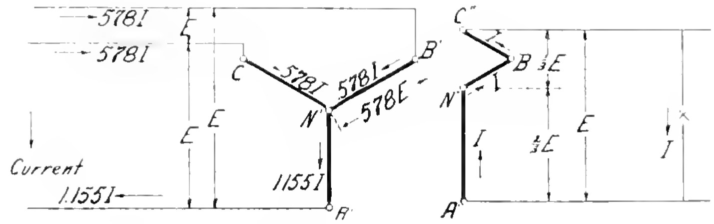

Fig. 8. Y-Connection, One Leg of Secondary Reversed, Ratio of One Phase One-Half Ratio of Other Phases

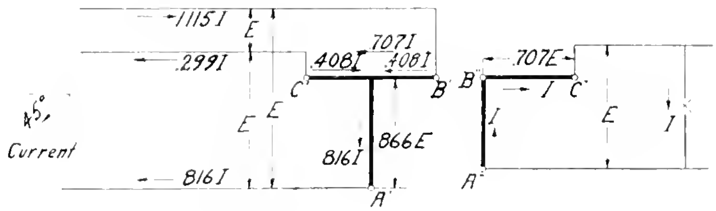

Fig. 9. Primary T, Secondary L

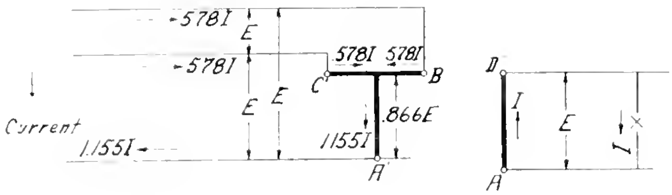

Fig. 10. Primary T, Secondary Single-Phase

are no longer equal nor 120 degrees apart. With certain connections this will introduce serious complications, for instance, heavy unbalanced currents in the neutral in scheme 7 (Fig. 7).

We may conclude that with the exception of scheme 1, none of the schemes suggested has sufficient merit to warrant its use.

Sketch No.	Case	TRANSFORMERS Division of Power	Power-Factor	Line Current	GENERATOR Connection	Current	Division of Power
1 a	Single-phase	EI	1.00	I I 0	Y	I I 0	1/2 EI 1/2 EI zero
1 b	Single-phase	EI	1.00	I I 0	Delta	2/3 I 1/3 I 1/3 I	2/3 EI 1/6 EI 1/6 EI
2 a	Open delta	1/2 EI 1/2 EI	0.5	I I 0	Y	I I 0	1/2 EI 1/2 EI zero
2 b	Open delta	1/2 EI 1/2 EI	0.5	I I 0	Delta	2/3 I 1/3 I 1/3 I	2/3 EI 1/6 EI 1/6 EI
3 a	Open delta, One leg sec. Reversed	1/2 EI 1/2 EI	0.866	1.155 I 0.578 I 0.578 I	Y	1.155 I 0.578 I 0.578 I	2/3 EI 1/6 EI 1/6 EI
3 b	Open delta, One leg sec. Reversed	1/2 EI 1/2 EI	0.866	1.155 I 0.578 I 0.578 I	Delta	0.578 I 0.578 I 0	1/2 EI 1/2 EI zero
4 a	Delta	2/3 EI 1/6 EI 1/6 EI	0.5	I I 0	Y	I I 0	1/2 EI 1/2 EI zero
[illegible]	Delta	2/3 EI 1/6 EI 1/6 EI	0.5	I I 0	Delta	2/3 I 1/3 I 1/3 I	2/3 EI 1/6 EI 1/6 EI
5 a	Delta One leg sec. Reversed	1/2 EI 1/4 EI 1/4 EI	0.66	I I 0	Y	I I 0	1/2 EI 1/2 EI zero
[illegible]	Delta One leg sec. Reversed	1/2 EI 1/4 EI 1/4 EI	0.66	I I 0	Delta	2/3 I 1/3 I 1/3 I	2/3 EI 1/6 EI 1/6 EI
6	Y	1/2 EI 1/2 EI zero	0.578	I I 0	Y	I I 0	1/2 EI 1/2 EI zero
[illegible]	Y	1/2 EI 1/2 EI zero	0.578	I I 0	Delta	2/3 I 1/3 I 1/3 I	2/3 EI 1/6 EI 1/6 EI
[illegible]	[illegible]	1/2 EI 1/4 EI 1/4 EI	0.666	0.866 I 0.866 I 0.866 I 0.866 I	Y with Neutral	0.866 I 0.866 I 0.866 I	1/2 EI 1/4 EI 1/4 EI
[illegible]	[illegible]	[illegible] EI [illegible] EI [illegible] EI	0.75	1.155 I 0.578 I 0.578 I	Y	1.155 I 0.578 I 0.578 I	2/3 EI 1/6 EI 1/6 EI
[illegible]	[illegible]	[illegible]	[illegible]75	1.155 I 0.578 I 0.578 I	Delta	0.578 I 0.578 I 0	1/2 EI 1/2 EI zero

Scheme No.	Transformers			Line Current	Generator		
	Connection	Division of Power	Power-Factor		Connection	Current	Division of Power
9 a	T pri. L sec.	1/2 EI 1/2 EI	0.707	1.115 I 0.816 I 0.299 I	Y	1.115 I 0.816 I 0.299 I	15/24 EI 1/3 EI 1/24 EI
9 b	T pri. L sec.	1/2 EI 1/2 EI	0.707	1.115 I 0.816 I 0.299 I	Delta	0.644 I 0.471 I 0.172 I	15/24 EI 1/3 EI 1/24 EI
10 a	T pri. Single-phase Sec.	EI	0.778	1.155 I 0.578 I 0.578 I	Y	1.155 I 0.578 I 0.578 I	2/3 EI 1/6 EI 1/6 EI
10 b	T pri. Single-phase Sec.	EI	0.778	1.155 I 0.578 I 0.578 I	Delta	0.578 I 0.578 I 0	1/2 EI 1/2 EI zero

THE MIXED PRESSURE STEAM TURBINE WITH SPECIAL REFERENCE TO THE USE OF THE STEAM REGENERATOR

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In this article, which is a reprint of a paper presented at the recent Milwaukee convention of the Association of Iron and Steel Electrical Engineers, mixed pressure turbines are broadly divided into three types, which may be distinguished as follows: (1) Turbines designed to give highest efficiency on low pressure steam, but arranged to automatically admit high pressure steam to the low pressure header; (2) turbines designed primarily for low pressure steam, but supplied with nozzles for the admission of high pressure steam; and (3) turbines designed for continuous operation on mixed pressure, but capable of giving good efficiency on high pressure and of carrying some load on low pressure. In order to realize the best results from a given installation, that type should be used which by design is intended for the conditions of service at hand; what these conditions should be for the different types are briefly outlined by the author. The latter portion of the article is devoted to a discussion of the principles governing the action of the steam regenerator—storing heat during excessive supply of low pressure steam and regenerating steam when the supply falls short. Included in this section are some figures based on data secured from an actual installation, which show that the regenerator may effect a very considerable economy in many instances.—Editor.

The various makes of steam turbines now on the market may be broadly divided into two classes; viz.: Those in which the steam expands through nozzles, and is directed against buckets on wheels carried on a shaft (Fig. 1); and those in which the steam expands in both moving and stationary buckets. In the latter type the moving buckets are generally carried on a drum or cylinder. Machines similar to those shown in Fig. 1 are classed as impulse turbines. In some makes there is but one set of moving buckets to a stage.

As was natural, machines of both types were first developed to compete with reciprocating steam engines, and therefore were designed to operate under conditions already adopted in engine practice. For the driving of electric generators, the turbine had a great advantage because of its higher speed, this feature greatly reducing the cost of building; and as the industry has developed, it has been shown that a higher efficiency may be secured with the steam turbine than with the reciprocating engine under commercial operating conditions. This is the more apparent where the driven apparatus is well adapted to high speeds, as in the case of electric generators and centrifugal air compressors.

In the early days of its development it was apparent that the steam turbine could be easily modified to suit special cases, where the steam engine was not readily applicable. It is the intention of the writer to briefly describe one of the more important special uses to which the steam turbine has been put in commercial practice.

The Low Pressure Turbine

The low pressure turbine cannot properly be considered a special machine: it is essentially a turbine designed to operate on steam at a pressure much below that generated in the boilers. As generally understood, the term "low pressure turbine" means a turbine designed to operate on exhaust steam at about atmospheric pressure, and for this reason must discharge into a vacuum. In such a machine the number of rows of buckets does not have to be so great as in a high pressure turbine of the same speed and capacity, for the reason that the energy in the steam is very much less. On the other hand, however, in order to get the same power a great deal more steam must be used. The available energy in a pound of steam from atmospheric pressure to a vacuum of 28 in. is only about half that between 150 lb. pressure and the same vacuum; therefore, a low pressure turbine of a given capacity must have steam passages, nozzles, buckets, and condenser connection of approximately twice the size required for a high pressure turbine of the same output.

The first and most obvious application of the low pressure turbine is in connection with non-condensing engines, many installations of this character having proved most profitable investments. The increased capacity has been secured at a very low price per kilowatt, and the greater output has very materially reduced the cost of power.

The second and less apparent use for the low pressure turbine is in connection with engines already operating condensing. Of course in such installations, when combined with a turbine, the engine would have to exhaust against some pressure above the vacuum in the condenser, generally about 15 lb. absolute, or near that of the atmosphere.

The fundamental reason warranting such a radical installation is that the turbine can be built to give a higher efficiency than the engine over the very low pressure ranges; that is, it can extract a larger amount of power from steam expanded to the high vacuum attainable with modern condensing machinery.

In stations where the engines are in good repair and have sufficient capacity to drive their generators when running non-condensing, a large amount of additional power can be secured at low cost by the installation of a low pressure turbine. The largest installation of this nature is in the plant of the Interboro Rapid Transit Co., New York, where there are five low pressure turbines, one for each of five reciprocating engines.

In those cases where there is a sufficient supply of low pressure steam at all times, the straight low pressure turbine fulfills all requirements. In cases where the load carried by the low pressure turbine is in parallel with that on the engine and fluctuates with it, the turbine may be regarded as an additional low pressure cylinder.

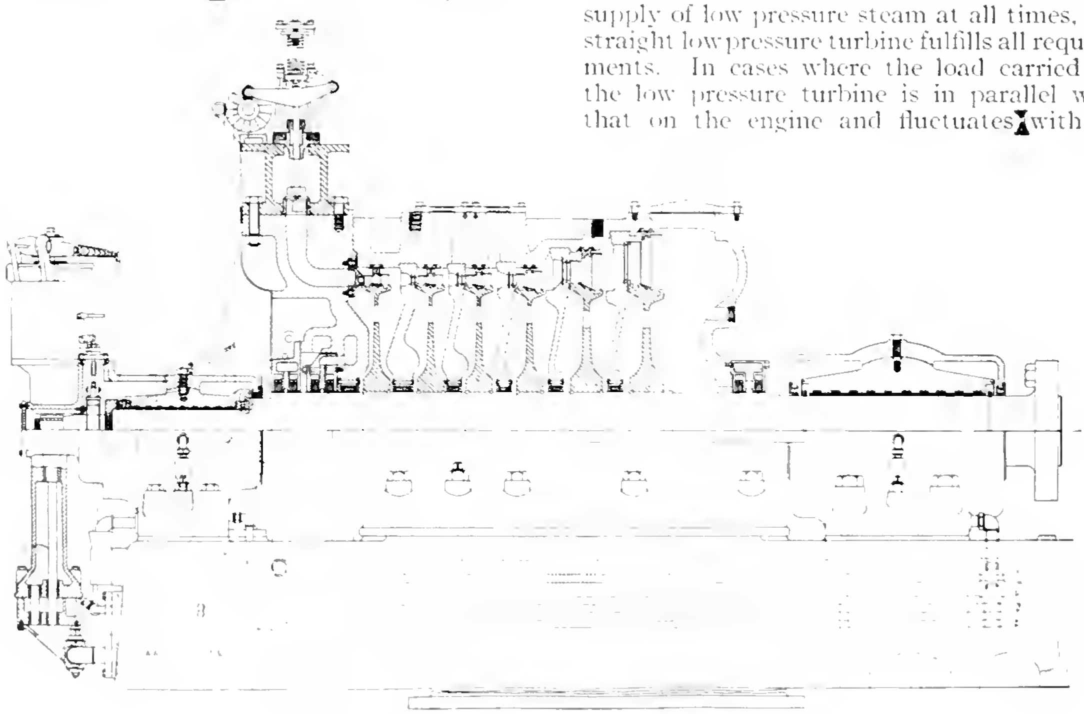


Fig. 1. A Six-Stage Impulse Turbine

There are many places where the supply of low pressure steam is not constant, or where it cannot be relied upon, and some places where it is desired to secure somewhat more electrical power than can be generated from low pressure steam alone. The simplest method of securing the required power is to admit high pressure steam to the low pressure pipe at times when the supply of low pressure steam is insufficient. This can be accomplished automatically, either by a reducing valve, set to maintain a fixed pressure in the low pressure header, or by providing a special valve, operated by the governor. A very simple arrangement is shown in Fig. 2. The pressure-operated reducing valve has one inherent defect; viz., it is extremely difficult to maintain a valve that will work positively, maintain the required pressure, and shut off tight when there is sufficient low pressure steam. Any steam that passes at such time is lost.

Straight low pressure turbines are best suited for installations where there will be an adequate supply of low pressure steam at all times. Arrangements can be made so that high pressure steam may be admitted to the low pressure header, should the supply be interrupted by accident to the engine from which the low pressure steam is taken. The straight low pressure turbine is the simplest, and will give the best efficiency.

The Mixed Pressure Turbine

There are many instances where the amount of electrical power required is in excess of that which can be generated by

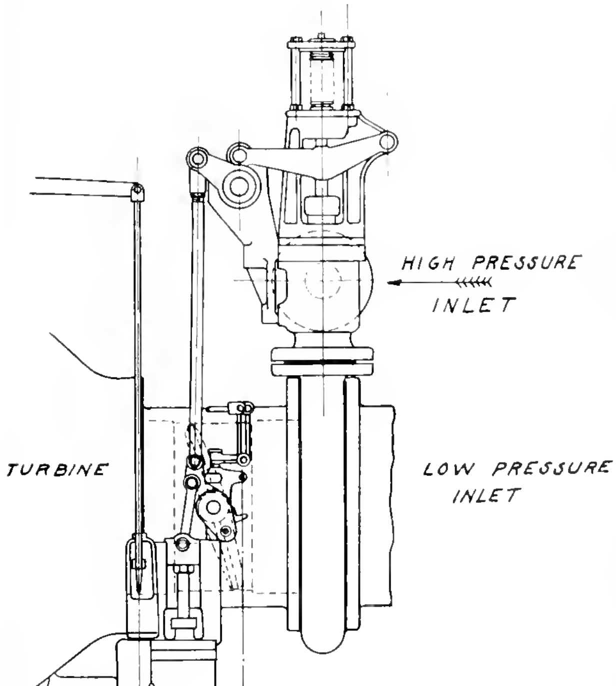


Fig. 2. Governor Operated Reducing Valve for Automatically Admitting High Pressure Steam in a Low Pressure Header

the continuous supply of low pressure steam. These have called for a special machine designed to operate from two separate sources of steam. Machines of this type have been given the name "mixed pressure," and have been developed in several forms. To get the best results from a given installation, it is essential that the machine be of the form intended for the conditions under which it is to operate. The various forms may be divided into three general classes:

(1) Turbines designed to give the best economy on low pressure steam and which are equipped with a special valve (Fig. 2) for admitting high pressure steam to the low pressure header automatically. This machine will not carry any load non-condensing, and will be very inefficient on high pressure steam. It may be used where the condensing facilities are very reliable, and when high pressure may be considered an emergency condition.

(2) Turbines designed to give the best economy when operated low pressure, and arranged to admit high pressure steam through separate nozzles (Fig. 3). This machine will give fairly good efficiency on high pressure steam, will carry some load non-condensing, and some overload mixed pressure. It will carry its full rated load mixed pressure when there is insufficient low pressure steam, or should the vacuum drop below that for which it was designed. This class should be used where it is intended to operate a large proportion of the time on low pressure, or in installations where the boilers will blow when the engine is shut down, or where there is liability of the vacuum occasionally dropping off. These machines will continue to use all the low pressure steam available when operating mixed pressure.

(3) Turbines designed to give good efficiency at high pressure, and also arranged to carry load on low pressure steam (Fig. 4.) Machines of this class should be used when it is intended to operate continuously, or nearly so, on mixed pressure, and where there is a limited amount of low pressure steam which would otherwise go to waste. In this machine the admission of high pressure steam will decrease the quantity of low pressure steam that will enter. This means that, should the machine have to operate mixed pressure on account of low vacuum, the amount of low pressure steam will be automatically reduced and a greater amount of high pressure steam will be required. Such machines are a compromise between a low pressure and a high pressure turbine. If designed to carry full load when operating either way, they cannot be made to give an efficiency as high as that obtainable on turbines primarily built for either high or low pressure operation. These machines can be designed to give a

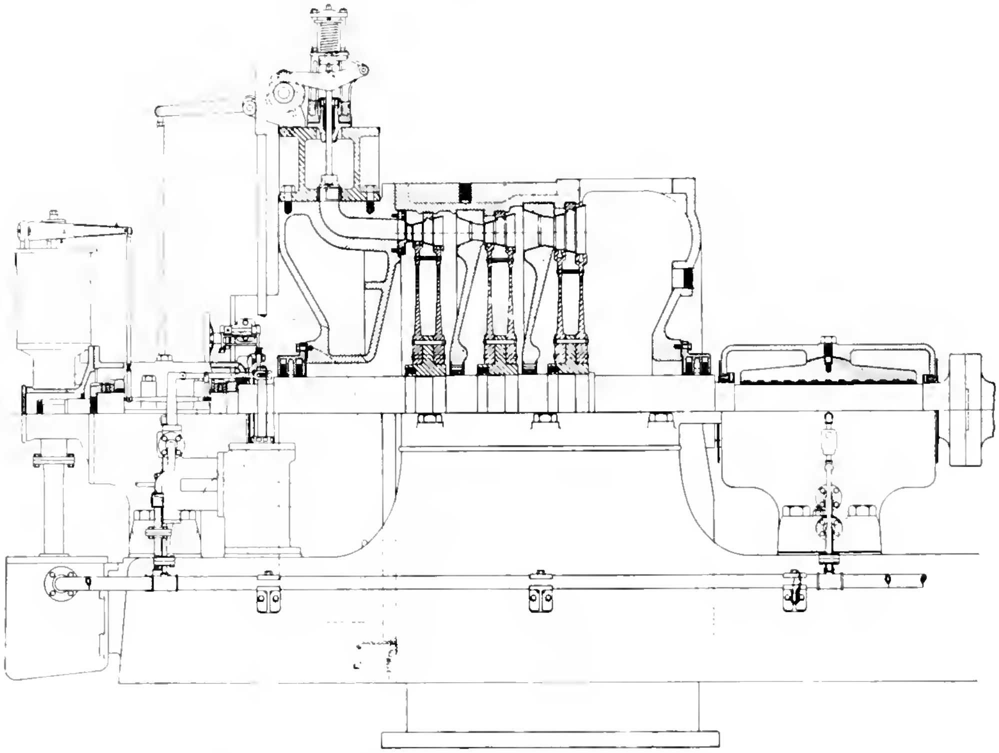


Fig. 3. Mixed Pressure Turbine Designed Primarily for Low Pressure but which will Operate with Fair Efficiency on High Pressure

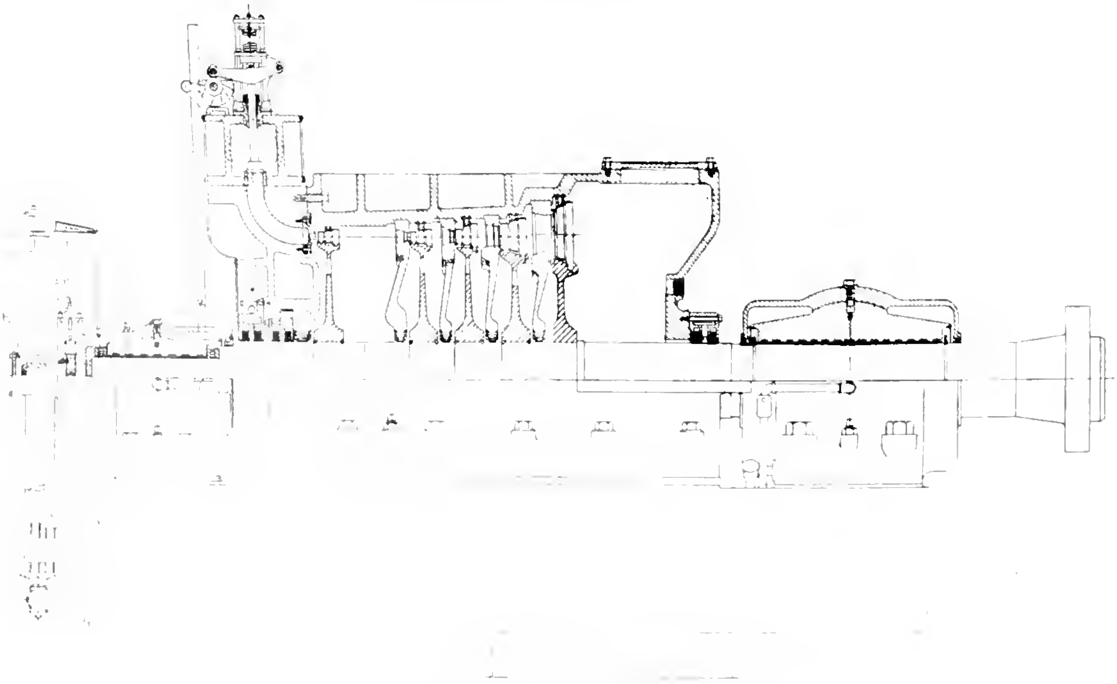


Fig. 4. Mixed Pressure Turbine A Compromise Between High and Low Pressure and can Operate Exclusively on Either

good efficiency and carry full load high pressure, or carry about half load low pressure at fair efficiency.

In the mixed pressure turbine, the speed governor will automatically open the low pressure valve with a decrease in speed, or a falling off in the supply of steam. By a special pressure actuated device, the low pressure valve may be made to close and the high pressure valves open automatically with decreasing supply of low pressure steam.

In nearly every low pressure, and in the majority of mixed pressure installations, the best operating conditions and highest efficiency are secured by allowing the speed governor to control the low pressure valve. This allows the vacuum to extend back to the engine supplying the steam during periods of operation when there is insufficient steam for the turbine.

In certain installations it is not feasible to operate in this manner for one or both of the following reasons: First, inability to maintain air-tight joints in the piping between the engine and turbine, or in the engine itself. (In this case the vacuum on the condenser would be affected by the indrawing of air.) Second, the back pressure on the engine at times being reduced below atmosphere, as in reversing rolling mill or hoisting engines. In installations of this nature, a valve can readily be installed in the low pressure pipe to automatically prevent the vacuum from extending back, thereby maintaining a pressure above atmosphere on the piping and engine. Fig. 5 shows a valve for this purpose. This valve has been given the name of "flow regulating valve."

When it is desired to maintain a fixed load on a mixed pressure turbine, with varying quantities of low pressure steam, this can be accomplished by a pressure actuated device arranged to automatically open high pressure valves with a decreasing quantity of low pressure steam. Fig 6 shows a simple arrangement which has been placed on several machines in commercial operation and has maintained a very steady load under extreme conditions.

The Steam Regenerator

The idea of storing heat is quite old. The action of the steam regenerator is based on the principle that the difference between the temperature of the steam available at a given time, and the temperature of the steam at a somewhat reduced pressure, may still be used to do work.

There are many different designs of steam regenerators, nearly all of which consist of a chamber containing a quantity of water, and so arranged that a large surface is exposed to the entering steam. Some time will be

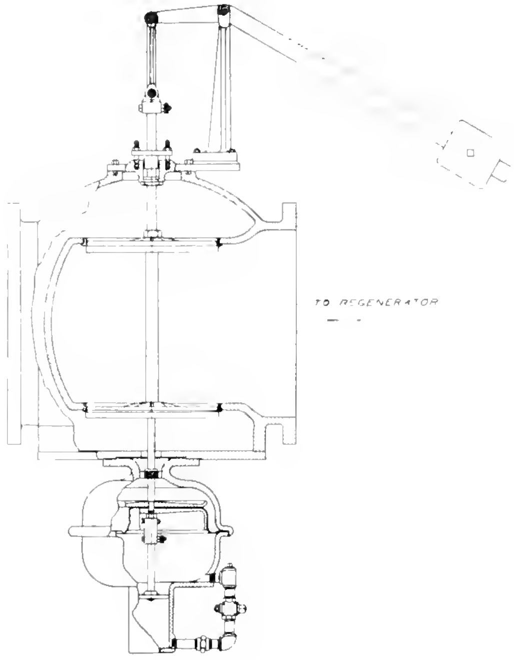


Fig. 5. Flow Regulating Valve

required to heat the water in the regenerator, and this time element must be taken into consideration in all cases. This means that where the supply of excess steam lasts for very short intervals it cannot be expected that the water will be heated up to the temperature corresponding to steam pressure.

A regenerator will generate steam only when the pressure in the chamber is lower than the steam pressure corresponding to the temperature of the water in the generator. For example, if the water has a temperature of 212 deg. F. corresponding to 14.7 lb. absolute pressure, as soon as the pressure in the regenerator is reduced below this, a part of the water will be given off as steam, taking heat from the mass of water until its temperature is reduced to the steam temperature at lower pressure.

Regenerator Capacity

The capacity of a regenerator, or the amount of steam which it will give, depends on the quantity of water and also on the temperature range through which it may be operated. This means that a given quantity of steam may be stored and regained in a regenerator of smaller size and therefore of lower cost if the temperature range can be increased. In order to increase the temperature range, it is necessary to either raise the upper pressure limit or lower the low pressure limit, or both. The following table gives approximately the theoretical amount of steam that can be regenerated.

This means that 1000 lb. of water at 19 lb. absolute and 225 deg. F. will give off about 62 lb. of steam if the pressure is reduced to 5 lb. For intermediate ranges take the sum of the amounts for each pound drop. For example, 997 lb. of water at 18 lb. absolute and 22.4 deg. F. will regenerate 13.2 lb. of steam if the pressure is reduced to 14 lb. For approximate results, to find the number of pounds of water to regenerate 1 lb. of steam, divide the average latent heat by the temperature drop. The curves of Fig. 7 make it possible to estimate very quickly the size of regenerator necessary under any given conditions. Example: If the water can be heated to the temperature corresponding to 17 lb. absolute, and if steam may be extracted down to 10 lb. absolute, follow the horizontal line 17 until it intersects the 10 lb. final pres-

Steam Pressure Pounds Absolute	Steam Temp. F°	Drop ° F	Latent Heat B.t.u.	Lb. Water	Lb. Regenerated
19	225.2		956.3		
		2.8		1000.0	2.9
18	222.4		958.3		
		3.0		997.1	3.1
17	219.4		960.5		
		3.1		994.0	3.2
16	216.3		962.7		
		3.3		990.8	3.4
15	213.0		956.0		
		3.4		987.4	3.5
14	209.6		967.4		
		3.7		983.9	3.7
13	205.9		970.0		
		3.9		980.2	3.9
12	202.0		972.8		
		4.2		976.3	4.2
11	197.8		975.8		
		4.6		972.1	4.6
10	193.2		979.0		
		4.9		969.5	4.9
9	188.3		982.4		
		5.4		962.6	5.2
8	182.9		986.2		
		6.0		957.4	5.8
7	176.9		990.5		
		6.8		951.6	6.5
6	170.1		995.2		
		7.8		945.1	7.4
5	162.3		1000.7		
			Total		62.3

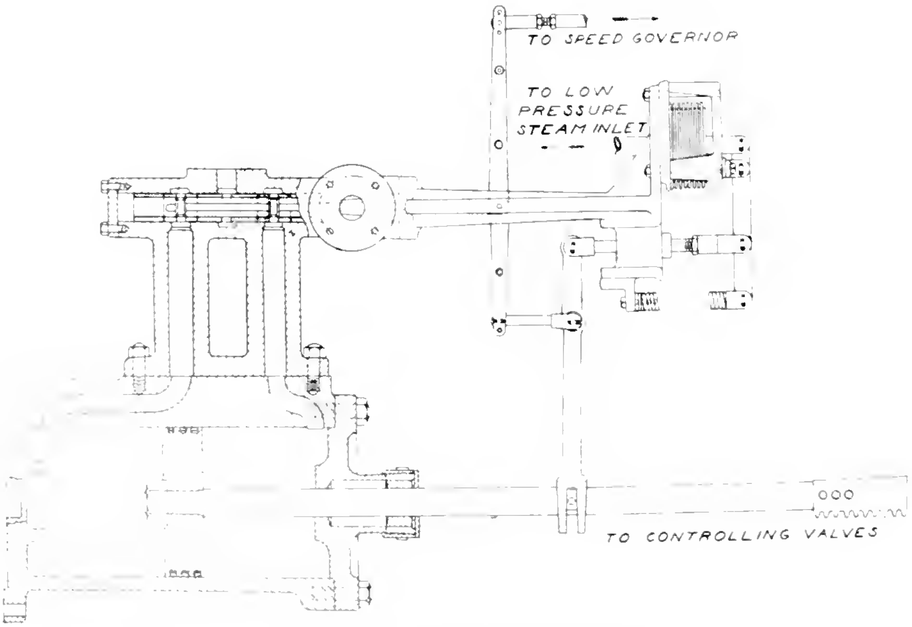


Fig. 6. Device for Automatically Opening and Closing High Pressure Valves with Variations in Supply of Low Pressure Steam

sure line, and directly below this find that 38 lb. of water are required for each pound of steam regenerated. It must be remembered that with the same valve opening, a steam turbine will take less steam and therefore carry less load as the pressure drops below that for which it is designed.

A regenerator is necessary in order to secure the best economy in any low or mixed pressure turbine installations where the supply of low pressure steam is intermittent, and where, during periods of supply, there will be more steam than is required to carry the load on the turbine. By intermittent is meant frequently interrupted, similar to the exhaust from a reversing rolling mill or hoisting engine.

Limitations of Pressure Range

From the preceding table it is obvious that the greater the pressure range, the smaller the regenerator required to regenerate a given weight of steam. The upper pressure is fixed by the back pressure which may be put on the engine supplying the low pressure steam. In order to have the low pressure limit below atmospheric pressure, it is necessary that the regenerator and piping be tight so that air cannot be drawn in.

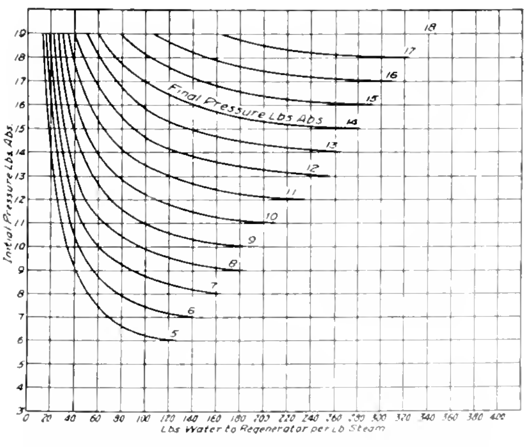


Fig. 7. Curves Showing Pounds of Water in Regenerator per Pound of Steam Generated, when Working Between Various Initial and Final Pressures

Flow Regulating Valve

In order that the regenerator may have the benefits of a wide pressure range, it is necessary that the flow regulating valve be installed between the engine and the regenerator. It will open automatically only when the engine is in operation. Should this valve be placed between the regenerator and the turbine, it will effectually prevent vacuum from extending back to the regenerator, thereby very greatly decreasing its regenerating capacity.

The same argument applies against the method of control referred to in the second paragraph on page 95, in which the low pressure valve is made to close automatically with decreasing supply of low pressure steam.

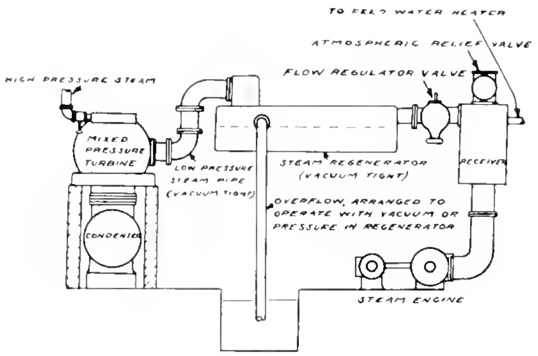


Fig. 8. Diagram Showing Flow Regulator Valve Installed Between Engine and Regenerator

Experience in commercial practice has shown that with few exceptions the flow regulating valve is necessary only in installations where the supply of low pressure steam is intermittent or very fluctuating. For these reasons this valve should be independent of the turbine, so that it may be installed between the engine and the regenerator. When the valve is so installed, the regenerator as well as the piping between this valve and the turbine must be designed and installed so as to operate under vacuum. An additional reason for installing the flow regulator valve between the engine and regenerator is to prevent the regenerator from filling with air during periods when the supply of low pressure steam is interrupted.

Fig. 8 shows diagrammatically the arrangement described. The overflow from the regenerator must be so arranged that it will prevent the water rising above a fixed point under any condition of operation. This can be accomplished either by a barometric column, as indicated in the diagram, or, if this is impracticable, by a vacuum trap. When the engine is shut down for some time, the piping between it and the flow regulating valve will fill with air, and it is undesirable that this air be driven into the turbine as it would affect the vacuum. A very excellent arrangement, therefore, is to provide an opening in the receiver, which can be piped

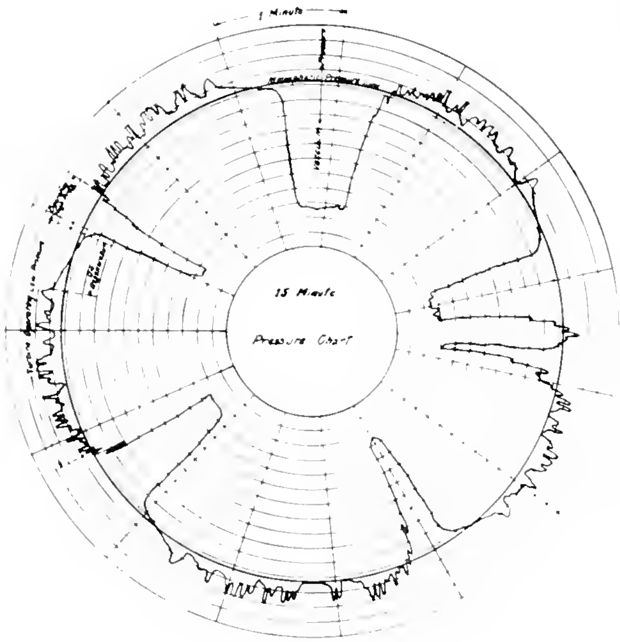


Fig. 9 Chart Showing Low Pressure Steam Supply

to a feed water heater; this connection carrying off most, if not all of the air, and conserving the heat in the steam. Arrangements similar to this are operating commercially.

An article in London *Engineering*, March 22, 1912, on "Waste-Heat Accumulators," cites several installations where power has been secured at a very low rate by the use of low pressure turbines. It is also stated that the accumulators or regenerators may be made to work satisfactorily if the pressure falls below atmosphere, and that in such cases the flow regulating valve would have to be placed between the engine and the regenerator.

A Mixed Pressure Turbine Installation

A description of a specific installation may be of interest in showing under what severe conditions a mixed pressure turbine will operate successfully. Figs. 9 and 10 show charts of the low pressure steam supply. From Fig. 9, it will be seen that the supply was interrupted at the rate of twenty-four times an hour, and during this time the machine would automatically change over and carry the same load on high pressure steam. Fig. 10 shows how the regenerator would carry the load for several minutes after it had been in operation a sufficient time for the water to become thoroughly heated. According to the chart, the turbine carried its load, approximately 1500 kw., for about 1.8 minutes on low pressure steam furnished by the regenerator. From the chart, the pressure drop on the regenerator was 2 lb. The regenerator in this installation holds 240,000 lb. of water. From the curve of Fig. 7, for a range of pressure between 17 and 15 lb. absolute, 152 lb. of water will generate 1 lb. of steam; therefore $\frac{240,000}{152} =$ 1580 lb. of steam regenerated. Under operating vacuum conditions, the turbine would take approximately 36 lb. per kilowatt-hour = 0.6 per kilowatt-minute; 0.6×1500 kw. = 900 lb. per min. $\frac{1580}{900} = 1.75$ minutes out of the 15 minutes, or 11.6 per cent of the time of low pressure operation.

Records for one month showed that the regenerator carried the turbine for 11.5 per cent of the time of low pressure operation; also, that the turbine operated 39 per cent of the time high pressure and 61 per cent of the time low pressure. Therefore the regenerator carried the load for 7 per cent of the time of operation. After making allowances for power used by auxiliaries, etc., there was a net output for the month, generated by low pressure steam, of 298,500 kw-hrs. $298,500 \times 0.3$ cents per kw-hr. = $895.50 per month. Allowing for labor and supplies, a profit of approximately $758.00, or $9096 per year should be credited to the investment.

In estimating the cost of a low pressure turbine installation, due allowance must be made for the cost of necessary boilers, turbine condensers, etc., to generate the same power on high pressure steam. That is, the net value of power generated on low pressure steam is the interest on the difference between the cost of a low and a complete high pressure installation.

During a considerable portion of the periods of low pressure operation there was an excess of low pressure steam, and therefore an increase in the regenerator capacity would have increased the total power generated by low pressure steam. The least expensive method of securing the extra capacity is to arrange the regenerators so that they will continue to give off steam at pressures below atmosphere. The following calculations will show approximately the extra power that should be regenerated with the arrangement shown in Fig. 8.

Between 15 and 13 lb. average load, 1500 kw. at 40 lb. per kw-hr.
Between 13 and 10 lb. average load, 1200 kw. at 42 lb. per kw-hr.
Between 10 and 8 lb. average load, 830 kw. at 48 lb per kw-hr.

Regenerators contain 240,000 lb. water.

For a pressure range of 15 to 13 lb. abs., 135 lb. water will regenerate 1 lb. steam.

$\frac{240,000}{135} = 1775$ lb. steam regenerated.

40 lb. per kw-hr. = 0.66 lb. per kw-min.
0.66 × 1500 kw. = 1000 lb. per min.

$\frac{1775}{1000} = 1.72$ min.

1.72 × 1500 = 2580 kw-min.

Similarly, between 13 and 10 lb. absolute, there would be regenerated 4400 kw-min.; and between 10 and 8 lb. absolute, there would be generated 3090 kw-min.

Total power regenerated at one time = 10,070 kw-min.

Time required for pressure to drop = 3.+ minutes.

Assume that twice per hour the engine is down for over three minutes, after the pressure in the regenerators has dropped to atmosphere and after the engine has been running for a sufficient length of time to heat the water to 213 deg. F. Then there will be developed from steam below atmospheric pressure 2 × 10,070 = 20,140 kw-min. per hr., or 336 kw-hrs. per hour.

In one month of 550 hrs. operation, there would be developed 185,000 kw-hr. per month. Making allowances for power used for auxiliaries, etc. (approximately 25 per cent.), there remains 138,500 kw-hrs. net per month. Allowing 0.3 cents per kw-hr. for the power less 0.058 cents per kw-hr. for cost of labor, there remains 0.242 cents per kw-hr net, 138,500 × 0.242 = $335.00 per month, or $4000 per year additional, which might be credited to the installation.

These figures, of course, are approximate, and would vary with the character of the operation. However, it is readily conceivable that, under certain conditions of operation, even greater credit would have to be given

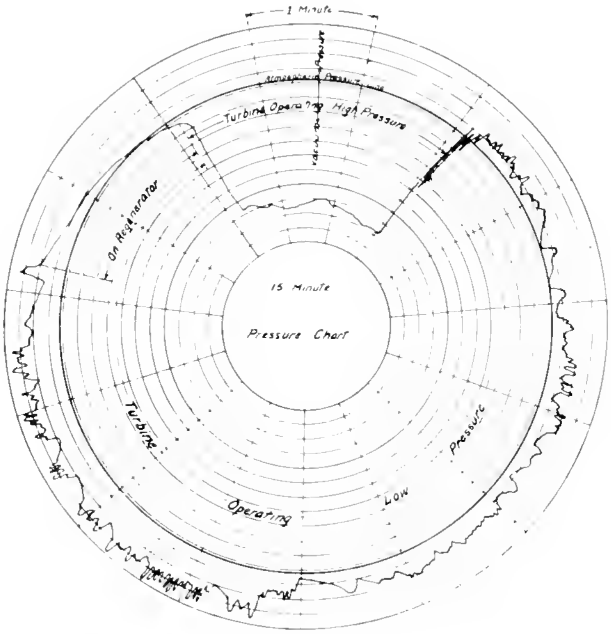


Fig. 10. Chart Showing Performance of Regenerator

the turbine and regenerator and that only at infrequent intervals would the turbine carry full load on high pressure steam.

Conclusion

Local conditions must all be carefully investigated and thoroughly understood, before recommendations can be made as to the type of machine best suited for any particular case. There are undoubtedly many places where the installation of a mixed pressure turbine would give the best returns on the money invested for increased generating capacity, whether this be considered on the basis of a lower cost per kilowatt-hour generated, or the increased output as interest on the money invested.

AN APPROXIMATE METHOD OF DETERMINING ELECTRICAL CONSTANTS OF AIR COILS

By Hugh A. Brown

Graduate Student, University of Illinois

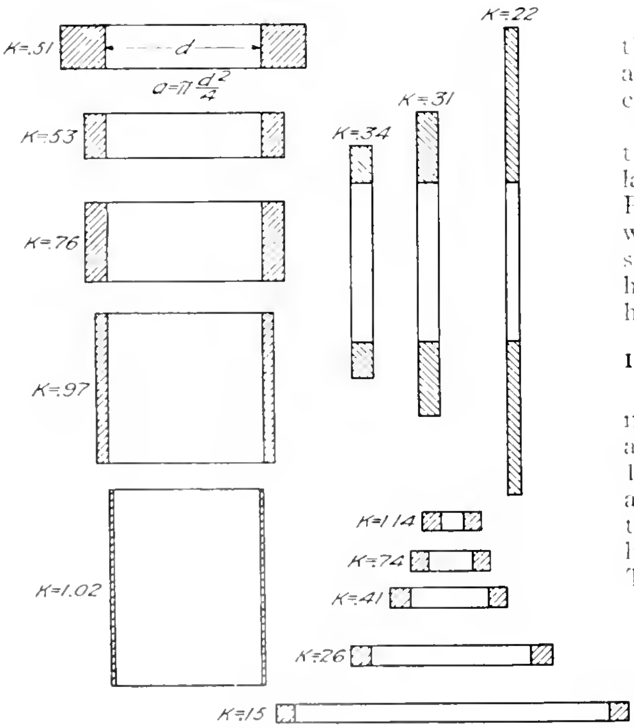
The accurate determination of the inductance of coils requires very elaborate calculations and unfortunately but few engineers can use even the simplified expressions. In this monograph the author has evolved a method employing only simple diagrams and formulæ by means of which the constants of practically any coil can be obtained with a fair degree of accuracy and little calculation.—Editor.

It is well known that the relation between density and magnetomotive force in a long air coil is expressed by the following equation:

$$mmf. = amp.\text{-}turns = NI = \frac{Bl}{0.4\pi} = 0.8\,Bl$$

$$= 0.8\,\frac{\phi}{a}\,l \qquad (1)$$

where l is the axial length and a the cross section in cm. and cm² respectively of the coil, B the density, and ϕ the total flux. For other coil shapes a constant k differing from 0.8 can be introduced, and this article



gives the value of this constant so that for any coil shape the above equation may be written:

$$Ni = kBl \qquad (2)$$

It is proven below that this constant k or rather its reciprocal $K = \frac{1}{k}$ divided by 10^8 also enters in the inductance formula.

From (1) we get $\phi = \frac{KaNi}{l}$;

but the inductance L is $\frac{N\phi}{10^8 i}$,

thus $L = \frac{KaN^2}{10^8 l}$ = henrys.

The constant K has been determined under the arbitrary assumption that a is the inside area of the coil even though it is evident that considerable flux exists among the wires.

The value of the constant as shown in the accompanying diagram has been calculated from a universal formula derived by Professor Morgan Brooks, which is accurate within a fraction of one per cent. The constant is obviously always the same no matter how large or how small the coil may be, or how many turns of wire it may have.

Illustration of the Use of the Diagrams

Determine for instance the relation between mmf. and density and the inductance of a coil of wire having 1000 turns and carrying 10 amperes, assuming that the proportions are similar to those of the second coil illustrated in the diagram. Let the inside radius be 15 cm. and the axial length of the coil 7 cm. Then $K = 0.53$

$$B = \frac{KAT}{l} = \frac{0.53 \times 10000}{7} = 757 \text{ lines per sq. cm.}$$

and

$$L = \frac{KaN^2}{10^8 l} = \frac{0.53 \times 706.0 \times 10^6}{10^8 \times 7} = 0.534 \text{ henrys}$$

The accuracy of the results depends upon how closely the proportions of the coil agree with those of the diagram.

THE CONSTRUCTION, INSTALLATION AND MAINTENANCE OF ALUMINUM ARRESTERS AND THEIR AUXILIARIES

PART II

By R. T. Wagner

Supply Department, General Electric Company

Part I of this paper (January, 1913) dealt with the principles and characteristics of the aluminum arrester, and described its construction, the functions of the horn gap, the use of charging resistances, the difference between arresters for grounded neutral and non-grounded neutral systems, and the transfer device. Part II takes up the question of the location of arresters for indoor and outdoor use; and deals in a practical way with installing, wiring and connecting up. A section on placing arresters in service shows how to assemble and fill the cones, make the initial tests and preliminary charge, adjust the horn gaps, and connect the apparatus to the line; and concludes with notes on daily charging, inspection, repairs, reconstruction and renewal of electrolyte. Part III will deal with some of the auxiliaries, such as charging current indicator, discharge recorder, and choke coils.—Editor.

LOCATION, INSTALLATION AND VOLTAGE LIMITS OF ARRESTERS

Indoor Arresters

The location and arrangement of an aluminum lightning arrester installation depends upon the station layout. In general, the arrester should be installed as near as possible to the apparatus or station to be protected. The ideal arrangement would be to have the tanks and horn gaps installed as a complete unit just inside the station. For lower voltage equipments this is feasible, as the arcing at the gaps is not severe even in abnormal cases. Above 27,000 volts, this practice is usually questionable and it is recommended that the horn gaps be installed outside the building, with leads tapping the line near its entrance to the station. The tanks and transfer device should be installed inside of the station in a suitable compartment. This requires the use of either wall or roof entrance bushings for the connecting wires. The object of placing the horn gaps outside of the station is to isolate any arc from the station apparatus.

The horn gaps for arresters for 27,000 volts and above are supported on a 2 in. pipe framework which is so designed as to permit mounting on either wooden or steel towers, or if desirable on the roof of the station or on suitable brackets on the outside wall of the station. They should be so located that the pipe and lever, by which they are operated can be brought down in a place convenient for the operator and if possible where he can observe the arcing at the horns during discharge. It is also advisable to have the transfer device and horn gaps operated from the same place so as to reduce the work of charging to a minimum. The horn gaps for lower voltages are sent complete with pipe supports for mounting inside the station.

Wherever horn gaps are mounted inside the building sufficient clearance should be allowed over them. The exact distance to be allowed depends upon the voltage and the nature of the material or apparatus under which the horns are installed. If there are cables, wires, busses, or any material which would be damaged by fire, considerable distance should be allowed. On the other hand, if there are only concrete and iron beams of the floor or roof, a much smaller clearance is permissible. Normally there is no appreciable arc at the gaps, but in abnormal cases where the film has been allowed to get out of order, the arc might be of considerable size. Where there are no busses or inflammable apparatus, the following are the minimum clearances from the tops of horns to be allowed:

Up to 16,100 volts, 3 ft.
16,101 to 37,900 volts, 4 ft.
37,901 to 70,000 volts, 6 ft.

Above 70,000 volts, the horn gaps should never be placed indoors.

In accordance with the above, standard equipments of 27,000 and below are designed as complete units to be installed inside the station, while for those above 27,000 volts the horn gaps should preferably be installed outside the station and the tanks inside. Exception to this rule can be made where there is sufficient space in the station over the gaps. Figs. 7*, 14, 15 and 16 illustrate methods of installing arresters.

Outdoor Arresters

The objection to installing arrester tanks out of doors comes from the increased liability of freezing the electrolyte in cold weather and the abnormal film dissolution when exposed to the sun on hot days. Even though the electrolyte is not itself injured by

* See Part I of this article in General Electric Review, January, 1913.

freezing, the internal resistance of the arrester is considerably increased and hence its discharge rate is materially lowered. Where warm climatic conditions prevail the arrester should be in as cool a place as possible and protected from the direct rays of the sun. A high initial temperature will reduce the available heat storage capacity of an arrester and its ability to care for long continuous discharges. A high operating temperature also increases the rate of dissolution of the films which would necessitate more frequent charging. In some cases it may be found advisable to charge two or more times a day. When operating under conditions of high temperature any failure to periodically charge the arrester increases the liability of damage from a heavy charging current.

Only arresters of the outdoor type, with special bushings and covers, should be installed out of doors. Care must be taken to see that the bushings and covers are correctly assembled to be watertight. The arresters may be mounted either on a platform between poles or on a platform near the ground and surrounded by a fence. The position of the arresters should preferably be such that their operation can be observed by the station attendant. While installing arresters out of doors, care must be taken not to let the wooden and fiber parts of the cone stack become wet in case of rain and to keep dust from the cones and electrolyte.

Connections and Wiring

The wiring connections of lightning arresters are an important consideration. The discharge circuit should contain minimum impedance and hence must furnish the shortest and most direct path from line to ground. The most severe disturbances which an arrester is called upon to handle are of high frequencies and it is, therefore, imperative to eliminate all unnecessary inductance. The features favorable for low inductance are short length of conductor, large radius bends and large surface of conductor. For wiring high voltage arresters the use of copper tubing is strongly recommended. Such copper tubing has the advantage over either copper strip or solid conductors in that it is easily supported, requires fewer insulators and is, therefore, cheaper to install. Copper tubing can be designed so that when the wiring is complete all joints are flush, all sharp bends are eliminated and there are no points where corona or brush discharge may take place.

Ground Connections*

From arrester to ground it is sometimes more convenient to use copper strip than tubing. Copper strip, say 1.5 in. by 0.03 in. can be fastened to the station wall leading directly down to ground.

In all lightning arrester installations it is of the utmost importance to make proper ground connections, since many lightning arrester troubles can be traced to bad grounds. It has been customary to ground a lightning arrester by means of a large metal plate buried in a bed of charcoal at a depth of six or eight feet in the earth. A more satisfactory method of making a ground is to drive a number of one-inch iron pipes six or eight feet into the earth about the station, connecting all these pipes together by means of a copper wire or, preferably, by a thin copper strip. A quantity of salt should be placed around each pipe under the surface of the earth and the ground thoroughly moistened with water. It is advisable to connect these earth pipes to the iron frame work of the station, and also to any water mains, metal flumes, or trolley rails that are available. For the usual size station the following recommendation is made: place

TABLE 1

Rated Voltage	Operating Voltage	
	Minimum	Maximum
2500	1000	2550
3300	2551	2600
4600	3601	4680
6600	4681	7250
10000	7251	11900
12500	11901	14000
15000	14001	16100
17500	16101	18700
20000	18701	21800
25000	21801	27000
30000	27001	32200
35000	32201	37900
40000	37901	43000
45000	43001	48250
50000	48251	53500
60000	53501	64250
70000	64251	75000
90000	75001	95000
110000	95001	115000
140000	115001	145000

* The general subject of the ground connection in lightning protective systems has already been treated at considerable length in the GENERAL ELECTRIC REVIEW by Mr. E. E. F. Creighton (Jan. and Feb., 1912).

three earth pipes equally spaced near each outside wall, making twelve altogether, and place three extra pipes spaced about six feet apart at a point nearest the arrester.

Where plates are placed in streams of running water, they should be buried in the mud along the bank in preference to laying them in the stream. Streams with rocky bottoms are to be avoided. Whenever plates are placed at any distance from the arrester it is necessary also to drive a pipe in the earth directly beneath the arrester, thus making the ground connections as short as possible. Earth plates at a distance can not be depended upon. Long ground wires in a station can not be depended upon unless a lead is carried to the multiple earth pipes described above. As it is advisable to occasionally examine the underground connections to see that they are in proper condition, it is well to keep on file exact plans of the location of ground plates, ground wires and pipes, with a brief description, so that the data may be readily referred to. From time to time the resistance of these ground connections should be measured to determine their condition. This is very easily done when pipe grounds are installed, as the resistance of one pipe can be accurately determined when three or more pipes are used. The resistance of a single pipe ground in good conditions has an average value of about 15 ohms. A simple and satisfactory method of keeping account of the condition of the earth connections is to divide the earth pipes into two groups, and connect each group to the 110 volt lighting circuit with an ammeter in series. If there is a flow of about 20 amperes the conditions are satisfactory, provided the earth pipes are properly distributed around the station.

Voltage Ratings and Limits

Table 1 on page 102 gives the voltage ratings of various arresters, together with the minimum and maximum voltages at which they may be operated. Special note should be made of the maximum limits, and in no case should arresters be operated at higher values. A mistake is often made by selecting an arrester of lower voltage rating for a substation than for the generating station, allowance being made for line drop. Disastrous results may follow such an error, as it is possible to have the generating station voltage thrown on the substation arresters when the load is light or is suddenly cut off at the substation. For this reason all of the arresters on a system should be capable of operating on the generating station voltage.

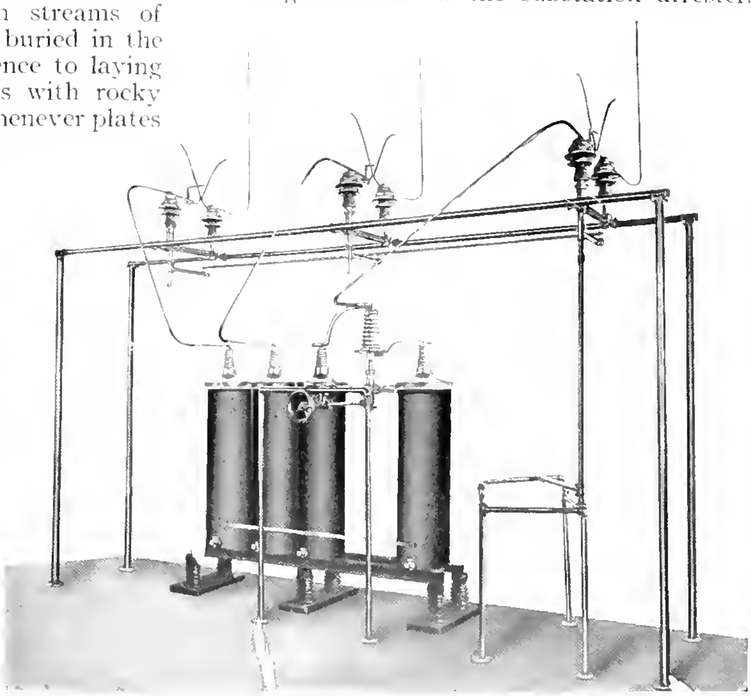


Fig. 14. Lightning Arrester for 35,000 Volt Three-Phase Non-Grounded Neutral Circuits with Horn Gaps Mounted Indoors

PLACING ARRESTERS IN SERVICE

Assembling and Filling Cones

The stacks of cones are shipped assembled in the iron tanks. Just before they are installed they should be carefully unpacked and thoroughly blown out with dry air to remove any dust which may have collected during packing and shipment. If it should be necessary to disassemble the cones, care should be taken not to touch the film surface with the hands. The cones may be held by the rim, however, as this part of the cone is never in contact with the electrolyte.

The cones should be filled with electrolyte as hereafter described but this should not be done until everything is in readiness to put the arresters into service on the line. Not more than a few hours should be allowed to elapse between the time of filling in the electrolyte and putting the arrester into service; otherwise the electrolyte, standing in the cells without voltage, will dissolve the film somewhat and make it necessary to do considerable "forming up" when the arrester is finally put into service.

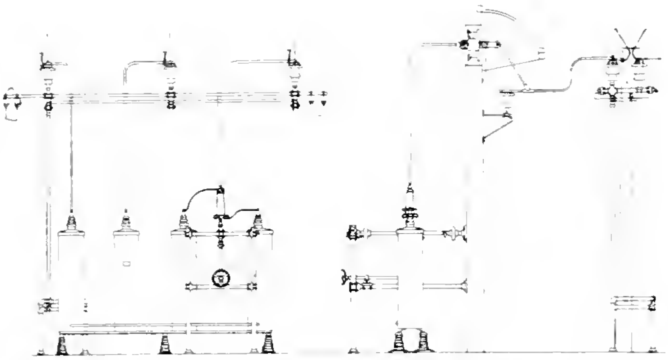


Fig. 15. Lightning Arrester Installation for 45,000 Volt Three-Phase Non-Grounded Neutral System, Showing Horn Gaps on Wooden Poles, Wall Entrances and Tanks Inside of Station

Great care should be exercised to keep the electrolyte and cones clean and free from dust. Impurities even in small quantities may cause an extra current to flow during charging which would result in the wearing out of the cones. A considerable amount of impurity will cause such a current as to prevent the arrester from operating properly. Impure electrolyte usually shows itself gradually and produces a larger arc at the horns each day when the cells are charged.

Use only glass, earthenware, rubber or aluminum vessels in handling the electrolyte. Use such precautions as wiping the mouth of the carboy when it is opened, washing out the rubber tubes of the cone filler with water, and covering the cones if it is necessary to leave them standing outside of the tanks. Keep the tanks covered.

The cells are to be only partially filled with electrolyte. One-fourth or three-eighths of a pint, depending on the spacing between cones, should be placed in each cell (see Fig. 17). The carboy should be raised about two feet higher than the stack of cones, so that the electrolyte will siphon rapidly. A piece of glass tubing inserted in the end of the rubber tube leading into the carboy will prevent this tube from floating on the electrolyte. The pinch cock on the tube from the filler to the cones must be near the filler, otherwise the amount of electrolyte measured will not be correct.

It is important that each cell contain the same amount of electrolyte so as to have equal distribution of voltage over the arrester. Great care should be taken to see that no cell is omitted or any filled twice. Some good system of routine should be followed to guard against this danger. Do not wet any of the wooden or fiber parts which support the cones. The filling tube should be always inserted halfway between the supporting rods and pushed well in.

Testing and Preliminary Charging

After the entire stack of cones has been filled and before placing it in the tank, it is desirable to test out each cell to see if it has been properly filled and to give it a preliminary "charge." This should be done by connecting 250 to 300 volts alternating current to each cell successively with a bank of lamps in series. A sufficient number of lamps should be used to limit the current to 2 amperes when the aluminum cell is not in circuit. When put across the cell, the lamps may first burn bright, and if so should be allowed to dim down. In doing this care should be taken not to allow the electrolyte to get warm. If the lamps do not burn brightly

Fig. 16. Lightning Arresters on 44,000 Volt Three-Phase Non-Grounded Neutral Circuits

at first it is an indication either that the film is already formed or that the cell has not been filled with electrolyte, which can easily be determined by noting if there is a spark when making contact.

If 250 volts is not available 500 volts may be used, testing two cells in series. If only 125 volts is available an indication of whether or not the cells are filled may be had, but charging is not fully accomplished and special precautions must be taken when first connecting the arrester to the line as explained later. This testing and charging usually takes about ten seconds per cell.

In case direct current only is available the testing operation must be repeated so that the potential is applied in both directions to each cell.

When the stacks of cones have been filled and tested they should be lowered into the tanks, being sure of good contact between the base and tank. The tanks are then filled with oil to within three inches of the top. Care must be taken to prevent the oil from washing out the electrolyte from between the cones. The electrolyte is only slightly heavier than the oil and a stream of oil hitting the side of the stack will wash the electrolyte out. Oil may be either pumped or siphoned in through a pipe running to the bottom of the tank, or may be poured gently into the top cone. Oil from standard iron barrels contains iron scale, which must be removed; and it is therefore necessary to filter the oil by passing it through thin muslin or doubled cheese-cloth.

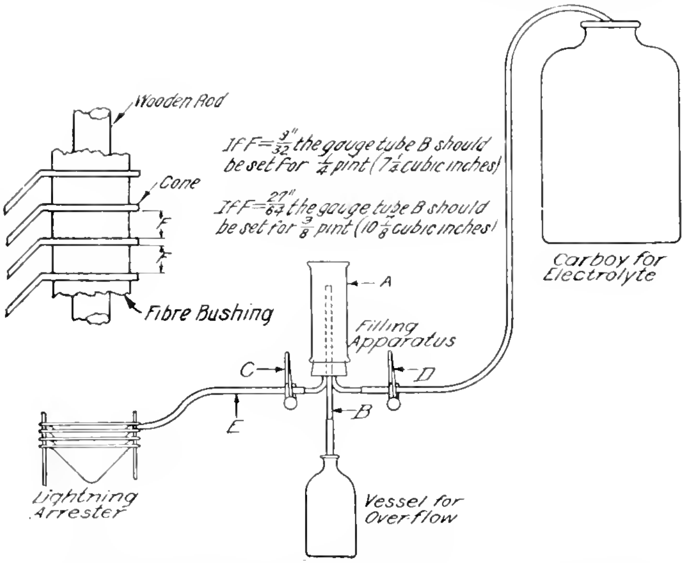
Adjusting Horn Gaps

The setting of the horn gaps of aluminum arresters is affected by several operating conditions as follows:

First, it is influenced by the wave form. It is always the peak value and not the effective value of potential that starts the discharge. Consequently, if the generator wave has a sharp peak the gap will spark over for a low effective value of potential; and, *vice versa*, if a wave shape is flat it will require a high effective voltage to start a spark across the gap.

Second, the spark potential is less for stations located in high altitu .es; and the horn gaps, therefore, require higher settings.

Third, the spark potential is affected by the local conditions of the circuit; for example, the nearness of the horns to other metallic



Electrolyte should be siphoned from carboy into tube "A" until its surface has risen to the top of tube "B." Any overflow may be caught from bottom of tube "B" in a glass vessel and poured back into carboy.

Electrolyte should be released from tube "A" into cones by pinch cock "C." It is extremely important that the same quantity of electrolyte be put into each cone.

Hence care should be taken to:

"a" Have pinchcock "C" closed while "D" is open.

"b" Have electrolyte in "A" as high as top of tube "B" and no higher before opening "C."

"c" Move tube "E" systematically, i.e., just before allowing electrolyte to run into a cone or just after. This is to avoid skipping a cone or giving one a double quantity of liquid.

Fig. 17. Filling Apparatus for Aluminum Lightning Arresters

objects, the tendencies to resonate with some higher frequency, etc.

In consideration of the above variables, it is impossible to give a definite gap setting for different circuits of the same voltage. The tables on page 107 give the allowable limits in gap settings for arresters of various voltages. The maximum values are settings which have been found to give moderate protection on the average system; the lower values are settings closely adjusted to the breakdown point, and can be used on systems operating under the most favorable conditions of the three factors previously mentioned. As it is not possible to operate with the minimum gap setting on all systems, and as it is difficult to predetermine whether conditions are suitable for this minimum setting, it is recommended that the gaps be set at medium values when arresters are first installed. The performance of the arrester should then be closely watched for a few weeks; and if it is found that discharges occur at frequent intervals during times of disturbances and that the arcs at the horns break without difficulty, the gap setting may be considered satisfactory. If a more sensitive setting seems advisable, smaller than medium values may be used; but in no case should the gaps be reduced below the minimum settings given in the table. These values should be approached cautiously, to make certain that settings are not used which are too small for the conditions of the system.

The values given in Tables 2 and 3 are for single-phase, two-phase four-wire and three-phase circuits. For two-phase three-wire circuits the gaps for the outer wires should be made to correspond to the voltage between the outer wires. The gap for the middle wire should be set to correspond to the phase voltage.

In adjusting horn gaps of the rotating type the following instructions should be noted:

First, set the stationary horn blades as far back as possible, so as to get the greatest available clearance in the disconnected position.

Second, the proper gap setting on each phase is then obtained by adjusting the movable horn blade, and keeping the horns in line in the same vertical plane.

Third, the short-circuiting contacts should be clamped to the straight horizontal part of the movable horn. The location of the clamp should be such that when the movable horn is revolved the flexible strip will strike the opposite horn and project past it by at least half an inch. In the case of arresters equipped with charging resistances this strip should strike only the upper or auxiliary horn.

Fourth, the gaps between the horns of all phases should be set equally except on two-phase three-wire circuits, as before noted. With the horns set in line in the normal operating position the flexible strip should be bent so that the gap between it and the other horn is approximately 25 per cent greater than the gap between the two horns.

Fig. 18 shows the arrangement of horn gaps and short-circuiting contacts for arresters with and without charging resistances.

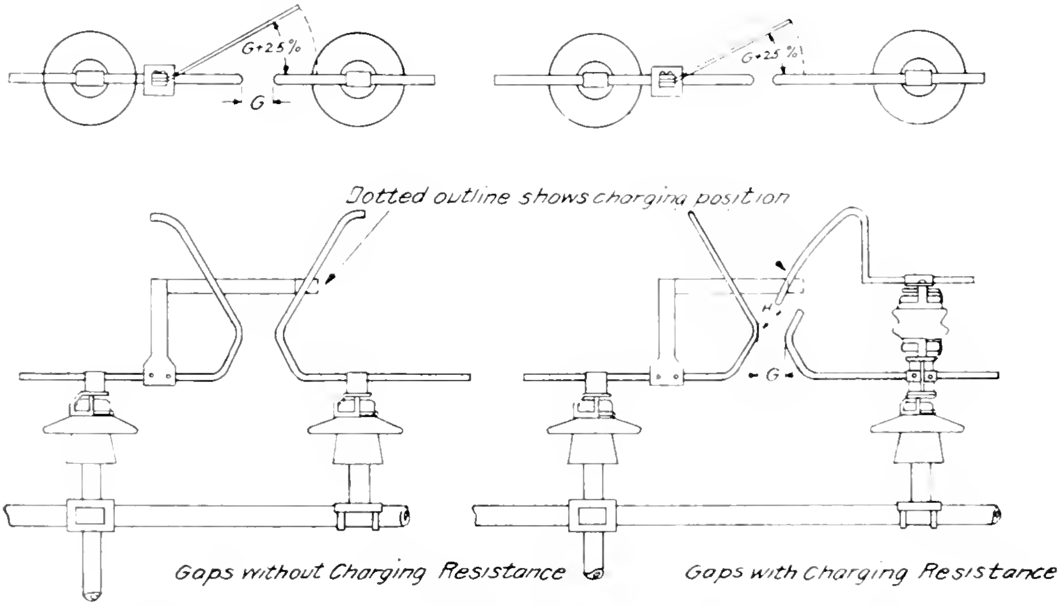


Fig. 18. Horn Gaps for Arresters for 7250 to 27,000 Volts Showing Short Circuiting Contacts

It should be noted that the gap settings given in tables on page 107 correspond to the specific voltages mentioned. When arresters are operated at higher or lower voltages than given in the table proportionately larger or smaller gap settings should be used, so that the settings will correspond to the operating voltage.

Arresters Equipped with Charging Resistances

Above 7250 volts the resistances are mounted on porcelain bases supported in front of the horn gaps, or in porcelain tubes fastened to the insulator supporting the stationary horn. Below 7250 volts the resistance is supported in clips mounted on the horn gap insulator. In all cases the resistance rods furnished for each phase should be connected in series, and should be so connected to the horns that the current will flow through the resistance when the arrester is being charged.

TABLE 2

Arrester Voltage	Gap Setting in Inches for Arresters without Charging Resistances: Maximum	Minimum
2500	3/32	3/64
3300	1/8	5/64
4600	3/16	1/8
6600	5/16	7/32
10000	3/8	1/4
12500	7/16	5/16
15000	9/16	3/8
17500	11/16	7/16
20000	3/4	1/2
25000	1	11/16
30000	1 1/4	7/8
35000	1 5/8	1 1/8
40000	2 1/8	1 3/8
45000	2 5/8	1 3/4
50000	3 1/4	2 1/8
60000	4 1/2	3
70000	6	4
80000	8	5 1/4
90000	10	6 3/4
100000	12 1/2	8 1/2
110000	14	10
140000	18	13

TABLE 3

GAP SETTING IN INCHES FOR ARRESTERS WITH CHARGING RESISTANCES

Arrester Voltage	F	G Max.	G Min.	H Max.	H Min.
2500	1/8	3/32	3/64	1/16	1/32
3300	3/16	1/8	5/64	3/32	1/16
4600	3/16	3/16	1/8	5/32	3/32
6600	5/16	5/16	7/32	1/4	5/32
10000		3/8	1/4	5/16	3/16
12500		7/16	5/16	3/8	1/4
15000		9/16	3/8	15/32	5/16
17500		11/16	7/16	9/16	3/8
20000		3/4	1/2	5/8	7/16
25000		1	11/16	13/16	9/16
30000		1 1/4	7/8	1 1/8	3/4
35000		1 5/8	1 1/8	1 1/2	1
40000		2 1/8	1 3/8	1 7/8	1 1/4
45000		2 5/8	1 3/4	2 3/8	1 1/2
50000		3 1/4	2 1/8	3	1 7/8
60000		4 1/2	3	4	2 3/4
70000		6	4	5 1/2	3 1/2

The gap settings for the main and resistance gaps are given in the foregoing table. (See also Figs. 18 and 19.) The resistance gap "H" must always be slightly smaller than the main gap "G", thereby giving a selective path for discharges. Light discharges take the smaller gap and pass through the resistance to the arrester. Any heavy discharges that are impeded by the resistance are caused to jump the main gap. If the cells are in normal condition the spark at the gap is immediately extinguished without rising and without any flow of dynamic current. Should the arc rise it will be intercepted by the horn in series with the resistance, and be safely extinguished.

Connecting Arrester to the Line

The arresters when first installed have a film completely formed on each separate aluminum cone. They have, however, never been operated assembled and it is advisable to use certain cautions when first placing them in service.

If the preliminary charging is correctly done, using 250 to 300 volts per cell as described, and if not more than a few hours have elapsed since this charging, the arresters can be put in service by operating the device provided to short-circuit the horn gaps, charging the cells as described under "Daily Charging." If only 125 volts were used for testing or if the cells have been standing for a longer time than a few hours, or if, having once been in service, a period of several days has elapsed without charging, it is not advisable to throw full potential on them at once. With the potential about one-half normal, start the arcs across the horn gaps, opening the gaps again immediately. The operation should be repeated several times as described under "Daily Charging." Then raise the voltage to three-fourths normal value, and again start a momentary discharge across the gaps several times. Finally raise the potential to full normal value and again start the momentary arcs several times. If the cells are in poor condition the first arc at the gaps for each step in the potential may be white, flaring and rising half way or even to the top of the horns before it is extinguished, thus showing considerable current in the initial reformation. Each successive arc should show less flaring and rise less on the horns. Finally the discharging current produces, in daylight, a bluish snappy arc, which does not rise much on the horns. When charging resistances are added to an arrester the arc is more of a reddish yellow color and loses some of its snap. This is due to the slight change in power-factor of the charging current.

Another equally satisfactory method of reforming the films is to insert sufficient resistance in series with each section of cells to limit the current to a maximum of 10 amperes. The horn gaps can then be momentarily closed, as described above, with normal potential on the line. If the arrester, however, is fitted with charging resistances, the use of additional resistance is unnecessary.

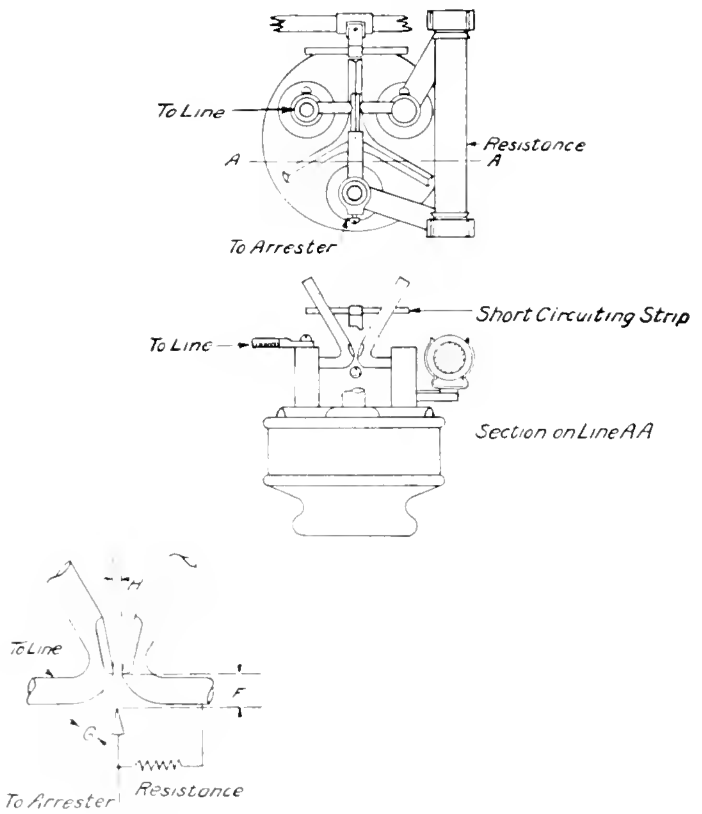


Fig. 19. Connections of Horn Gaps and Charging Resistance for Arresters for 7250 Volts and Below

If the internal connections in the tank are poor or a cell has not been filled, there will be a rumbling sound in the tank, provided that the potential is sufficient to start an arc in the oil. In such a case it is necessary to withdraw the faulty stack of cones and correct the trouble before proceeding with tests. If the impressed potential is not sufficient to start an arc in the oil there will be no dynamic arc at the horn gaps and there will be only a feeble spark when the gaps are diminished to the sparking length.

Daily Charging, Care, Inspection and Repairs

The dissolution of the films on the aluminum cones when they are left in the electrolyte is brought out in the discussion of the characteristics of the arrester.* In order to keep the film in perfect condition it is necessary to charge the arresters daily.

The daily charging of arresters on non-grounded neutral circuits should be done as follows:

First—Close the horn gaps momentarily, and then open again to normal position. If the arc is flary repeat this momentary charge at intervals of three minutes. As soon as the momentary charging no longer produces a flaring arc, close the horn gaps and leave closed for five seconds. With arresters having horn gaps fitted with charging resistances it is only necessary to close the horn gaps and leave closed for five seconds. *Second*—With the horn gaps in normal position reverse the transfer device, thereby interchanging the connections to the ground stack of cones and one of the line stacks. *Third*—The first operation should again be repeated, thus charging the fourth stack of cones, which was originally the ground stack.

Arresters on grounded neutral circuits, i.e., those having no ground stack of cones or transfer device, should be charged in accordance with the first operation described in the preceding paragraph.

When an arrester is first installed and also when one has been off the circuit for several days the initial charging current is sometimes above normal. It is recommended that the cells be charged six or eight times the first day, and three times a day during the remainder of the first week. This charging should be performed as just described. After the first week the regular daily charging will be found sufficient.

The charging period should always be for five seconds. It is important that the charging should be done at a time of the day when the

* See Part I of this article in GENERAL ELECTRIC REVIEW, January, 1913.

line voltage is at a maximum value. This is to insure having the film formed to the highest operating voltage, so as to prevent injury to the arrester in case of accidental discharge at a time when such voltage prevails. In cases where aluminum lightning arresters are installed in engine rooms, or where the temperature is excessive, it is sometimes advisable to charge the arresters twice a day. This condition will be indicated by an increase in the charging arc and charging current from day to day.

The charging operation is valuable not only to keep the films in good condition; but also to give the operator some idea of the condition of the arrester, by observing the size of the arc which forms during charging. It is recommended that this daily charging of the arrester be made part of the station routine, and that records be made of the time of charging and the size and color of the arc which rises on the horns. Too large or too small an arc indicates that there may be an abnormal internal condition, which should be investigated before trouble occurs. This will not only increase the operator's interest in the arrester; but, when once he becomes familiar with the proper operations, the test gives an indication of the internal condition of the cells.

The charging current indicator, which will be described in next month's installment of this paper, affords the most reliable means of determining the internal condition of the arrester. However, when this convenient means is not available, observations during charging should be carefully made as noted above.

The tanks have sufficient heat storage capacity to allow the arrester to discharge continuously for half an hour in case of a recurrent discharge. If such an abnormal condition should ever occur the arrester and also the affected circuit should be disconnected when the disturbance lasts over half an hour. After an arrester has been subjected to a discharge long enough to heat it up, great care should be exercised subsequently when it is again put under the daily test. The hot electrolyte has a much greater dissolving effect on the film than cool electrolyte. If the electrolyte becomes very warm it is better to take the same precaution in the next test as is taken when first connecting the arrester to the circuit.

The pipe frame-work should be thoroughly grounded to insure safety to operator. All insulated parts such as the transfer device except operating handle—tanks, bushings and horn gaps should be considered as alive at all times, except when the horn gaps are properly disconnected and the insulated parts are grounded.

If an arrester is to be out of service for several weeks the cone stacks should be removed from the tanks, and the electrolyte and oil completely drained from the cells. If this is not done the films will be so completely dissolved that they cannot be reformed except with great difficulty. In removing the electrolyte from the cells, care should be taken to prevent the solution from coming in contact with the fiber insulators between the cones.

Reconstruction of Arresters

Arresters are frequently operated for a number of years at a given voltage and later reconstructed for operation at higher voltages. In other cases it is necessary to rebuild the cone stacks on account of some serious damage to the cells. Whenever it is necessary to rebuild the cone stacks of an arrester, the best results are obtained by installing an entire new set of cones and new electrolyte, especially if the arrester has been in service for three years or longer. However, should it be seriously inconvenient to install a new set of cones, a sufficient number should be obtained so that each individual cone stack contains either all new or all old cones. This is essential since the distribution of potential across the cells depends upon the electrostatic capacity of each cell, which in turn varies with the length of time in service.

Cones which have been in service can be washed, when necessary, in clean transil oil or gasolene, using a piece of soft cheese-cloth. If on cleaning or testing the cells the films appear defective, the cones can be returned to the factory to be reformed. All cones that are pitted should be rejected. As the oil is in direct contact with the electrolyte, it absorbs moisture with a consequent reduction of its dielectric strength. This fact has been considered in the design of the arrester. It is advisable to filter the oil at times of reassembling the arrester to remove foreign materials.

Renewal of Electrolyte

Experience extending over a number of years has proven that the electrolyte does not have an indefinitely long life. The length of useful life, however, varies according to the conditions of service, such as temperature variations, voltage regulations of systems, frequency of charging, etc. The only reliable way of keeping track of the condition of the electrolyte is to measure the charging current about once a week. (See charging current indicator in next month's installment.) When the value of this current is observed to gradually increase, daily readings should be taken and if more frequent charging does not restore the charging current to normal, the arrester should be overhauled and electrolyte renewed. For average installations the usual life of electrolyte varies from three to five years.

(To be Continued)

FLOW OF ENERGY NEAR A SOURCE OF ELECTRIC CURRENT

By J. Willard Milnor

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This exceedingly interesting article, which was written at the suggestion of Professor W. S. Franklin, of Lehigh University, illustrates the physical meaning of Poynting's theorem, which has been exercising the minds of the theorists for the past twenty-five years. In a very simple manner, and with the assistance of a few clearly-drawn cross-sectional diagrams, the author traces the direction of energy flow in the immediate vicinity of various typical generators of electric current—a thermo-couple, a primary battery, and a dynamo-electric machine.—Editor.

It was shown by Professor J. H. Poynting in 1884 that the energy which passes from an electric generator to a motor or to a lamp travels through the space surrounding the wires, rather than through the wires themselves. Poynting based his proof upon the expressions for the energy contained in the electric field and in the magnetic field. Starting with the assumption that this energy must have entered a given region by passing through the bounding surfaces of that region, he established a mathematical expression for the energy stream at a point.

Energy flows only in a space which is both an electric field and a magnetic field. The direction of flow of energy is perpendicular to both the direction of the electric field and that of the magnetic field. Its value at a given point is, in ergs per second per square centimeter (the quantities being in c.g.s. units),

$$\frac{\text{electric field intensity} \times \text{magnetic field intensity} \times \text{sine included angle}}{4\pi}$$

In the case of a circuit without outside influences the electric and magnetic fields which cause the transfer of energy are the fields due to the voltage and current of the circuit itself. If there is a magnetic or electric field from an outside source in the neighborhood of the circuit, there will be superposed upon the energy stream due to the circuit itself an additional reentrant energy stream. The latter stream circulates around closed curves, without gain or loss.

The object of this paper is to trace the stream of energy in the immediate vicinity of various generators of current. In each case the flow will be traced to its source. For the sake of simplicity the circuits are represented in two dimensions, i.e., the conductor is a sheet of metal, extending indefinitely in both directions perpendicular to the plane of the paper. The illustrations are cross-sections of these rather artificial circuits.

Thermo-electric Couple. Thomson Effect Absent

Consider first the case of a thermo-element of metals or alloys which, like lead, exhibit no Thomson effect. Here the voltages at the two junctions are to each other as their absolute temperatures, and oppose each other.

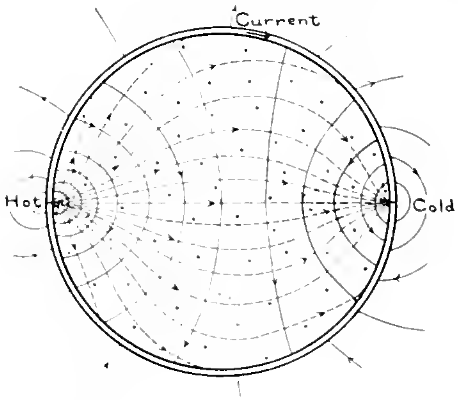

Fig. 1. Energy Flow Near a Thermo-Electric Circuit

Their difference of electromotive force produces the current in accordance with Ohm's law.

Fig. 1 illustrates the phenomenon occurring near a very simple thermo-electric circuit. The conductor is a cylindrical sheet, like a stove-pipe, of two metals joined lengthwise along two elements at opposite ends of a diameter of the cylinder. The figure is an end view of the arrangement. The dots represent the magnetic field, directed downward; this being uniform inside the cylinder, and zero outside. The electric field is represented by full lines, and the energy stream by dotted lines. The dotted lines also represent surfaces of equal electric potential. It will be seen that the greater part of the energy generated passes over to the cold junction, there to raise the temperature of that junction, and thus to produce the "Peltier" effect. The comparatively small remainder of energy generated passes into the conductor, heating it at the rate RI^2. The temperature of the hot junction falls because of the flow of energy away from it, unless heat is supplied from an outside source.

Fig. 2 is a magnified and highly artificial view of the hot junction. The surface of contact is, in fact, a region of intense electric field; it is also shown in the figure as an open space. The magnetic field is "tapering" it varies from zero at the left to $4\pi I$ at the right side of the surface of contact.

Thermo-electric Couple. Thomson Effect Present

When current flows from a hotter to a cooler portion of a copper rod the rod is heated by the current, exclusive of the heating due to the RI^2 loss in the rod. If the current is

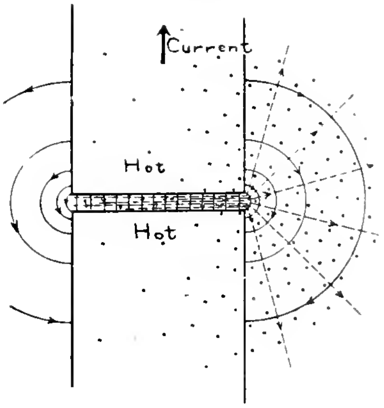

Fig. 2. Energy Flow at a Thermo-Electric Junction

reversed the rod is cooled. This so-called "Thomson" effect occurs in most metals. It is reversed in some cases. Since energy is generated or absorbed during the passage of current the two points of unequal temperature are at different electrical potentials. These potential differences are of a magnitude comparable with those at the thermo-electric junctions.

The numerical values have been calculated from data given in the *Encyclopedia Britannica*, for the case of a copper-silver couple.

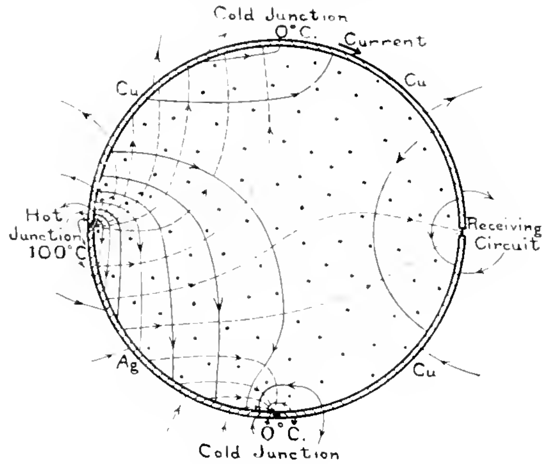

Fig. 3 Energy Flow Near a Thermo-Electric Circuit

The temperatures of the junctions are taken as 100 deg. C. and 0 deg. C. respectively. The results follow:

210 microvolts generated at hot junction, copper being positive.

260 microvolts lost in copper between hot and cold junctions.

140 microvolts lost at cold junction.

240 microvolts gained in silver between cold and hot junctions.

50 microvolts net, which is consumed in the circuit according to Ohm's law.

The electric field, magnetic field, and energy stream are illustrated in Fig. 3. The resistance of the conductors is neglected, the entire resistance of the circuit being assumed to be concentrated in a receiving circuit at the right of the figure. Energy flows away from the hot junction and from the silver conductor; it flows into the copper conductor, the cold junction, and the receiving circuit.

Electric Battery

In the electric battery there is an acid, base, or salt, in solution, which is broken down by the passage of current. The metal or hydrogen ions go to the cathode, there to be deposited or liberated. The acid-radical or hydroxyl ions go to the anode, and combine with the substances of the anode to form a new compound. The energy given off by the battery is generated at the surfaces of the electrodes, where the chemical actions take place. The amounts of energy given off at the two are not necessarily the same. Surrounding each electrode is a very

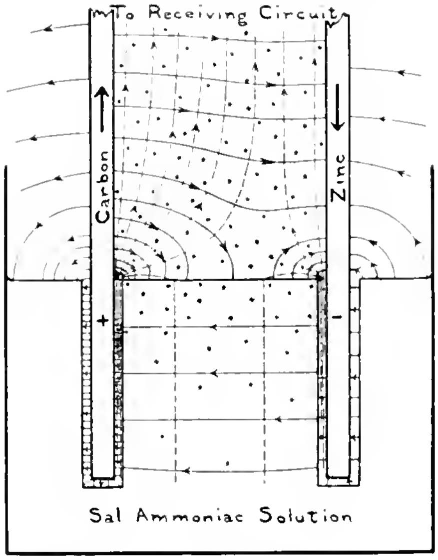

Fig. 4. Energy Stream Near an Electric Battery

thin space in which the chemical actions occur. This space is an intense electric field, since the electrode on one side and the electrolyte on the other side are at differences of potential in the neighborhood of a volt, although separated by a very small fraction of an inch. This space in which the energy is generated also serves to conduct the energy out of the battery. There is a small drop of potential in the electrolyte due to its ohmic resistance; hence some energy is returned to it from the electrodes.

Fig. 4 shows in a general way the lines of the electric field and the energy in a simple sal-ammoniac battery. The approximate values of potential are: solution positive with respect to zinc electrode, 0.1 volt; carbon electrode positive with respect to solution, 1.2 volt; total voltage, carbon positive with respect to zinc, 1.6 volt.

The source of the energy stream is thus traced to the chemical actions at the electrodes. But just what goes on here is difficult to state. It is known that each ion carries an electric charge, and this charge in motion produces a magnetic field around it, the same as around a wire carrying current. Now if this ion is moving in the direction of an electric field there is an energy stream toward or away from the ion. The motion of the ions near the electrodes therefore produces the energy streams; at the same time producing the current, the voltage, and the chemical reactions.

Induced Current

The energy stream from the dynamo has its origin at the point where a moving wire cuts lines of magnetic flux. From there it flows to the receiving circuit through the electromagnetic field surrounding the wires. The effect of the strong magnetic field from the poles of the dynamo is to cause additional energy to circulate in closed curves near the poles.

The action cannot be completely illustrated in two dimensions. What is probably the simplest possible physical case is illustrated in Fig. 5. The conductors are wires in this figure, instead of sheets of metal as before. The poles of the dynamo are shown in the side view; the magnetic field produced by them is represented in the top view by the heavy dots. The bridging wire at the left is moving toward the right, thus cutting flux. The magnetic field due to the current in the wires is represented by the small dots, and the useful energy stream by the light dotted lines. The circulating energy is represented

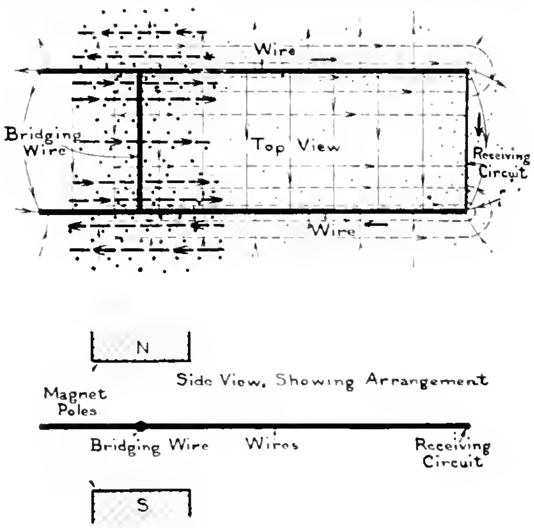

Fig. 5. Energy Stream Near a Dynamo

by the heavy dotted lines. It crosses from the stream inside the wires to that outside the wires in the space above and below the plane of the wires. This circulating energy may be many times as large as the useful energy. The actual energy stream at each point is the sum of the two energy streams.

STORAGE BATTERIES IN MODERN ELECTRICAL ENGINEERING

Part IV

By D. Basch

Switchboard Engineering Department, General Electric Company

Part I of this paper (November, 1912) was concerned with lead batteries; part II (December) treated of the Edison nickel-iron battery, discussed three common arrangements of charging sources, and dealt with batteries for exciting the controlling circuits in power houses and substations; part III (January, 1913) considered batteries for isolated lighting plants, private and public garage charging of batteries, ignition outfits, and automatic cut-outs. This month's instalment concludes Mr. Basch's valuable paper, and deals with boosters and booster arrangements for battery charging.—Editor.

BOOSTERS AND BOOSTER ARRANGEMENTS FOR BATTERY CHARGING

In large stations the methods employed in small and isolated plants, for charge and discharge and for running the battery and charging source in parallel, are unsuitable. Charging-generators cannot economically be designed in large sizes with voltage variations great enough to meet the demands of a thorough charge; resistance control would entail too heavy a loss of energy. Floating a battery on the charging source does not give results accurate enough to conform to the general standard of a large installation; and in such cases "boosters" are used.

A booster is a motor-generator, placed in series with the battery or the supply line to the bus, across which the battery is connected. It may be either hand-regulated or self-regulated, i.e., automatic.

A hand-regulated booster is ordinarily used for charging batteries; sometimes also for discharging. Self-regulating boosters are used where battery and supply generator are run in parallel and where the generator load must be kept constant. In such cases

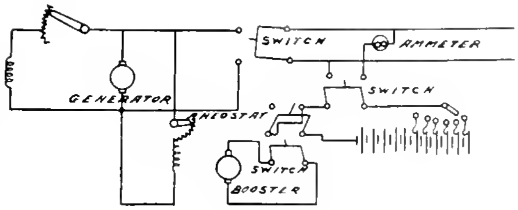

Fig. 20. Connections for Shunt Booster

fluctuations in the total load are equalized by the battery, which absorb the idle energy of the generator, when the total load is below normal, in charge, and supplies in discharge any amount of the total load in excess of the load apportioned to the generator. The booster is then simply a means to cause instantaneous charge and discharge of the battery as the load fluctuates.

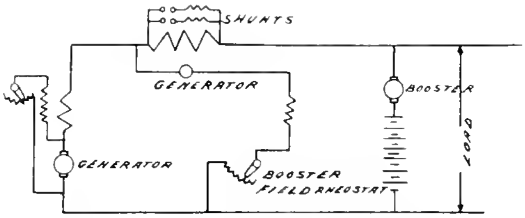

Fig. 21. Connections for Counter E.M F. Booster

Hand-regulated Booster

The only type of hand-regulated booster in general use is the shunt booster, which in charging adds its voltage to that of the charging source. (See Fig. 20.) Its armature should be able to carry the charging current; its maximum voltage should be equal to the difference between the voltage of the charging source and the highest voltage required for charging the battery; and it should be able to vary its voltage from zero to the maximum. The shunt field should be excited either from the charging source or from the battery.

Self-regulating Boosters

The three simplest forms of self-regulating boosters are the series, compound and differential boosters. The series booster is practically obsolete; the compound and differential boosters, which depend for their action on the combined effect of shunt and series coil, while in general use, are not made, as other boosters have been found better in regard to regulation, cost and efficiency.

The so-called counter e.m.f. or Hubbard booster, see Fig. 21 (used by the Gould Storage Battery Company), employs a regulating coil carrying a definite shunted portion of the generator load, which coil forms the field of an auxiliary exciting machine, usually mounted on the same shaft with the booster generator and driven at virtually constant

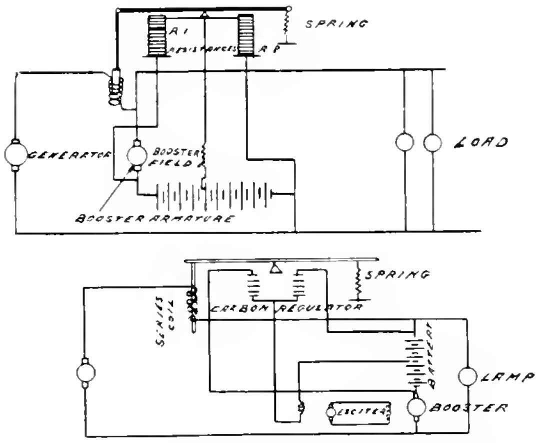

Fig. 22. The Upper Diagram is for the Entz Externally Controlled Booster. The lower one illustrates the use of a small auxiliary exciting dynamo, introduced into the Entz system for boosters of large capacity

speed by a motor. The voltage of this auxiliary machine is consequently proportional to the generator load. It is opposite in direction to the line voltage; and the difference in voltage between the exciting machine and the line is therefore impressed on the booster field. With a decrease in generator load, the booster field is excited in a direction to assist the line voltage, causing the battery to be charged; with an increase in generator load, the booster field is excited in the opposite direction and the booster causes the battery to discharge.

The so-called Entz or carbon regulator, (see Fig. 22) is used by the Electric Storage Battery Company. *R* and *R-2* are two resistances made up of piles of carbon disks. They are arranged on opposite sides of the fulcrum of a lever, this lever being subjected, on one end, to the tension of a spring, and at the other end to the pull of the solenoid *S*, connected in the main bus. Variations in the force applied to opposite ends of the lever will increase the pressure on one group of carbon disks, reducing its resistance, and decrease the pressure on the other, raising its resistance. The carbon piles are connected in series across the battery terminals, while the field winding of the booster is connected between the middle point of the battery and a point in the circuit between the two carbon groups. Variations of pressure on the piles produced by the lever, by varying the resistance of these piles, will cause current to flow in one direction or the other through the booster field, thus creating a booster e.m.f. in line with, or in opposition to, the battery voltage, and causing the battery to charge or discharge. The load on the generator, which is to be held constant, determines the adjustment of the spring—at this load the tension of the spring must counter balance the pull of the series solenoid. Owing to the comparatively large amount of power required to quickly change the field strength and to the limited capacity of the piles, a small exciting dynamo is introduced for boosters of large capacity. The field of the auxiliary exciter is controlled by the carbon piles, in the same manner as the field of the booster in the other method; the armature supplies the field of the booster. The principle of operation remains otherwise exactly the same.

An externally controlled booster operated on a similar principle is shown in Fig. 23. Three fixed resistances are connected in series across the storage battery. The booster field is arranged between a point in the center of the battery and another point in the middle between two resistances, *R-1* and *R-2*. A controlling equipment, based on a well-known voltage regulator principle, has its relay contacts connected across the third resistance, *R-3*, in such a manner that, when the voltage of the system falls below a certain pre-determined amount, resistance *R-3* is short-circuited, to be open-circuited again

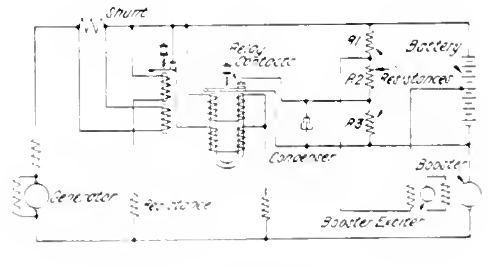

Fig. 23. Another Example of Externally-Controlled Booster

when the voltage is brought up. By cutting *R-3* in or out the direction of current in the booster exciter field is varied, causing the booster to charge or discharge the battery as the situation may demand.

Adjusters for Average Load in Systems with Boosters

The generator load, for which the booster is adjusted, is supposed to be the average value of the external load, so that the amount of energy taken out of the battery during discharge is equal to the amount put in during charge. In power stations the average load is apt to vary very considerably at different hours of the day; consequently, if the adjustment of the booster is not changed, to follow the variations in average load, the battery is apt to receive a continuous charge or to give out a continuous discharge, resulting in the necessity to make the size of the battery larger than if the adjustment for average load were made to vary with the load. It is possible to change the adjustment manually during the day at different periods, but this method is not always reliable.

An automatic adjuster is manufactured by the Electric Storage Battery Company, which may be used with any regulator provided with an adjusting shaft or screw or which may have its normal current regulated by a shunt. This adjustment consists of a small motor connected by reducing gear to the adjusting part of the regulator. The armature of the motor is connected to the main busses, and the field across the booster. Thus, for instance, when the booster voltage is in the direction to discharge the battery, the motor field is energized and the motor revolves in the direction to gradually increase the tension of the spring or to decrease the shunted amount of the load current, thus gradually increasing the load on the generator and relieving the battery of its discharge until the booster voltage comes back to zero. This transfer of load between battery and generator is brought about slowly, responding only to protracted charges or discharges. A special load-limiting device is furnished to prevent throwing load on the generator beyond its capacity.

An electrolytic aluminum cell is connected in series with the motor field and ordinarily short-circuited by a switch. When the adjustment corresponds to the maximum permissible load on the generator the short-circuiting switch is opened automatically, and the cell will prevent current from passing through the field. The cell, will, however, permit current to flow in the other 'irection, so that adjustment can be made to decrease the generator load.

Automatic Current Stop

While the capacity of a storage battery to withstand an excessive momentary overload is practically unlimited, the circuit-breaker protecting the booster cannot be set high

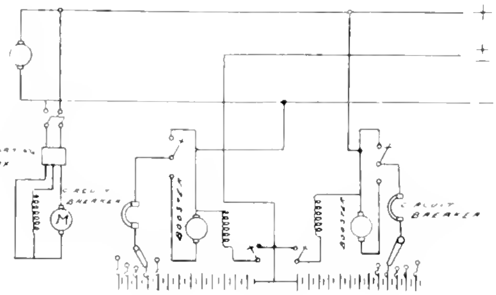

Fig. 24. 3-Wire Battery

enough to hold in at such excessive loads. When this booster breaker opens, the whole load is thrown on the generator, opening the protective device of the generator. The Electric Storage Battery Company has developed the so-called automatic current stop, to allow the battery to discharge up to the maximum limit of the booster.

A horse-shoe magnet is connected in series with battery and booster. The armature of this magnet is pulled away from the magnet by a spring and closes a contact, short-circuiting an aluminum cell in the booster field or in the exciter field, until the discharge current of the battery becomes strong enough to pull the armature away from the contact. The field of the booster or exciter is thus interrupted, and the discharge of the battery will fall off until it falls below the setting of the horse-shoe magnet, when the armature will be pulled away from the magnet and the aluminum cell again be short-circuited. The generator is thus subjected only to the difference between the maximum current rush and the current for which the horse-shoe magnet is set and which constitutes the load limit of the booster. The aluminum cell acts as a condenser to suppress sparking at the point where the field circuit is opened.

Three-wire Systems

Fig. 24 shows a battery connected on a three-wire system acting both as an equalizer and for power storage. If the battery is used to give regulation on fluctuating loads, some automatic booster must be used. If the boosters are merely for charging, i.e., if the battery carries the load alone or floats in parallel with the generator, an ordinary manually-controlled shunt booster is sufficient.

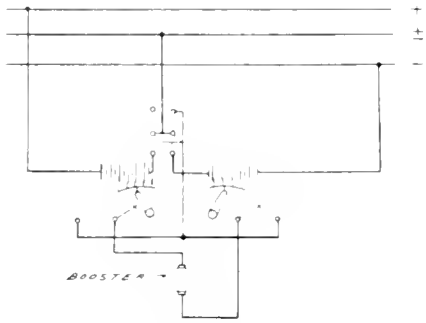

Fig. 25. 3-Wire Battery

If one side of the system is liable to be loaded more heavily than the other one, it is advisable to arrange an equalizing load, which can be thrown on either half of the battery so as to equalize the battery discharge. A slight variation, which is frequently used, may be made by connecting the two booster armatures in series between the two halves of the battery and taking the neutral from the middle point between the two armatures. In practically every case it is possible to use only one motor to drive both boosters, with the motor connected across the outside.

A method employing a single booster for charging is shown in Fig. 25. Either half may be charged independently of the other, or the whole battery may be charged in series. This scheme necessitates the use of so-called double end-cell switches, one end of this end-cell switch being needed for charging and the other one for discharging.

In general, any service which a battery may be made to give on a two-wire system may also be obtained on a three-wire system.

SOME NOTES ON OIL-SWITCH ARRANGEMENTS

By Emil Bern

Switchboard Engineering Department, General Electric Company

The evolution of the control and layout of oil switches, made desirable or necessary by the increasing voltage and capacity handled, is presented in a very explicit manner in this article. It shows how the introduction of current transformers made it possible to remove the switches from the board and locate them behind it with an aisle intervening, or perhaps place them below the switchboard floor, the switches in either case being operated by a system of balanced cranks and rods. The reasons for the introduction of the remote controlled, solenoid operated switch are given and its advantages enumerated; and it is further shown how a maximum degree of flexibility in the location of station equipment and also the best continuity of service may be obtained by the addition of disconnecting switches to one or both sides of the oil switch. It may be remembered that in the General Electric Review for August, 1912, there appeared an article by Mr. Bern on "Bus and Switch Compartments for Power Stations."—Editor.

When the word "switchboard" was coined it carried with it, without doubt, the thought of a board with one or more switches, and perhaps, certain necessary instruments. The switches of the early days were, of course, mounted on the front of the board, as are the knife switches of today; but when somewhat higher voltages came into use the *oil-switch* was developed and the best place for it was found to be on the rear side of the board with its operating mechanism extending through and mounted on the front side. With this arrangement all live parts of dangerous potential were kept out of reach of the operator, and the more or less voluminous switches did not detract from the appearance of the face of the board. For small and medium size plants this is still the most popular arrangement, on account of its simplicity and small space.

With further increase in voltage and capacity of stations the instruments and overload trips of switches were made to operate through current transformers instead of directly from the main circuits, thus abolishing the necessity of locating the main connections on or near the switchboard. The same conditions also made it desirable to remove the switches and high tension connections some distance from the switchboard, as shown in Fig. 1. The oil-switches are here supported on a framework between the board and the wall, oftentimes only a small distance from the wall, sufficient for carrying the leads from the switches up or down the wall as desired. Between the oil-switches and the board an aisle of liberal dimensions should be provided, so as to give safe access to the rear of the board while alive, and also for removing the oil-vessels and adjusting the switches. The busses, which in most cases consist of bare copper bars, are usually located some distance above the switches so as to be out of reach, and the connections between them and the switches should be insulated, except for low voltage installations. A convenient place for the instrument transformers may be found on the wall, back of the oil-switches; and their secondary leads may be brought to the board through conduit laid in the floor, or—less costly—through the iron pipes bracing the switchboard to the wall. Fig. 1 shows the oil-switch operated by a system of bell cranks and rods, which latter are usually made of iron pipe. It is customary to run these mechanisms under the floor where convenient to do so, or otherwise in trenches in the floor covered by plates or wooden boards.

It is sometimes desirable to locate the switchboard on a small gallery overlooking the machines, while the oil-switches and

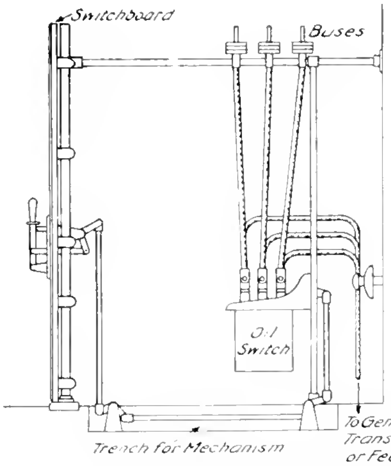

Fig. 1. A Common Arrangement of Oil-Switch on Frame-work back of Switchboard

busses are installed on the machine floor as shown in Fig. 2; or a similar arrangement may be used if the switchboard is installed on the main floor, and the oil-switches with the busses in the basement, so as to be more out of reach. The different features of this arrangement are about the same as for Fig. 1; but care must be taken that the two vertical members of the oil-switch mechanism balance each other in weight as nearly as possible,

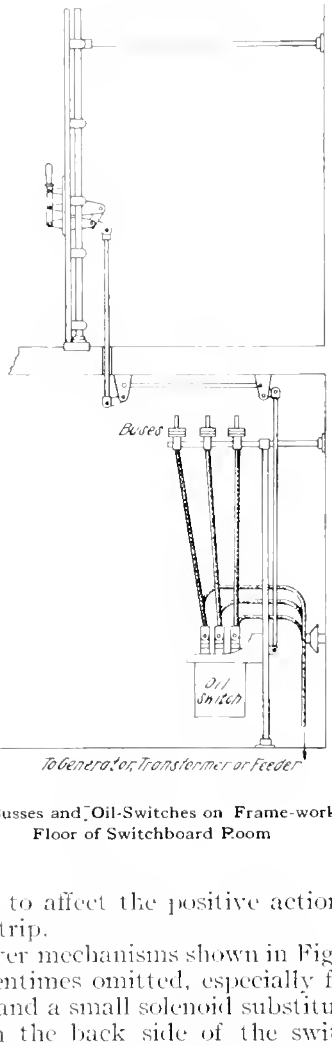

Fig. 2. Busses and Oil-Switches on Frame-work below Floor of Switchboard Room

so as not to affect the positive action of the overload trip.

The lever mechanisms shown in Figs. 1 and 2 are oftentimes omitted, especially for large stations, and a small solenoid substituted and placed on the back side of the switch (see Fig. 3). This solenoid when energized by direct current from a small control switch on the board, operates the oil-switch. The introduction of electrical control gives a greater flexibility to the whole layout; the oil-switches need no longer be located directly opposite the panels that control them; and it is thereby possible to save a considerable item of bus material by proper grouping of feeders and generators on the bus, instead of locating all generators at one end of the bus and all feeders at the other, as it is customary and convenient to locate the control and instrument equipments.

Continuity of service is in nearly all stations of great importance; and it is, therefor, essential that any oil-switch may be taken out of service, and cleaned or repaired, without interrupting other circuits. For this purpose disconnecting switches are often required between the busses and the oil-switches (as shown in Fig. 4). To obtain the proper phase clearance between the disconnecting switches somewhat more space is required longitudinally for this arrangement

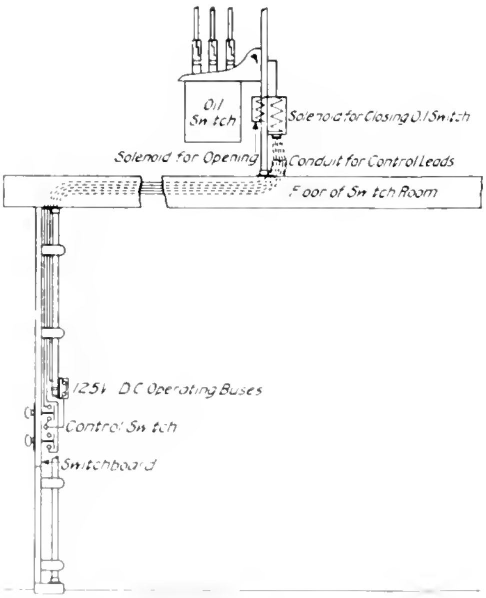

Fig. 3. Solenoid Operated Oil-Switch, some distance from the Switchboard

than that shown in Figs. 1 and 2. With this space on hand a better arrangement can be made by turning the oil-switches around 90 degrees, as shown in Fig. 4. This works out equally well for hand and solenoid-operated oil-switches. In determining the distance between the disconnecting switches it is well to bear in mind that they are usually manipulated by a stick with a metal hook which is liable to almost bridge the small spacing if not carefully handled. For this reason barriers are sometimes used between the switches which also prevent metal objects from dropping on the bare metal of two [illegible] phases. Sometimes these barriers are made of slate or marble, but generally they are built up of 1/4 in.

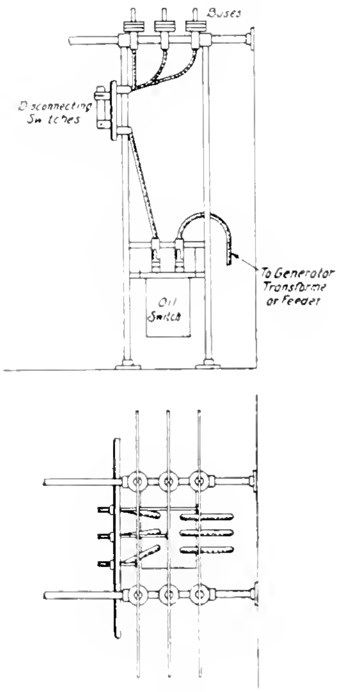

Fig. 4. Arrangement of Disconnecting Switches between Oil-Switches and Busses on Frame-work

asbestos lumber on each side of a wooden frame about 3/4 in. thick, with a thin band

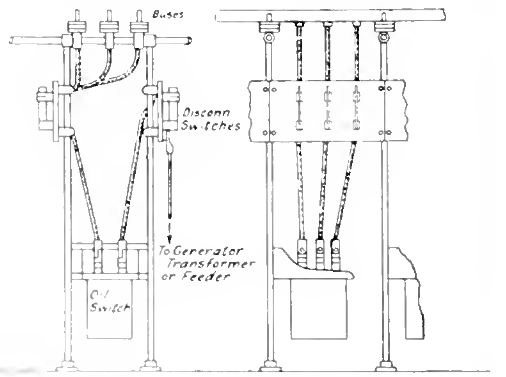

Fig. 5. Arrangement of Oil-Switches with double set of Disconnecting Switches on Frame-work

of fiber to cover the edge and give it a finished appearance. This construction is considerably lighter than slate or marble, and is, therefore, less difficult to support without metal brackets between the disconnecting switches.

Oftentimes it is necessary to install dis-

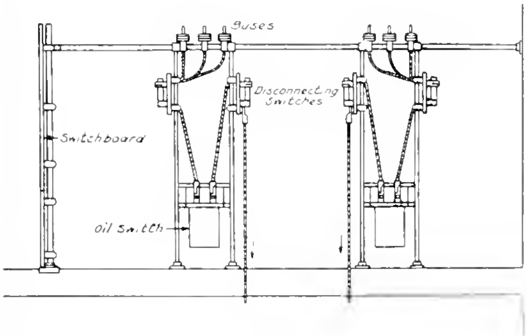

Fig. 6. Arrangement of Switching Apparatus with several sets of Busses

connecting switches on each side of the oil-switch as shown in Fig. 5. This is especially the case for feeders energized at the further end. The instrument transformers should then be connected inside the disconnecting switches so that they may be isolated from the system if necessary.

Arrangements shown in Figs. 4 and 5 may be located independently of the switchboard if the oil-switches are electrically-operated; or the whole equipment may be installed directly back of the board as shown in Fig. 6. The construction indicated in this figure is particularly applicable to *double bus* systems and so-called *ring busses*, where it is desirable to provide for the greatest flexibility in grouping, and for isolating certain sections of the system as the conditions of operation may require from time to time. Fig. 7 is intended to represent diagrammatically a simple ring bus. The bus section switches are oil-switches where it is desirable to make a change in the grouping of the system without disturbing the operation. It can readily be seen by referring to Figs. 5 and 6 that these

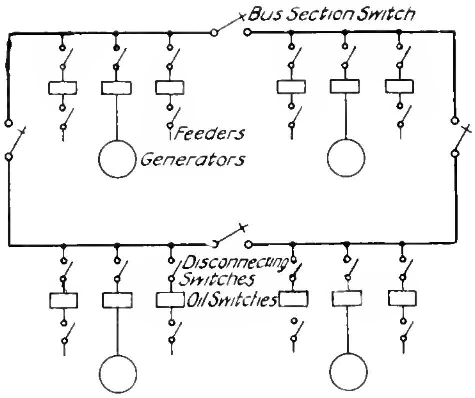

Fig. 7. Ring Bus System

section oil-switches can be installed in line with the other switches; and disconnecting switches can be installed on each side of them without difficulty if desired.

THE CONDUCTION OF HEAT: WITH RESULTS OF AN INVESTIGATION OF THE THERMAL RESISTIVITY OF HEAT-INSULATING MATERIALS

By C. P. Randolph

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Much has been written of late on the subject of research work as a financial asset of the manufacturer. In the business of manufacturing electrical apparatus, more than in any other perhaps, the advantages of research facilities, or even the necessity for them, become strikingly apparent; and in many lines of the business the industry indeed looks to the producer for the progress which must be made. This article, of great value in itself, is also very interesting solely from the viewpoint of what its subject matter represents. In making a systematic design of heating devices and cooking ranges, the lack of data on thermal resistivity became obvious. Here appears the financial value of the research faculty. From the laboratory the engineers demanded concrete figures as to the physical constants of insulating materials. An extensive investigation was carried out, which is in part reported here, on a wide range of substances—organic materials, asbestos products, ceramics, etc., to determine the thermal resistivity of these substances; and the article shows how the data so obtained may be employed in calculating the heat energy which is lost from a body surrounded with various insulations.—Editor.

There are three distinct ways in which heat is transferred from one place to another, viz.: by conduction, by convection, and by radiation.

The radiation of heat is similar to the setting-up of Hertzian waves that occurs in wireless telegraphy, with the difference that the latter waves are far longer than heat waves. In both cases energy is considered to be transferred from one body to another by means of a wave motion in the ether. There is no material substance connecting the two bodies, the agency of matter being required only to maintain the waves in the ether.

The convection of heat occurs when a relatively hot body is immersed in a fluid (either liquid or gaseous) which is at a lower temperature than the hot body. This heats the portion of the fluid adjacent to the hot body to a higher temperature than that part of the fluid which is removed further from the body. The density of the fluid is now no longer uniform, so that currents are set up which carry heat from the hot body to the more remote parts of the fluid. Heat is here actually carried from place to place by the movement of particles of matter, which are warmed by contact with a relatively hot body at one place and cooled by contact with a relatively cold body at another place. It has been shown recently* that a hot body immersed in a gas, as air, is covered with a comparatively stationary film of air, through which heat is *conducted* to the surrounding air, where it causes convection currents that carry the heat away from the outer surface of the stationary conducting film.

* Langmuir, Proc. A.I.E.E., XXX (1912), 1011; Phys. Rev., 34 (1912), 401.

Calculations involving thermal conduction are made in general just as though we were dealing with electrical conduction. A difference of temperature between two points in a body (corresponding to electrical potential difference) causes a flow of energy from the point at the higher temperature to that at the lower. For a given temperature difference the rate of transfer of heat depends on the material of the conducting body. Ohm's law applies to thermal conduction as well as to electrical; that is, the rate of flow of heat is directly proportional to the difference of temperature between two places, and is inversely proportional to the resistance of the material between them. But the extreme simplicity of this has been masked by the clumsy and inefficient units used in engineering calculations, of which there are six or more in all. The ordinary unit used by engineers is the British thermal unit (B.t.u.), which defines the quantity of heat, corresponding—though not equivalent—to the coulomb of electricity. The objection to the above unit is that awkward conversion factors are always needed. The watt has been long in use in scientific calculations involving conduction of heat, as the unit defining the rate of flow; and recently the convenience of this unit for use in connection with electrical heating has been pointed out to engineers, in numerous articles by Mr. Carl Hering.* No conversion factor is then needed to change from the electrical energy input to the rate of heat flow, as such, since they are equal.

It is of course far more convenient to use the centigrade degree as the unit of temper-

* Carl Hering, Proc. A.I.E.E., XXXI, (1912), 885.

ature than the Fahrenheit degree. Let

W = watts flowing as heat,

$T_2 - T_1$ = temperature difference in degrees centigrade.

R = thermal resistance.

Then, from Ohm's law,

$$R = \frac{T_2 - T_1}{W}.$$

This defines thermal *resistance* as the difference in temperature in degrees centigrade, per watt of heat flow. Inversely, thermal *conductance* is the number of watts flowing between two places, per degree centigrade difference in temperature. Thermal resistivity, or specific resistance, is then, the difference in temperature in degrees centigrade required per watt flowing per inch cube, when we use inch units. The *thermal ohm* is defined as the resistance which allows a flow of heat of one watt per degree centigrade difference in temperature.

Let r = thermal resistivity.

c = thermal conductivity.

L = length of path of heat flow between temperatures T_2 and T_1.

A = area of the path of heat flow.

Then $R = \frac{L}{A} r = \frac{L}{A} \frac{1}{c}$.

Assuming (1) the area of the path of heat flow to be constant throughout its length and (2) the thermal resistivity to be independent of the temperature, we have

$$(1) \quad W = \frac{A}{L} \frac{T_2 - T_1}{r} = \frac{A}{L} c\,(T_2 - T_1).$$

This simple formula can be used in a good many cases. It is seen from the tables below, however, that for many materials the thermal resistivity varies with the temperature. Now, the treatment of thermal resistivity must differ from electrical resistivity here; because no transfer of heat, as such, ever can occur at one definite temperature, whereas electricity can flow when the whole conductor is at a uniform temperature; and therefore the temperature coefficient of electrical resistivity can be taken care of more easily in calculations. The conduction of heat is due solely to a difference of temperature, and this conduction itself varies with the temperature. In designing heating devices, etc., or making any calculation of the heat loss through insulation, then, it is necessary to know the average resistivity between the two temperatures T_2 and T_1 in question. Where the temperature coefficient of thermal resistivity is important, our formula becomes:

$$(2) \quad W = \frac{A}{L} \int_{T_1}^{T_2} c\,dT.$$

A being constant throughout the distance L.

For convenience, let $\phi = \int_0^T c\,dT$, then†

$$W = \frac{A}{L} (\phi_2 - \phi_1).$$

The Practical Bearing of Accurate Data on the Design of Heating Devices

On undertaking a scientific study of the design of heating devices, cooking ranges, etc., we found immediately that most of the data necessary for our calculations was lacking, and that very few accurate measurements of thermal resistivity had been made. Without such data it is possible only to guess at the actual behavior of any design; and of course such haphazard methods can never be satisfactory, nor can they cope with modern competition. A small amount of time and money spent on a careful scientific study of the whole problem saves much greater amounts spent in testing and learning by cut-and-try methods. So we were forced to determine a good many of the physical constants required by our engineering department, as well as to work out some of the necessary formulæ.

An apparatus was devised* first for conveniently and rapidly making a large number of measurements of thermal resistivity, and some of the results are given in the tables.

From the results obtained it is possible to draw a number of general conclusions:

(1) There are no materials that we can call thermal insulators in the same sense that is understood when we speak of electrical insulators.

(2) There is no method of preventing the flow of heat as good as an evacuated space.

(3) The organic fibrous materials (natural materials, containing carbon) such as eiderdown, wool, etc., are the best insulating materials we have found.

(4) Materials which are relatively coarse, such as poplox, may be very good insulators at low temperatures, as 100 degrees centigrade, but seem always to have a very great negative temperature coefficient.

(5) Increasing the density of any material by compression (within the limits of our apparatus) increases its resistivity, but of course there must be a point beyond which further compression will decrease the resistivity. The ratio of the increase in resistivity

* Randolph, J. Am. Elec. Soc. XXI, (1912), 545.

† Langmuir, Phys. Rev., 34, (1912), 401.

to the compression is very small and becomes smaller as the density is increased.

(6) The thermal conductivity of bricks varies inversely as the temperature of burning.

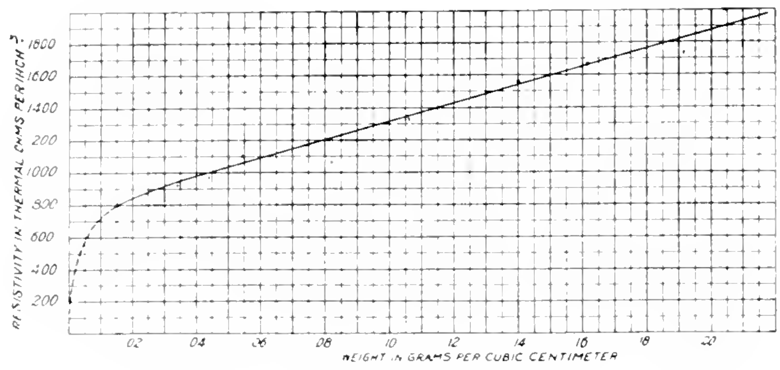


Fig. 1 Curve Showing the Relation Between the Density and Thermal Resistivity of Woolen Fibres

THERMAL RESISTIVITY OF INSULATING MATERIALS

In the following tables are given the results of an extensive investigation carried out on a wide variety of insulating materials in order that some of these physical constants might be determined. Some particulars in regard to the nature and composition of the various materials are given in the text, while the tables give the observed values of density, temperature and resistivity. The figures in the reference column of the tables indicate the source from which the results were secured, the key to these references being given at the end of the article. The density is given in pounds per cubic foot; and the temperature, in degrees C., represents approximately the temperature of the side of the material where the heat flux enters, the temperature of the other side being always about 10 deg. C. The resistivity, r, represents degrees per watt per cubic inch. Where the temperature coefficient is important curves were plotted, giving the relation between the temperature and ϕ_t, as shown in the figures.

Nature and Composition of Organic Insulating Materials Listed in Table I

The *wool* is a pure wool of a light cream color which takes up moisture very rapidly. The curve in Fig. 1 shows the variation of the resistivity with the density within the limits of our apparatus. It can be used at temperatures up to 100 deg. C. The *eiderdown* is a genuine eiderdown from the Cold Blast Feather Co., Philadelphia, Pa. The densities are the greatest and the least which we could get in our apparatus. This is the best insulator at atmospheric pressure which we have yet found, and is not affected at 150 deg. C. The *cotton* is ordinary cotton batting which will stand 100 deg. C. and shows no important temperature coefficient between 80 and 120 deg. C.

Of the *sawdust* listed the first is an oak sawdust from wood grown in Berkshire County, Massachusetts, consisting of a mixture of coarse and fine products just as it comes from the mill, dried at 100 deg. C. for two days. It can be used at temperatures not in excess of 100 deg. C. The second and third samples of *sawdust* listed were obtained after separating the above mentioned sample by sieving. No. 2 was retained on a 20 mesh, while No. 3 is the portion which passed through the 20 mesh.

The *silk* is a "pure raw silk" which comes from the P. W. Sothman Company, Toronto, roped or braided into lengths. It weighs 100 pounds per bale and can be used at 150 deg. C. The *silk wool* is in the form of clean fibres, not braided or roped, and its appearance is entirely different from the above. The *hair felt* is made of cattle hair and comes from the Johns-Manville Company, Boston, Mass. The sample was dried out at 125 deg. C., which increases its resistivity at lower temperatures by about 10 per cent. It has no important temperature coefficient from 50 to 150 deg. and can be used at 150 deg. C. The *lampblack* (Cabots No. 5) cannot be used at temperatures exceeding 300 deg. C. as spontaneous combustion occurs. Other samples have a resistivity 30 per cent greater than the one shown.

TABLE I

THERMAL RESISTIVITY OF ORGANIC INSULATING MATERIALS

Material	Density	Temp.	r	Ref.
Wool	0.955	100	802	1
	3.40	100	1100	1
	12.0	100	1730	1
Eiderdown	0.134	100	853	1
	0.134	150	623	1
	4.92	100	1615	1
	4.92	150	1625	1
	6.77	150	2035	1
Cotton	1.31	100	858	1
	6.30	100	1320	1
Sawdust (1)	20.0	100	1240	1
Sawdust (2)	18.8	100	697	1
Sawdust (3)	21.7	100	1100	1
Yel. pine sawdust	13.7	100	808	1
Silk	6.36	100	1170	1
		150	1110	1
Silk wool	1.81	100	1230	1
Hair felt	8.49	0 to 150	790	1
Fibre	67.4	100	383	1
Lampblack	12.1	500	878	1
	12.1	300	1040	1
	12.1	100	1270	1

Nature and Composition of Insulations Containing Asbestos Listed in Table II

The *diatomaceous earth and asbestos* is the "non-pareil high-pressure covering" made by the Armstrong Cork Company, Pittsburgh, and is a mixture of kieselguhr (pure $S_i O_2$) and asbestos, held together with a binder. The measurement given is the average of values found at five temperatures from 100 to 500 deg., none of which vary from the mean by more than 8 per cent and which show neither a definite increase nor decrease with the temperature. The material withstands heating to 500 deg. C. with only a slight tendency to crumble, and may safely be used at the above temperature. It is self-supporting. The material listed as *85 per cent magnesia* is made from magnesium carbonate and asbestos fibre by the Johns-Manville Company, Boston. It cannot be used safely where it will be exposed continuously to temperatures above 300 deg. C. as it disintegrates and carbon dioxide is evolved. If it is then subject to moisture, it will hydrate. It possesses no distinct temperature coefficient, and the value of r given is the average of five measurements at temperatures from 100 to 500 deg. The deviation from the mean is not more than 8 per cent. The material is self-supporting. The material listed as *35 per cent magnesia* was made by the Keasbey-Mattison Company, Ambler, Pa., and contains 35 per cent magnesium carbonate with 60 per cent fibre. It can safely be used continuously at temperatures not in excess of 300 degrees. It is self-supporting and is called "magnasnestos."

The *air-cell asbestos* (Johns-Manville) is also known as "asbestocel corrugated fire-proof paper." It is a self-supporting corrugated paper about $\frac{1}{32}$ in. thick, held in shape by a paper backing. The value given for the resistivity is accurate no closer than 10 per cent, as it varies greatly with different samples. This material cannot be used at temperatures exceeding 200 degrees, as it apparently contains an organic binder. The *asbestos fire-felt* (Johns-Manville) is the lightest self-supporting material we have ever been able to secure. The manufacturer states that it is made of pure asbestos fibre loosely felted together. It has a tough outer shell and is essentially a moulded material. It can be used continuously at temperatures not in excess of 300 deg. C. The *navy brand asbestos fire-felt* is the same material as the above, except that the density is much greater; and, according to the manufacturer, it is constructed of specially selected long-fibre asbestos. It withstands temperatures of 500 deg. C. perfectly, while heating at 500 deg. for 8 days does not affect appreciably the resistivity—increasing it slightly, in fact. The *asbestos roll fire-felt* (Johns-Manville) is an asbestos cloth, flexible and very tough. It is made of pure long staple asbestos, can be used at temperatures up to 600 deg. C. and has no distinct temperature coefficient. The *"C" fibre* listed (Johns-Manville) consists of asbestos fibre with a small amount of some powdered material. It can be used at 500 deg. C., but is not self-supporting. The *asbestos fibre* figures relate to five samples from the Eimer-Amend Company, New York. They apparently do not change on heating to 500 deg. C. The *asbestos sponge felt* (Johns-Manville) consists of layers of asbestos paper each about 0.04 inches thick. The manufacturer states that it is made of asbestos fibre and finely ground sponge. It cannot be used at temperatures exceeding 200 deg. C., as it loses all strength above this. It is a self-supporting material.

TABLE II

THERMAL RESISTIVITY OF INSULATIONS CONTAINING ASBESTOS

Material	Density	Temp.	r	Ref.
Diatomaceous earth and asbestos	20.7	400 to 0	550	1
85 per cent magnesia	13.5	400 to 0	600	1
35 per cent magnesia	29.8	0 to 400	480	1
Air-cell asbestos	15.6	0 to 200	400	1
Asbestos fire-felt	7.18	200	740	1
	7.18	300	620	1
	7.18	400	430	1
Navy brand asbestos fire-felt	19.8	500	465	1
		300	523	1
		100	793	1
Asbestos roll-fire fire-felt	35.8	0 to 600	490	1
"C" fibre	22.9	100	518	1
	22.9	200	448	1
	22.9	300	395	1
	22.9	400	374	1
	22.9	500	358	1
Asbestos fibre	12.5 to 18.7	500	450 to 550	1
Asbestos sponge felt	34.4	100	1020	1
		200	830	1

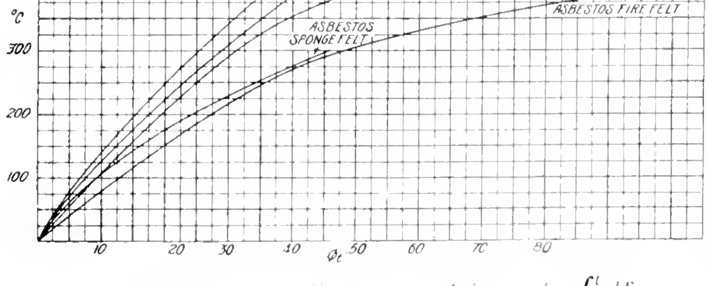


Fig. 2. Relation Between Temperature and ϕ_c. $\phi_c = \int_0^t c\,dT$

Nature and Composition of Miscellaneous Insulating Materials Listed in Table III

The first set of figures on *poplox* relate to a material made from sodium silicate (dried water glass) of the composition 1 Na_2O, 3 SiO_2. It is made by drying and grinding water glass, and then "popping" in a revolving tube furnace heated on the outside. Each particle usually forms a small hollow bulb, the size depending on the fineness of the grinding, usually $\frac{1}{32}$ inch to $\frac{1}{8}$ inch diameter. After popping, further slow drying will increase the temperature to which the material may be heated without sticking When freshly made this material is not affected by heating up to 300 deg. C. and it will be noticed that it is an extremely light material. The second set of *poplox* figures relate to a material made from sodium silicate of the composition 1 Na_2O, 3.8 SiO_2. This forms a very compact mass when pressed. The measurements were made on the undried sample, when it can be heated to 400 deg. C. without sticking. The third *poplox* sample is the same material as the preceding, except that it was dried at 400 deg. C. for two weeks and then kept at 500 deg. C. for 48 hours. It withstands heating to 500 deg. C. but no higher.

TABLE III

THERMAL RESISTIVITY OF MISCELLANEOUS MATERIALS

Material	Density	Temp.	r	Ref.
Poplox . .	1.43	200	973	1
	1.43	300	713	1
Poplox . .	3.93	200	1125	1
	3.93	300	880	1
	3.93	400	760	1
Poplox .	5.80	200	1040	1
	5.80	300	958	1
	5.80	400	786	1
	5.80	500	590	1
Mineral wool .	26.6	500	570	1
Steel wool . .	4.74	100	443	1
	6.30	100	457	1
	9.49	100	498	1
Silex . . .	65.5	500	387	1
Silica . . .	106	500	154	1
	102	500	153	1
	91.8	500	155	1
Aluminum powder . . .	51.4	100	138	1
		300	107	1
		500	94.7	1

The *mineral wool* from Eimer & Amend, New York, stands heating to 500 deg. C. The *steel wool* from the American Steel Wool Manufacturing Company, consists of long thin strips of steel that will burn when ignited with a match. The *silex* consists of extremely finely ground silica, resembling flour. It stands 800 deg. C. without shrinking. The *silica* is a coarse quartz from Eimer & Amend. The particles are very irregular and from $\frac{1}{32}$ in. to $\frac{1}{8}$ in. mean diameter. Ordinary coarse sand has then a resistivity of about 150 and will stand temperatures of about 1500 deg. C. The values for *aluminum powder* were checked over on different samples. This material will stand 500 deg. C.

Nature and Composition of Ceramics Listed in Table IV

One of the columns in the table shows the chemical composition of a number of these materials. With regard to the others it may be pointed out that the *alundum* comes from the Norton Company, Worcester, Mass. The three variables are sizes of grain, percentage of bond, and kind of bond. For numbers 84, 184, 225 and 98, the percentage of bond is the same, but the size of grain increases in the order given and is still larger in 217. 217 is supposed to have a greater amount of elasticity than any other. The bond is a mixture of clays. The *chromite and clay brick* contains chrome ore with a large amount of clay binder, making practically a clay brick. For *glass* the figures represent an average of several kinds, varying 10 per cent from the mean, plus and minus. The *glass pot brick* is made from the mixture used in making glass pots and is burned for 60 days. The *graphite brick* (composition given in the table) is the best-conducting brick which we possess, but of course cannot be used at high temperatures in an oxidizing atmosphere. The *retort brick* is made from a mixture used for making gas retort brick; while the two *stone ware bricks*, vitrified and not vitrified, are made from the same mixture.

The thermal resistivity of air, neglecting convection, between 100 and 0 deg. C., at atmospheric pressure, is 1430 (calculated);* very few materials are as good as this. The resistivity of gases is

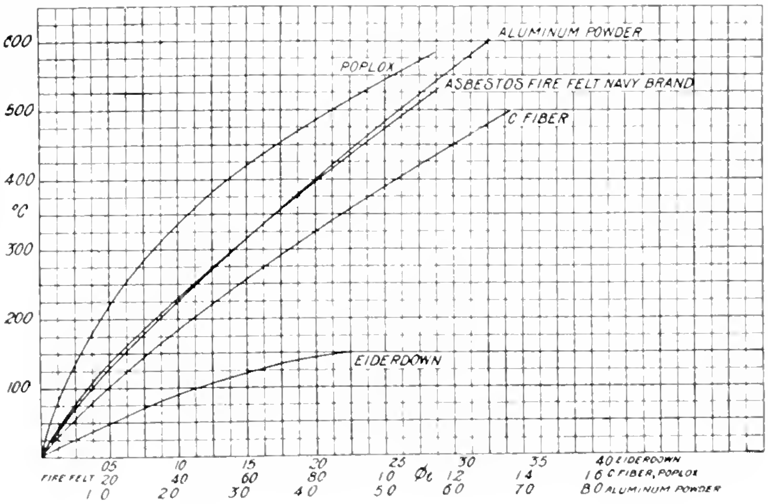


Fig. 3. Relation Between Temperature and ϕ. $\phi = \int_0^t c\,dT$

independent of the pressure till a critical point is reached at very low pressures; and, by exhausting to

* Langmuir Phys. Rev. 34, 401 (1912).

TABLE IV—THERMAL RESISTIVITY OF CERAMICS

Material	Chemical Composition	Temp. of Firing	Density	Temp.	r	Ref.
Alundum RA225			127	600	37.6	1
RA217			149	600	67.9	1
RA98			118	600	40.9	1
RA184			131	600	42.2	1
RA84			145	600	50.0	1
Bauxite brick	$SiO_2=28$, $Al_2O_3=66$, $FeO=5$	1050	118	1000	30	3
		1300	120	1200	28	3
Building brick, red	$SiO_2=75$, $Al_2O_3=14$, $Fe_2O_3=6$, $CaO=3$, $MgO=2$	1050		1000	27	3
	$SiO_2=74$, $Al_2O_3=16$, $Fe_2O_3=6.5$, $CaO=2.5$, $MgO=1$	1050	121	1000	34	3
Vallauris clay				1000	38	3
Light clay				1000	38	3
Building brick, white		1050	118	1000	25	3
Carborundum brick	$SiC=87$, $SiO_2=12$, $Fe_2O_3=0.4$	1050		1000	6.5	3
		1300		1200	4.1	3
	$SiC=75$, $SiO_2=20$, $Al_2O_3=3$, $Fe_2O_3=1$, $CaO+MgO=1$	1300	122	1200	6.7	3
Checker brick			112	1200	25	3
Chromite brick		1300		1200	38	3
			128	1200	17	3
				1200	14	3
Chromite and clay brick		1050	144	1000	34	3
		1300	155	1200	28	3
Fire brick	$SiO_2=78$, $Al_2O_3=18$, $Fe_2O_3=3.3$, $CaO=0.5$	1050	111	1000	25	3
		1300	120	1200	18	3
	$SiO_2=66$, $Al_2O_3=29$, $Fe_2O_3=4$, $CaO=0.5$	1050	111	1000	27	3
		1300	178	1200	22	3
Feldspar				100	17	7
Glass				15	63	5
Glass pot brick		Green		600	38	3
		1200	116	1200	38	3
		Green	110	600	30	3
		1600	122	1200	21	3
Graphite brick	$C=48.5$, $SiO_2=30.5$, $Al_2O_3=18$, $Fe_2O_3=2$		112		3.9	3
					3.8	3
Gypsum, artificial				0	105	6
natural				0	30	6
Kieselguhr brick			64.4	1200	52	3
Magnesia brick	$SiO_2=1$, $Al_2O_3+Fe_2O_3=0.5$, $MgO=95$	1050	125	1000	16	3
		1300	125	1200	14	3
				1200	13	3
Magnesia and clay brick				1200	26	3
			126	1200	32	3
Porcelain				100	38	4
Porcelain		1400			20.4	3
		1400			21.8	3
Quartz				0	6.0	6
Retort brick			116	1200	25	3
Sevres stoneware				1300	20.8	3
Silica brick	$SiO_2=94$, $Al_2O_3=2$, $CaO=2$	1050	98.5	1000	47	3
		1300	93.5	1200	30	3
Stoneware brick		1050		1000	30	3
		1300	136	1200	20	3

extremely low pressures, we can prevent heat transfer better than by the use of any of the above insulating materials. The best Dewar flasks, which are made similarly to the present Thermos bottle and consist of a double-walled glass vessel silvered in the vacuum space to decrease radiation, allow a flow of heat between the inner and outer vessels of about one-fifth to one-tenth† that which eiderdown allows for an equal temperature difference, through a layer one inch thick. Eiderdown has the highest thermal resistance of any material we have studied yet.

An outline of the methods of using the above data.

In ordinary practice we usually wish to calculate the energy lost from a body surrounded with insulation; and usually the area of the path of heat flow is not constant, but is a function of the distance from the hot body. For example, suppose we have a sphere 6 inches in diameter surrounded with 6 inches of insulation. What area must we use in calculating the heat losses?

† From measurements by W. E. Ruder of the Research Laboratory.

We have the differential equation defining specific thermal conductivity:

$$c = \frac{dW}{dT} \cdot \frac{dL}{dA}$$

For perfectly symmetrical figures this reduces to

$$W = \frac{A}{dL} \int_{T_1}^{T_2} c\,dT = \frac{A}{dL}(\phi_2 - \phi_1), \text{ in which } \frac{A}{dL}$$

is the *shape factor*.

Putting $s = \text{shape factor} = \frac{A}{dL}$,

(4) $W = s\,(\phi_2 - \phi_1)$,

which gives us the watts per square inch. Only three cases that are approximated in practice satisfy the requirement that the heat flux shall be constant throughout any isotherm and therefore allow s to be calculated:

(1) Conduction between two infinite parallel planes:

$$s = \frac{A}{L}$$

(2) Conduction between two concentric cylinders, infinitely long. All calculations of losses from insulated steam pipes involve this formula, as the length is here so great that any end effect is negligible.

Let a = radius of inner cylinder
b = radius of outer cylinder.

It can be shown that, per unit of length,

$$s = \frac{2\pi}{\log_e \frac{b}{a}}$$

(3) Conduction between two concentric spheres, a and b being the radii as above. It can be shown that

$$s = \frac{2\pi}{\frac{1}{a} - \frac{1}{b}}$$

For non-symmetrical figures, as a cube surrounded with insulation of uniform thickness, where the heat flux is not constant throughout all isothermal lines in the insulation, it is impossible to calculate rigorously the shape factor, although it can be often approximated by the substitution of one of the above cases for the actual one. A study of the more usual figures has recently been made by I. Langmuir, E. Q. Adams, and G. S. Meikle, of the General Electric Research Laboratory, and a full account will shortly be published in the Transactions of the American Electrochemical Society. Their method was to substitute an electrolyte for thermal insulation, and to study the electrical conductance instead of thermal conductance, which is more convenient and allows of more accuracy. Conductance for any shape was divided into parts more or less approximated by the above derived shape factor formulæ. To illustrate the general method, consider a rectangular prism, surrounded with insulation of uniform thickness. The following formula was found to be accurate for calculating the shape factor. Let

A = total surface area of inner prism.
L = thickness of insulation.
$\Sigma 1$ = sum of lengths of edges of the inner prism.

Then $s = \frac{A}{L} + 0.50\,\Sigma 1 + 1.20\,L$.

By the use of formulæ similar to this, we are able to calculate now the thermal losses from nearly all ordinary shapes and with a good many kinds of insulation.

KEY TO REFERENCES IN TABLES

(1) C. P. Randolph, J. Am. Elec. Soc. XXI, (1912) 545. This reference gives the method. The values are taken from various reports to the Research Laboratory.

(3) S. Woologdine. Elec. & Met. Ind. VII, 383 (1909). These results are accurate within 10 per cent between 0 deg. and 1000 deg. C. The method of measurement was to imbed thermo-couples in disks of the material, heating one side with a gas flame and cooling the other with water. The heat flux was calculated from the rate of flow and the rise in temperature of the water. The column headed temperature gives the range over which resistivity can be applied.

(4) Lees & Chorlton. Phil. Mag. (5), 41, 495; 1896.

(5) Meyer. Wied Ann. 34, 596; 1888.

(6) Weber. Arch. Sc. Phys. (3), 33, 590; (1895).

(7) Ayrton and Perry, Phil. Mag. (5), 5, 240; 1878.

DIRECT CURRENT LOCOMOTIVES FOR INTERURBAN AND MAIN LINE SERVICE

PART II

By S. T. Dodd

Railway Locomotive Engineering Department, General Electric Company

This article describes the more important features of construction embodied separately in four sizes of locomotives for direct current 600-volt operation, broadly classified as the 25-ton, 50-ton, 75-ton and 100-ton units. Part I gave a general discussion of the approximate fields of application of each size; and dealt with their design under the headings of motor equipment, truck design, platform framing, and superstructure. This month's section covers control and operation, and concludes the paper with a brief discussion of some curves relating to a very interesting series of tests taken on a 100-ton locomotive hauling a freight train.—Editor.

Control Apparatus

For all types of locomotives the same general type of control is required. Occasionally for small switching locomotives, where the horse power of the motors is not excessive, it is possible to employ a control system in which the main motor current is handled directly on the controller itself; but usually it is preferable to adopt the system in which a smaller master controller is employed, with contactors located in the auxiliary cabs. Such a scheme presents advantages in location and arrangement, safety to the operator, and ease of repair which make it preferable for locomotive service. The capacity of the rheostats and the number of control steps vary with the weight of the locomotive and the character of service. For small locomotives the motors are generally connected permanently two in parallel and are controlled with a relatively small number of control steps; but with the larger sizes of locomotives it is usually found necessary to have three running positions. The motors start all four in series, and at full speed are connected all four in parallel, with an intermediate series-parallel speed and with a resulting increase in the number of control steps. The following table gives approximately the number of control steps used for various weights of locomotives.

25-ton type—6 steps motors in series-parallel, 4 steps in parallel.

50-ton type—7 steps series-parallel, 5 steps parallel.

75-ton type—9 steps series, 8 steps series-parallel, 7 steps parallel.

100-ton type—10 steps series, 9 steps series-parallel, 8 steps parallel.

Location of Apparatus

The location of apparatus for 600 volt locomotives is so completely standardized that a description of one type serves for all. The illustrations, Figs. 11 to 14 inclusive, show the arrangement of apparatus in the 100-ton type. Practically the same description and the same illustrations would apply to any of the smaller types.

The central or main cab contains the apparatus which is manipulated in the direct control of the locomotive, including master controllers, air compressor, brake valves and controlling switches. The end cabs contain auxiliary apparatus such as rheostats and contactors. The engineer's operating seats are placed at diagonally opposite corners of the main cab. At each of these positions a leather-cushioned seat is hinged against the side of the cab; and an arm-rest is attached to the operating window-sill so that it may be laid across the sill when the window is open, or laid back, out of the way, when it is closed. The master controller is located within easy reach of the engineer's left hand. Directly in front of him are located the handles of the sanders and brake valves. The sander valves control the operation of pneumatic sanders located in each end cab, which are arranged for sanding the track in front of the locomotive when going in either direction. Two brake valves are supplied, one for operating the automatic air system for braking the train, the other for operating the straight air system when applied to the locomotive alone. Reducing valves for the air brake system are located against the cab wall directly behind the engineer's seat.

An illuminated duplex air gauge is placed at the right hand side of the engineer's window, and is illuminated with a 1 c-p. 10 volt shaded lamp connected across a section of the headlight rheostat. The headlights are of the luminous arc type and are mounted on the main cab directly between the front windows. These headlights are of a standard portable street-car type, and the terminals

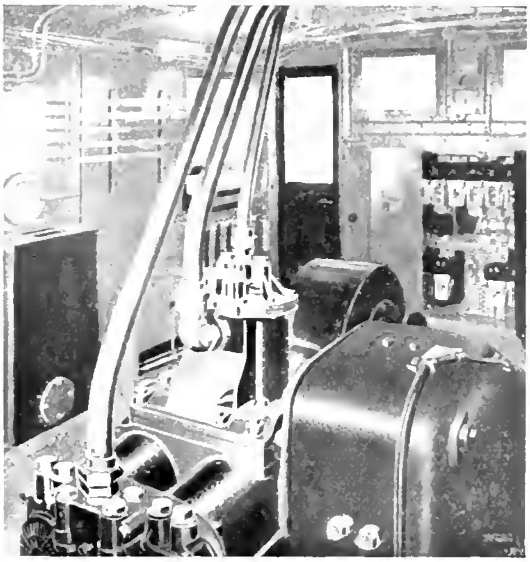


Fig. 11. Air Compressor and Contactors

Fig. 12. Control Apparatus

are plugged into terminal boxes located under the cab roof. A switchboard is mounted in the interior of the main cab occupying the space between the front windows, and contains the switches for the auxiliary circuits. These include one main auxiliary switch, two switches for the headlights, one for the cab lights, one for the compressor, and two switches for the control circuits.

Fig. 15 shows a 75-ton locomotive with end cabs removed, and gives a good view of the arrangement of the auxiliary apparatus. At the outer end of the platform are located the air reservoirs and sand

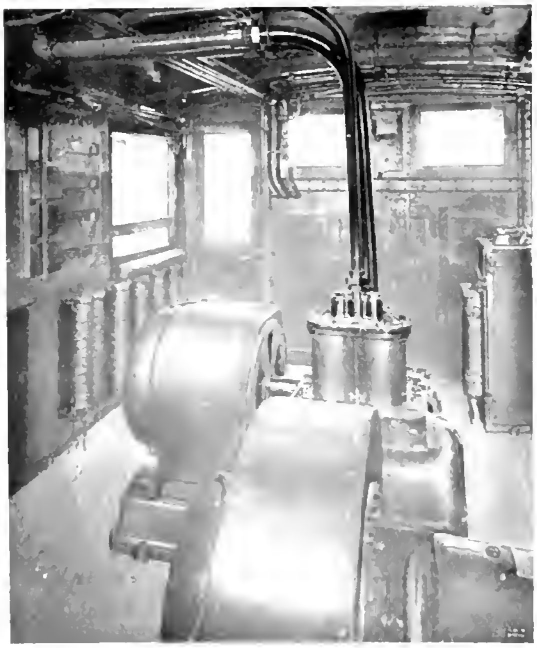


Fig. 13. Motor Driven Blower

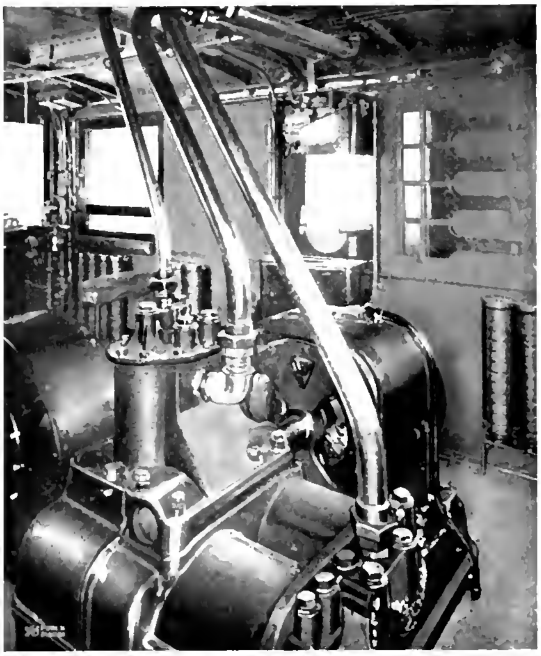


Fig. 14. Motor-Driven Air Compressor

boxes. Next to them are the rheostats and in front of them a bank of contactors supported on a channel iron framework.

All the wiring in the locomotive is drawn through conduits which are built into the locomotive during construction. The conduits and piping in the main cab are bracketed against the walls. A false flooring of wood is laid in the main cab and all conduits and pipes crossing the cab are cleated to the iron floor and covered by this false flooring.

The central piece of apparatus in the main cab is the air compressor. The various parts which may require attention such as valves, piston rings, brushes, etc., are naturally on different sides of the compressor. It must, therefore, be accessible from every side and for this reason the center of the cab has been chosen for its location rather than a less prominent place. Figs. 11 and 14 show the compressor and the piping leading to it. In passing from the low pressure to the high pressure cylinder the air is carried through a two-inch pipe to the roof of the cab; and then through about thirty-five feet of pipe lying on

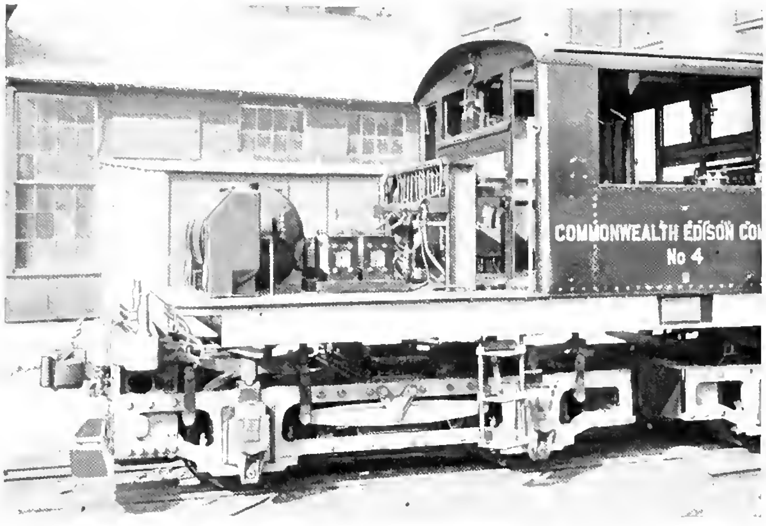


Fig. 15. 75-Ton Locomotive with End Cab Removed, Showing Auxiliary Apparatus

pneumatic governor for the control of the compressor is mounted on one side of the cab and is shown in Fig. 14.

The motor-driven fan for the forced ventilation of the motors is placed beside the compressor. Against the side walls of the cab, as shown in Figs. 13 and 14, are mounted the electric heaters and racks for the insulating paddles and flags. Sand boxes, for sanding the track in front of the rear truck, are also placed in the middle of the side walls

Contactors Closed on Each Step

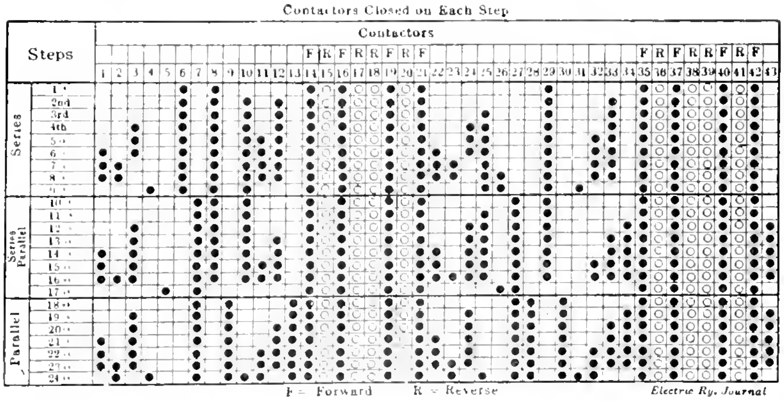


Fig. 16. Diagram of Controller Connections

the roof, which provides a radiating surface to reduce the temperature of the air before it enters the high pressure cylinders. A similar length of radiating pipe is inserted between the high pressure cylinder and the main reservoir for the same purpose. The electro- and are operated from the engineer's position simultaneously with the forward sand boxes in the auxiliary cabs. Fig. 12 shows apparatus around the engineer's seat, an arrangement which has been described above.

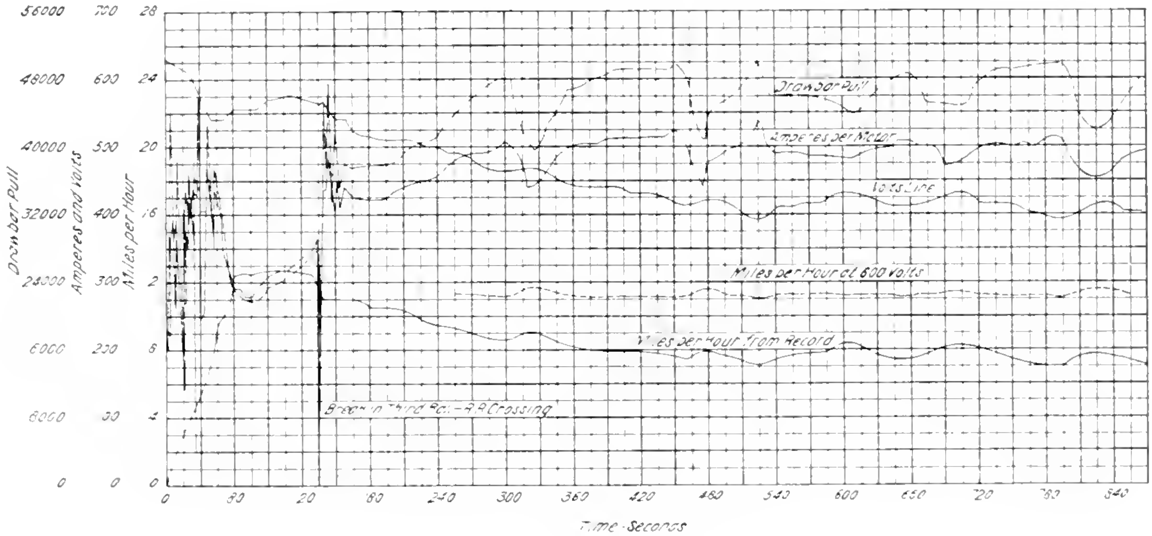


Fig. 17. Running Curves—22-Car Train

Operation

As has been abundantly illustrated in this article, a very careful study must be made of the conditions surrounding the handling of freight traffic on interurban and steam roads; and of the requirements of design and construction necessary to meet these conditions to make for economy in construction and convenience in operation. A good illustration of the operating results is shown in a series of tests made upon a 100-ton locomotive in accelerating a freight train, the results of some of which have been plotted in the curves shown in Figs. 17, 18 and 19. The difficulty presented in starting such a train is that a train of 1000 to 1500 tons consisting of 40 or 50 cars is not a rigid mass, but a long elastic body; and any inequality in the starting torque results in waves of jerking and buffing strains, which may easily reach abnormal values in some parts of the train.

The control circuits are arranged so that the motors may be operated in three different

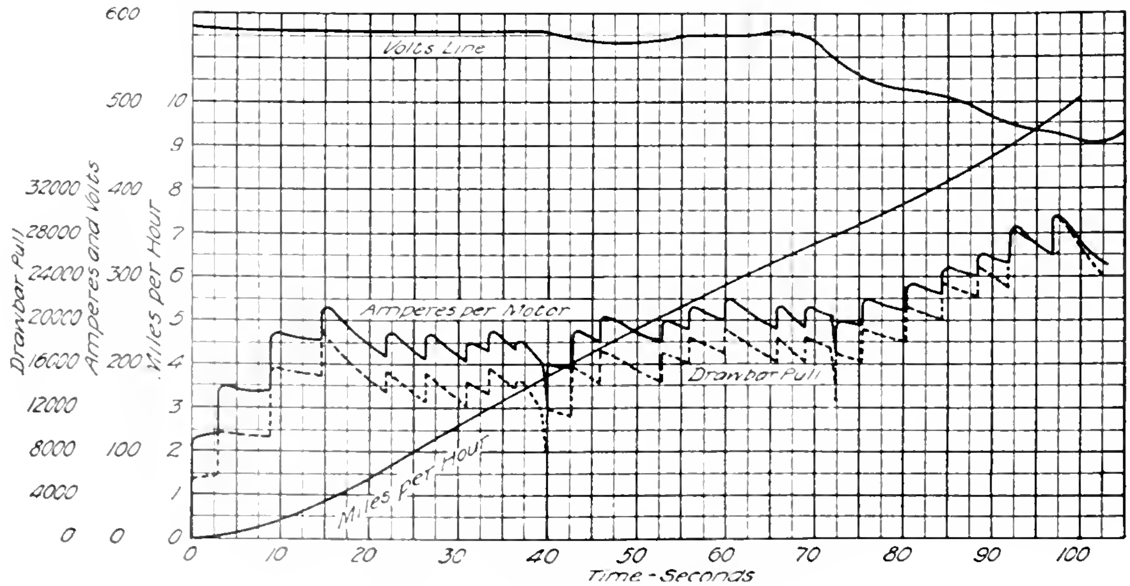


Fig. 18 Acceleration Curves—Locomotive and Twenty-six Freight Cars

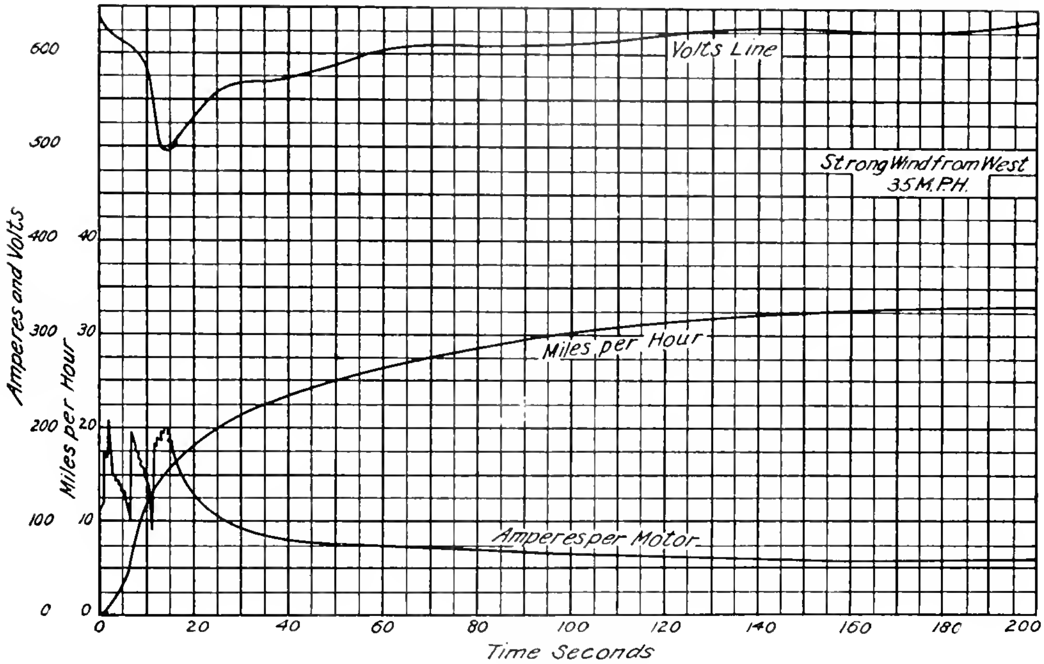


Fig. 19. Acceleration Curves—Locomotives Alone Ascending 0 1285 per cent Grade

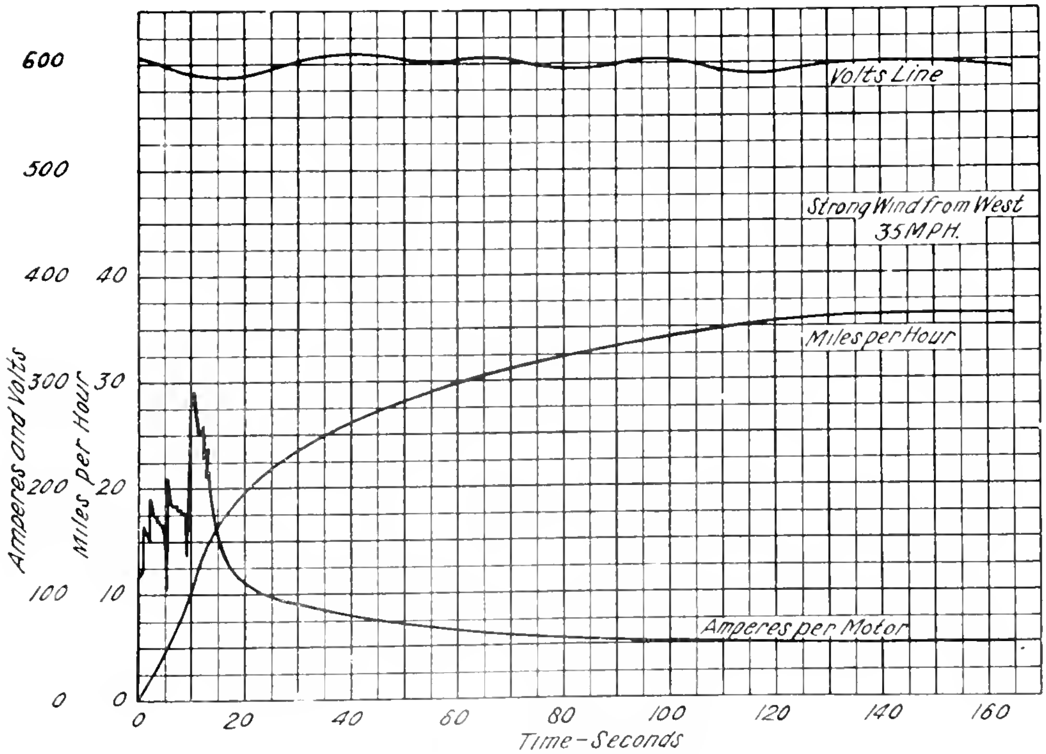


Fig. 20. Acceleration Curves Locomotives Alone Descending 0.1285 per cent Grade

combinations, either all four in series, two in series and two in parallel, or all four in parallel. There are nine steps in series, eight steps in series-parallel, and seven in the parallel position. A diagram of the control connections is given in Fig. 16. This control system produces an especially uniform increase of speed and torque during the period of acceleration. A smooth transition between the motor combinations is effected without opening the motor circuit; and smooth operation upon resistance points is obtained by the careful proportioning of the relative resistances on each step.

Fig. 18 shows the speed, current and tractive effort curves obtained in the acceleration of a train of 1578 tons consisting of the locomotive and twenty-six freight cars, from rest to 10 miles per hour, using this control. It will be noted that the maximum increase of the drawbar pull is about 6500 lb. on the first few steps; after which the maximum variation throughout the remainder of the acceleration is from 2000 to 3000 lb. The practical effect of this smooth acceleration is apparent to an observer standing in the caboose of such a train, in that the rear end of the train is started so gradually that the beginning of the motion is almost imperceptible. The contrast of this with the results obtained with a steam locomotive is very striking.

As an illustration of the maximum speed conditions, Fig. 19 shows the acceleration of the locomotives running light upon a grade of 0.1285 per cent. The speed conditions under heavy loads are seen in Fig. 17 which shows the locomotive running with a train of 1090 tons consisting of the locomotive and twenty-two cars. Hand brakes are used to supply the load representing the traction of this train on a 2 per cent grade. The average drawbar pull during the run was 46,530 lb. Fluctuations in the curves represent the adjustment of hand brakes necessitated from time to time in order to obtain the average drawbar pull required in the test.

ELECTRICAL EQUIPMENT AND OPERATION OF LIMESTONE QUARRIES

By John Liston

Publication Bureau, General Electric Company

The methods utilized for the various operations necessary in handling, crushing and delivering the products of quarries will depend largely upon the physical conditions and location of the quarry, and these conditions vary to such an extent that it is practically impossible to standardize an electrical equipment for this industry. There are, however, certain operations utilizing excavators, haulage systems, car dumps, crushers, elevators, screens and conveyors of various types, in which the mechanical problems have similar inherent characteristics, and for this reason the system of power application adopted by the engineers of the Michigan Limestone & Chemical Company at Calcite, Mich., as outlined in this article, will have a definite value for those entrusted with the designing of other quarry plants.—Editor.

The property of this Company is situated in Presque Isle County, in the north-east portion of the southern peninsula of Michigan, and consists of 8000 acres of land, with about eleven miles of frontage on the shore of Lake Huron. This acreage contains the greatest known deposit of high grade limestone. The location is especially favorable for the shipment of limestone by water, as it has a natural harbor of ample depth, and is practically in the center of a territory in which five million tons of crushed limestone are annually consumed for flux by the various blast furnaces located along the shores of the "Great Lakes."

The topographical conditions of Calcite may be briefly outlined as follows: The limestone formation at this point runs nearly parallel to, and at a short distance from, the lake shore, the section at present being worked consisting of a bluff approximately forty feet in thickness with an elevation at the crest averaging about seventy feet above the lake level. From the bottom of the bluff the ground slopes in a series of irregular terraces for a distance varying from 500 to 700 feet to the shore line. Along the base of the bluff runs a track which can be moved laterally with the progress of the work, and which connects the quarry with the crusher house by means of a trestle supported loop as shown in Fig. 1.

The quarrying equipment includes a Vulcan steam stripping shovel. After the rock is loosened by blasting it is gathered by means of two 100-ton Bucyrus steam shovels, which deposit the material into twelve-ton cars. Seven of these cars constitute a train, and are hauled by small steam locomotives to the crusher house, where their contents are successively dumped into a 42 in. gyratory crusher—the largest unit of its type in the world. From this point on all operations including the crushing, assorting and conveying of the rock until it is delivered to the storage pile or to the holds of ships for transport, are carried on automatically and utilize electric drive throughout.

There are in all eighteen motors aggregating 1280 h.p., and twelve belt conveyors covering a distance between centers of more than 2100 feet. As the various sections of the conveyor system are interdependent, it is essential that they operate with a close approach to synchronism, in order to realize the highest possible overall efficiency. This is accomplished with a minimum expenditure of power by applying individual motors to each section, driving through gears or relatively short belts, and maintaining uniform speed for all sections by virtue of the constant speed characteristics of the polyphase induction motors selected for the service.

For supplying current to the system a power station was constructed on the lake shore, about 200 feet south of the pier, and equipped with a 750-kw., 2300-volt, three-phase, 60-cycle, 3600 r.p.m., horizontal shaft, Curtis steam turbo-generator operating condensing at 150 lb. steam pressure. A separate 125-volt direct current turbo-generator of 25 kw. capacity is operated non-condensing, and, in addition to furnishing excitation current for the alternator, supplies the lighting and emergency cutout circuits for the plant. The power feeders transmit current at the generator voltage, and, with three exceptions, 2300-volt three-phase motors are used throughout.

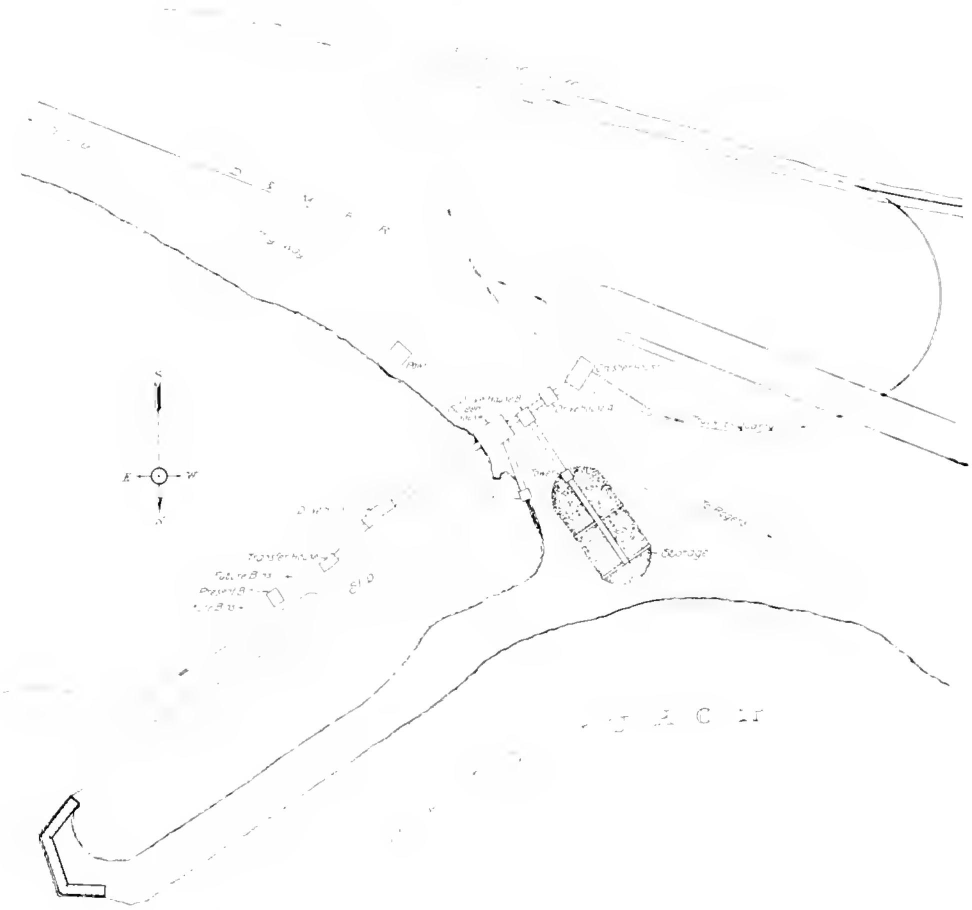


Fig. 1. Plan Showing General Arrangement of Plant at Calcite

The power station is provided with the usual switchboard equipment, and at the present time hand regulation is used. The entire plant is operated twenty hours per day under normal conditions, but the power station is in service continuously. Since it was started in June of this year only one shutdown due to the electrical system has occurred. This was caused by a drop in voltage which cannot justly be charged to the electrical system, but to the method of hand control which will be superseded at an early date.

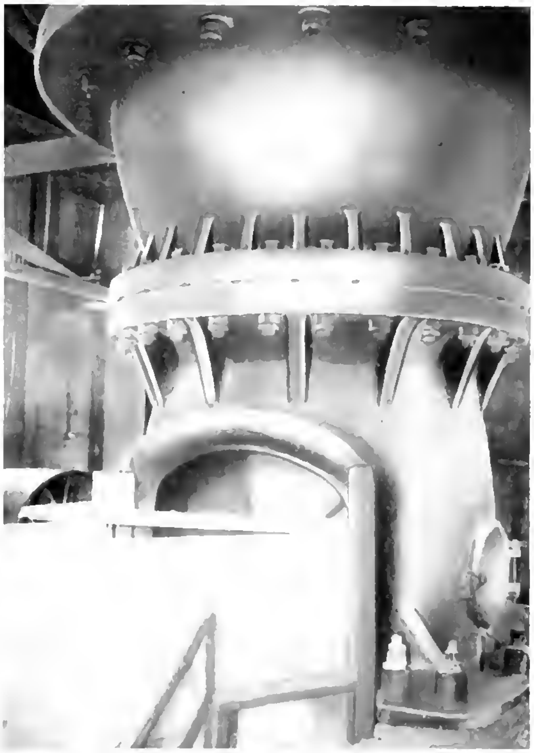
The first motor application is found in the crusher house, and consists of a 10 h.p., 220 volt alternating current, back geared motor, which drives a small winch with a steel hoisting cable passing over a pulley on a swinging structural iron beam located above the track. The car bodies are tilted sideways and their contents are thereby discharged into the crusher hopper. By this means it takes, approximately, one minute for the dumping of each car; and, as soon as the train has been unloaded, it continues around the loop, returns to the base of the quarry, and takes the place of another train which has in the meantime been loaded. As the trains of material are sent from both ends of the quarry, the feeding of rock to the crusher is as nearly continuous as operations of this kind can be made. The rock is delivered in any size which will enter the crusher, and is discharged in sizes not exceeding a diameter of eight inches. The dumping motor is of the wound rotor type and as it operates at 220 volts, current is supplied to it from the 2300 volt system through 2-7½ kw. delta connected transformers.

The crusher has a weight of five hundred thousand pounds and is driven through belting by a 200 h.p., 2300-volt, slip ring motor. The average load of this motor is approximately 60 h.p., and varies with the size and amount of rock delivered to the crusher from this load to a normal maximum of 265 h.p. The motor is not provided with an outboard bearing and has withstood this severe service without injury since it was installed. As a further instance of the overload capacity of this type of motor, it may be mentioned that the crusher has been started full from standstill, imposing a momentary load of 450 h.p., which has been safely carried by the motor.

From the base of the crusher the rock is discharged on to a 48-inch conveyor belt "A" (182 feet centers) having a capacity of 1450 tons per hour, which elevates it at an angle of 15 deg. to the screen house. Here it passes over an inverted V-shaped grizzly, which divides the load and delivers it in approximately equal volume to two inclined rotary screens. The driving motor for this conveyor is a 125 h.p. unit, back-geared to the driving pulley of the conveyor. The constant operating speed of the motor moves the traveling belt at a uniform rate of 400 feet per minute, regardless of the fluctuations of the load.

Owing to the interdependence of the various conveyor sections the belt speed has been standardized at 400 feet per minute, the only exception being two auxiliary belts in the recrushing section.

The rotary screens which assort the crushed rock each consist of a cylinder containing graduated perforations. They are seven feet in diameter and thirty-two feet long, and are individually driven by 50 h.p. motors which revolve the screens by means of a belt-driven jack-shaft, through direct gearing to the lower ends of the screens. These screens are the largest known units of this type, and separate the rock into three classes. That passing through holes less than one inch in diameter ("fines") is unfit for use as flux, and passes



Base of the Main Crusher

through a hopper below the screens to conveyor "C," running at right angles to the main conveyor line, and is carried to a "fines" bin, whence it is loaded into cars and utilized for filling. This cross conveyor "C" has a 24-in. belt of 250 tons per hour capacity, 140 feet between centers, and is driven by a 20 h.p. belt-connected motor, the load on which varies with the character of the rock passing through the screens, but does not normally exceed eighty per cent of the rated capacity of the motor.

The rock which passes through the perforations in the second section of the screens varies in size from one inch to six inches in diameter, constitutes a suitable "flux stone" which is received into a bin and from thence is spouted onto the main conveyor line, which carries it out to the pier; or else it is delivered to the belts serving the storage pile.

From the lower ends of the screens the "oversizes" are fed directly to two small gyratory crushers which are individually driven by 75 h.p. belt-connected motors. From the crushers the rock is elevated by two 30-in. belts ("B1" and "B2") of two hundred and fifty tons per hour capacity each, to a chute which re-delivers it to the conveyor "A". Along this it is again carried to the screen room, where the screening process is repeated. The belts B1 and B2 are each driven at a speed of 200 ft. per minute by a 20 h.p. belt-connected motor. This portion of the equipment will, however, be discarded at an early date, inasmuch as it has been found entirely feasible to eliminate the re-screening process by alterations on the small crushers, which will enable their output to be delivered directly to the conveyors leading to the loading dock or to the storage pile.

The relative locations of the crushers, screens and conveyors referred to above are shown in Fig. 2. The conveyor system for carrying the "flux stone" between the screen house and the loading bin on the pier is divided into three sections comprising three 44-in. belts "G", "H" and "H1", having a uniform capacity of 1300 tons per hour with a length between centers of 360, 140, and 130 feet respectively. Individual motor drive is used, there being two 125 h.p. motors geared to the driving pulleys and one 35 h.p. belt connected. In passing over the conveyors along the pier the "flux stone" is elevated about 54 feet and is deposited by the belt "H1" into a loading bin, having a capacity of 500 tons, near the outer end of the pier.

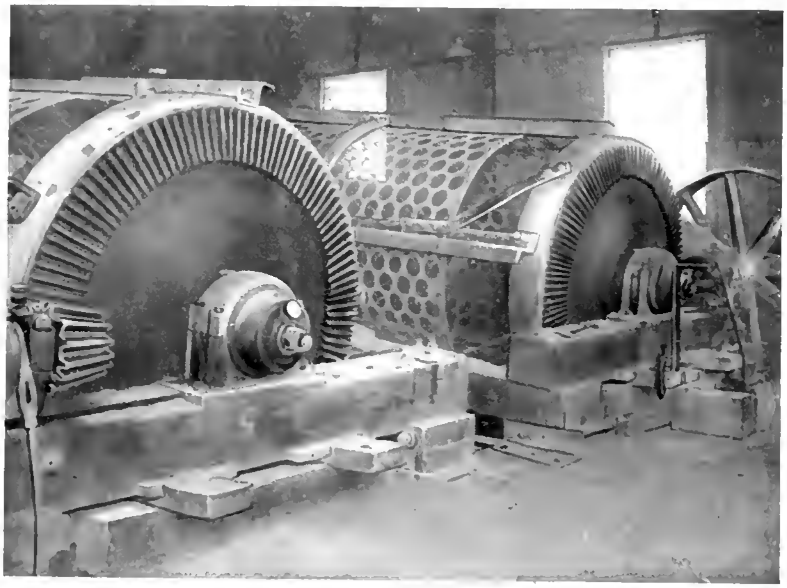
Up to this point all the motors used, with the single exception of the 10 h.p. unit driving the car-dumping winch, are slip ring machines with wound rotors and external resistances and give 150 per cent full load torque with approximately 150 per cent of full load current at starting. This type was selected for the reason that it would sometimes be necessary to start up the plant after a shutdown with the crushers, screens and conveyors either partially or fully loaded; under which conditions the use of the squirrel cage type of motor would cause a momentary current demand which might be in excess of the capacity of the generating equipment. With the slip ring motors, however, reliability in starting the machinery is assured even under the most adverse conditions.

The method used to deliver the "flux stone" to the holds of the lake steamers utilized for transport, is of especial interest, due to the unusual mechanism employed; and furnishes an excellent example of the adaptability of motor drive to special conditions. From the loading bin the "flux stone" drops through a manually-operated gate to the belt of a shuttle conveyor which operates at right angles to the delivering conveyor line, and consists of a structural steel framework, carrying an endless belt 48 inches in width and mounted on stationary wheels, so that it can be moved longitudinally. When in service it is projected over the hold of the ship and delivers its load in a constant stream at an average rate of 1000 tons per hour; its maximum capacity being 1400 tons per hour.

For the operation of this shuttle-conveyor two 20 h.p., 220-volt, squirrel cage motors are used. One of these is mounted directly on the conveyor framework and is back-geared to the driving pulley of the belt. The other is installed on a platform just below the conveyor and through gearing drives a drum which is provided with a steel cable connected to both ends of the conveyor framework, so that the operation of the drum serves to project or withdraw the conveyor to compensate for varying sizes of hatchways in the different ships, and to make the adjustments necessary for an even deposit of the "flux stone" in the hold.

This system of loading has proved extremely flexible in service. The control of the motors and bin gate is centered in an operator's house located above the shuttle, so that the loading process is in full view and in instantaneous control of the operator. The load conditions require a comparatively low starting torque, and do not impose severe demands on the current supply. For this reason the simple squirrel cage type of motor was selected, current being supplied to the motors from the 2300-volt feeder line through two 10 kv-a. 2300 220 volt transformers.

At present it takes about six hours to load a 6000-ton ship, and it is necessary to warp the ship along the pier as the successive hold compartments are filled. Upon the completion of the construction work at Calcite, however, there will be seven additional loading bins with their concomitant shuttle conveyors, so that a 6000-ton ship can then be loaded in approximately two hours.



Sorting Screens Each Driven Through Countershaft by a 50 H.P. 2300 Volt Induction Motor

Since quarrying operations were started in June, 1912, shipments of limestone for furnace flux have been sent by water to Buffalo and Chicago, and under normal weather conditions this service can be continued during seven or eight months each year. The facilities at Calcite include a slip, 1100 ft. long and 90 ft. wide, with a 21 ft. depth of water at the pier, so that the largest lake vessels may be utilized to transport the quarry output. A safe harbor has been assured by the construction of a stone breakwater, 1200 ft. in length and 80 ft. in width, which affords ample protection for the ships during the process of loading.

It is obvious that the loading of the ships cannot be made a continuous process, as some time must elapse while a loaded ship is clearing the harbor and an unloaded one is being brought alongside the pier. At the same time it is essential that the operation of the crushing and conveying system be maintained without interruption if the maximum efficiency of the plant is to be realized. To render this possible, storage facilities, having a recoverable capacity of 13,000 tons, have been provided.

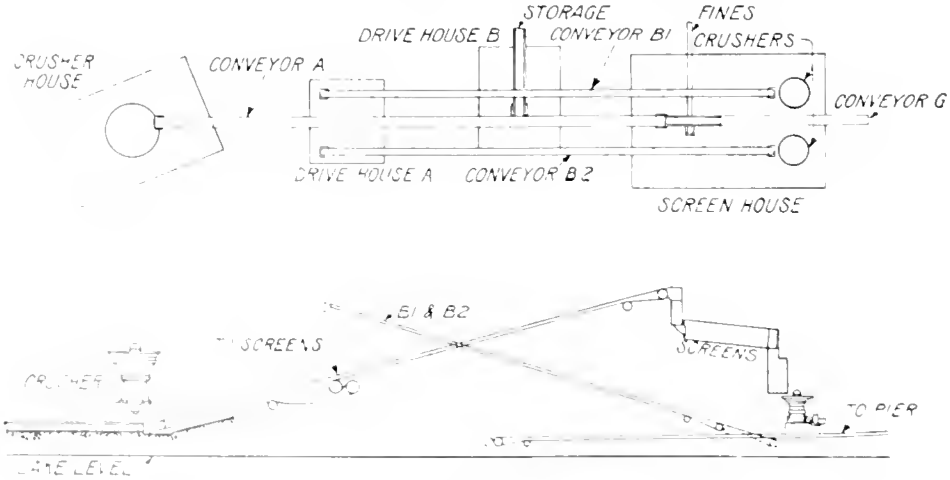


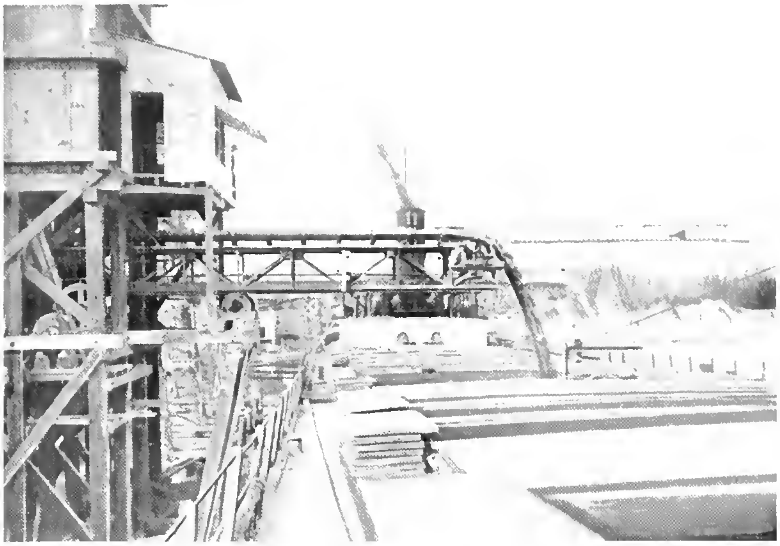
Fig. 2. Plan and Elevation Showing Relative Positions of Crushers, Screens and Conveyors Between Main Crusher House and Shore Line

When the "flux stone" is to be transferred to the storage pile it is carried by a short belt "D1" (68 ft. centers) to drive-house "B"; and is there deposited on a cross-conveyor "D", which elevates it at an angle of 15 deg. and delivers it to conveyor "E", running horizontally over the storage pile at an elevation of 65 feet above the lake level. These three belts are 40 in. in width and have a capacity of 1000 tons per hour. The short transfer belt utilizes a 35 h.p. belt-connected motor, while the elevating and delivering belts are driven by a 150 h.p. motor centrally located in a tower at the head of the storage pile (see Fig. 3) and gear connected to the driving pulleys at the junction of the two belts.

The delivering belt "E" is 190 ft. between centers and is installed on a structural steel bridge with A frame supports, mounted on concrete foundations, so located that the steel work is not subjected to abrasion by the running stone. A tripping device operates along the belt and insures an even distribution of material on the storage pile.

125 H.P., 2300 Volt Induction Motor Driving Conveyor Belt "H"

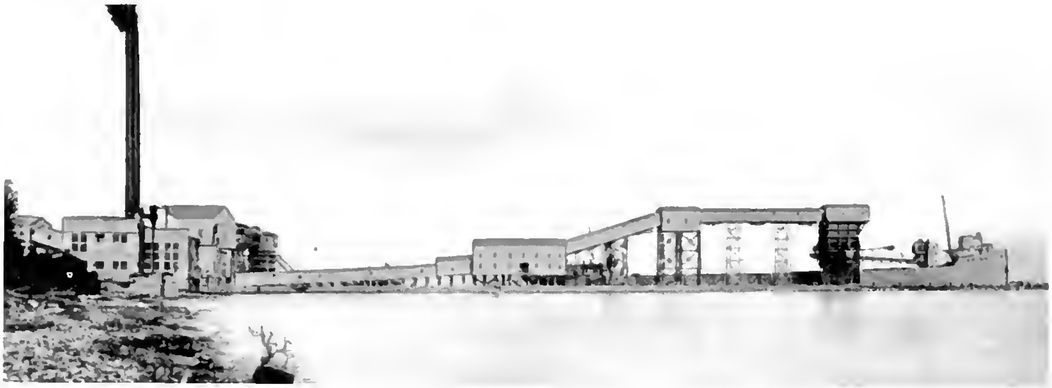
Under the bridge and parallel to it is a reinforced concrete tunnel provided with a row of gates located on either side near the tunnel top. When the stone is withdrawn from the storage pile it passes, by gravity, through these gates; and is deposited on a 14-in. reclaiming belt "F" (360 ft. centers) which runs level in the base of the tunnel, and is thereby re-conveyed to drive house "B". Here it is discharged onto the main conveyor line, and is carried directly to the loading bin on the pier. Conveyor "F" is gear driven by a 125-h.p. motor and has the same capacity as the main conveyor line, or 1300 tons per hour.



Shuttle Conveyor, Driven and Adjusted by Two 20 H P., 220 Volt Induction Motors, Delivering Flux Stone to Ship

When the stone is being delivered to the storage pile the reclaiming conveyor and the pier conveyor line are not in service, and the storage pile is drawn on when the crushing and screening machinery is not in operation; but when the rock is passing directly from the main crusher to the loading bin, none of the motors on the storage system are used. Due to this division of the power demand the 750 kw. turbo-alternator can at all times supply sufficient current for the operation of the plant, although the aggregate rated capacity of the motors on the feeder circuits is greatly in excess of the power station output.

The conditions under which the motors operate, vary with their location. Some are mounted on substantial concrete foundations, while others are supported on wooden beams. Those in the crusher and screen houses are unavoidably subjected to a certain amount of vibration. All are of the open-frame type, and with a few exceptions are not at present housed in; but operate, sometimes 24 hours



Power Station and Structure of Pier Conveying and Loading System

per day, in an atmosphere carrying considerable limestone dust. The motors have dust-proof bearings, and are cleaned each day with air, so that there have been no injuries due to dust. Eventually dust-proof housings will be provided with air-ducts in top and bottom,

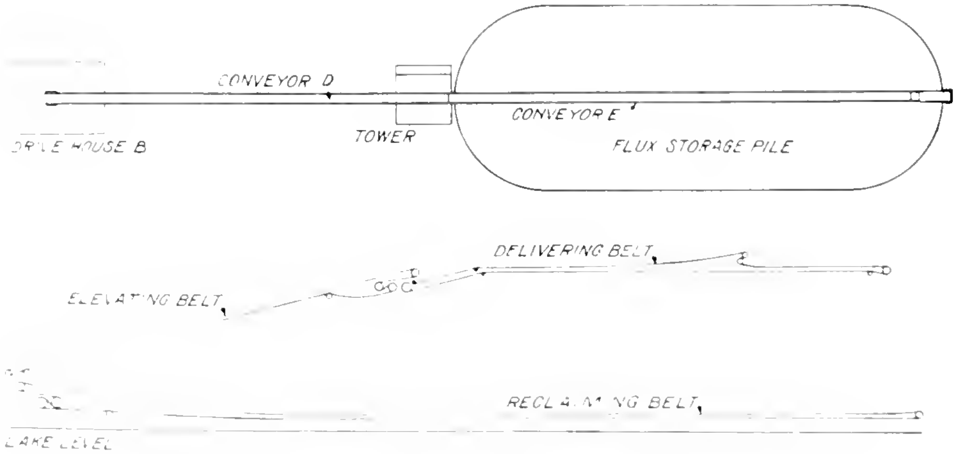


Fig. 3 Plan and Elevation Showing Arrangement of Delivering and Reclaiming Belts of the Storage System

which will give natural ventilation directly proportional to the heating effect.

The auxiliary motor equipment includes controllers, oil-switches and time limit relays, to take care of individual overloads, but no circuit-breakers or fuses are used as the safety of the equipment is assured by a simple but very reliable emergency system, which controls the motors in two groups and cuts out of service all the units in either group in the event of the injury or stoppage of any individual unit. The arrangement of this emergency system is as follows. All the motors are supplied from the power station by two main feeder circuits. The first feeder "A" serves the motors on the shore, including those on the storage system, while the second feeder "B" supplies the pier and shuttle conveying motors. By means of snap-switches located at various points in the plant, or carbon contacts on the motor panels connected across two independent direct current circuits, which are supplied by the direct current turbo-generator in the power station and are therefore uninfluenced by the alternating current power circuits, the trip coils on the oil-switches of either of the feeder circuits may be tripped, thereby stopping the motors throughout the section. In this way congestion of material at any one point, due to the shut-down of a motor, is obviated. The condition of the power circuits is indicated by red lamps connected across the emergency circuits, which remain lighted as long as the power circuits are alive.

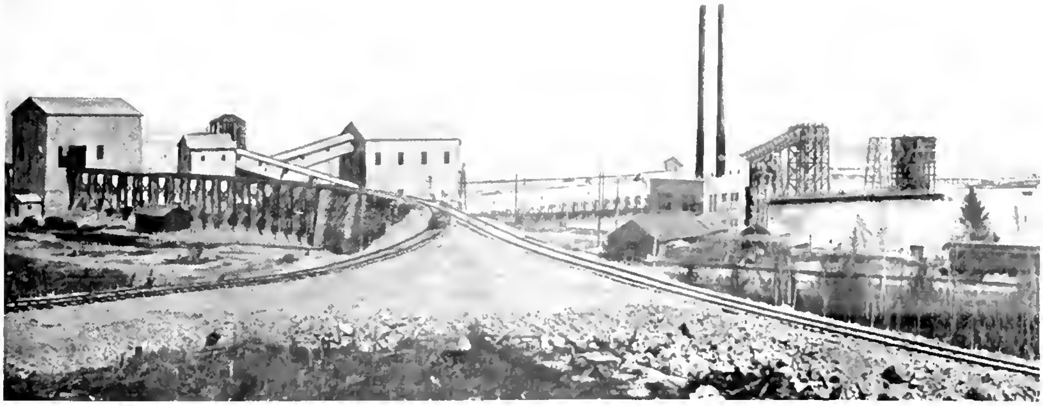
As the various centers of power applications are comparatively closely grouped, practically no allowances need be made for voltage drop; and no transformers, except those used with the three 220-volt motors, are required. The maximum transmission distance is about 1300 feet, and varnished paper insulated stranded cable is used. Except for the tunnel and pier circuits, all conductors inside the buildings are run in iron conduit.

The lighting system includes both multiple carbon and tungsten incandescent lamps operating on 125-volt circuits, fed from the exciter busses. Ultimately a series incandescent system will be installed for the illumination of all buildings, yards, roads and steam shovels with tungsten lamps.

In conclusion it may be said that the effective centralization of the power plant, the low friction loss in applying energy to the driving shafts, the simplicity and safety of the power supply system, and the positive co-ordinate operation of all sections of the material-handling equipment which has been attained at Calcite, would have been impossible with any other system than that of electric drive. The overall efficiency and operating economy secured in the handling of the quarry product in this instance, constitute a cogent argument for the general adoption of electric service for similar work in all branches of the industry.

The Michigan Limestone & Chemical Company assigned the design and installation of the power plant to J. G. White & Company of New York, the conveying system was provided by the Robins Conveying Belt Company, and the electrical apparatus was supplied by the General Electric Company.

Storage Pile Showing Bridge Carrying Delivering Belt and Concrete Tunnel Which Houses Reclaiming Belt



General View of Plant at Calcite

NEWS FROM THE CONSULTING ENGINEERING DEPARTMENT AND THE TRANSFORMER DEPARTMENT

EDITOR'S NOTE.—Commencing this month the last page in each issue of the Review will be appropriated for the use of the Consulting Engineering Department. The work covers some of the latest, most important and most interesting developments of electrical engineering. More detailed reference thereto and to the contributions which will appear on this page is to be found in an editorial in this issue on page 72.

SPECIAL TRAINING FOR STUDENT ENGINEERS

A limited number of student engineers employed by the Testing Department can be given some experience in the work of the Consulting Engineering Department, for a period not exceeding three months. Eligible herefor are student engineers in good standing, who have been in the Testing Department for not less than one year.

The work in the Consulting Engineering Department will consist in assisting one of the consulting engineers in his work; and the time spent in the department will depend on the time required to complete the particular work in which the student engineer assists, and may be from a few days to several months. After this, the student engineer may return to the Testing Department, or assist in some further Consulting Engineering work, depending on the conditions of work in the Department.

A general engineering extension course under the direction of the Consulting Engineering Department is available to a limited number of student engineers of good standing in the Testing Department. Required for admission to this course is, that the student engineer has spent not less than one year in the Testing Department, has had some previous experience in the Consulting Engineering Department, and is recommended for admission either by the Consulting Engineering Department or by the Transformer Department. The course extends over seven months. Of these, at least four will be spent in the Consulting Engineering Department, the other three months in the Transformer Engineering Department* or other allied departments. During his stay in the Consulting Engineering Department, the student engineer will be given experience with the various classes of theoretical, practical, experimental and development work, by having him assigned to different consulting engineers.

Weekly lectures are given, on Saturday forenoon, by Dr. Steinmetz and other prominent consulting engineers, on the engineering problems and the work done in the Consulting Engineering Department and by the company in general.

No promise of permanent employment with the Company can be held out to the student engineers entering this extension course; but some of the graduates of the extension course will be employed by the Consulting Engineering Department and by the Transformer Department; since places in the Consulting Engineering Department will be filled by graduates of its extension course, and in filling places in the Transformer Department preference will be given to such graduates. Efforts will also be made by the administration of the Consulting Engineering Department to place its graduates in the various other engineering departments. Those graduates who can not be accommodated immediately in the Engineering Department, will be given a diploma of their work in the Consulting Engineering Department.

* Transformer engineering and protective apparatus engineering are the two branches of electrical engineering in which during the last years the greatest progress has taken place. The most important electrical engineering problems are being met today in the phenomena of high voltage and high frequency, of mechanical magnetic forces, etc., and the most interesting work therefore is found here for a young engineer. The protective apparatus laboratory is a branch of the Consulting Engineering Department; and by an agreement with the Transformer Engineering Department, experience in the latter department has been made available to the student engineers in the Consulting Engineering Department, consisting of experience in the designing and developmental sections of the Transformer Engineering Department, and in advanced testing high tension insulation, cyclograph, etc., at the Pittsfield Works.

NOTES FROM PITTSFIELD SECTION A.I.E.E.

About sixty of the younger engineers of the Pittsfield Works have been organized in classes under the guidance of the Pittsfield Section A.I.E.E.

The class in HIGH VOLTAGE ENGINEERING which is the most largely attended, is under the leadership of Mr. F. W. Peek, Jr., of the Consulting Engineering Department. Meetings are held each week and papers read by various members of the class. Appropriate problems are assigned at each meeting and discussed at the succeeding meeting. The first part of the course consists of a consideration of the general phenomena of the magnetic and dielectric fields, and their effect on the design of insulation, insulators, leads and high voltage transformers. The second part of the course comprises the study of the transmission of electric power at high voltages, with a specific problem in high tension transmission to be carried out in parallel. The class in POWER PLANT DESIGN, under the direction of Mr. R. P. Sauerhering, local representative of the Isthmian Canal Commission, is considering the mechanical and electrical requirements for a typical central station. As the name implies, the class in ENGINEERING CALCULUS is studying the use of calculus as applied to engineering problems. Perry's *Mathematics for Engineers* is used as a text, and Mr. L. F. Blume, of the Transformer Engineering Department, is the leader. The members of the various classes are enthusiastic, and they will, without doubt, derive a great deal of benefit from the season's work.

Plans are being made by the Pittsfield Section of the A.I.E.E. to hold a National Meeting at Pittsfield, in May. The assistance of the Lynn, Pittsburg and Schenectady Section has been promised, and the success of the meeting appears assured.

STUDENT ENGINEERS LECTURES

To bring the student engineers of the Company, who are employed in the Testing Department, in closer touch with the men and the activities in the different departments of the Company, a system of lectures has recently been inaugurated. The lectures are given on Monday forenoon to half the student engineers in the Testing Department, and the same lecture repeated to the other half of the student engineers on the succeeding Monday. Up to February 1st, the following lectures have been given: Work of the Engineering Department, by Dr. Charles P. Steinmetz; Work of the Commercial Department, by Mr. C. W. Stone; Organization of the Testing Department, by Mr. C. Reid.

GENERAL ELECTRIC REVIEW

Published Monthly by the
GENERAL ELECTRIC COMPANY'S PUBLICATION BUREAU

Manager, M. P. RICE Editor, D. S. MARTIN Associate Editor, B. M. EOFF Assistant Editor, E. C. SANDERS

Subscription Rates: United States and Mexico, $2.00 per year; Canada, $2.25 per year; Foreign, $2.50 a year, payable in advance. Remit by post-office or express money orders, bank checks or drafts, made payable to the *General Electric Review*, Schenectady, N. Y.
Entered as second-class matter, March 26, 1912, at the post office at Schenectady, N. Y., under the Act of March 3, 1879.

VOL. XVI., No. 3 MARCH, 1913

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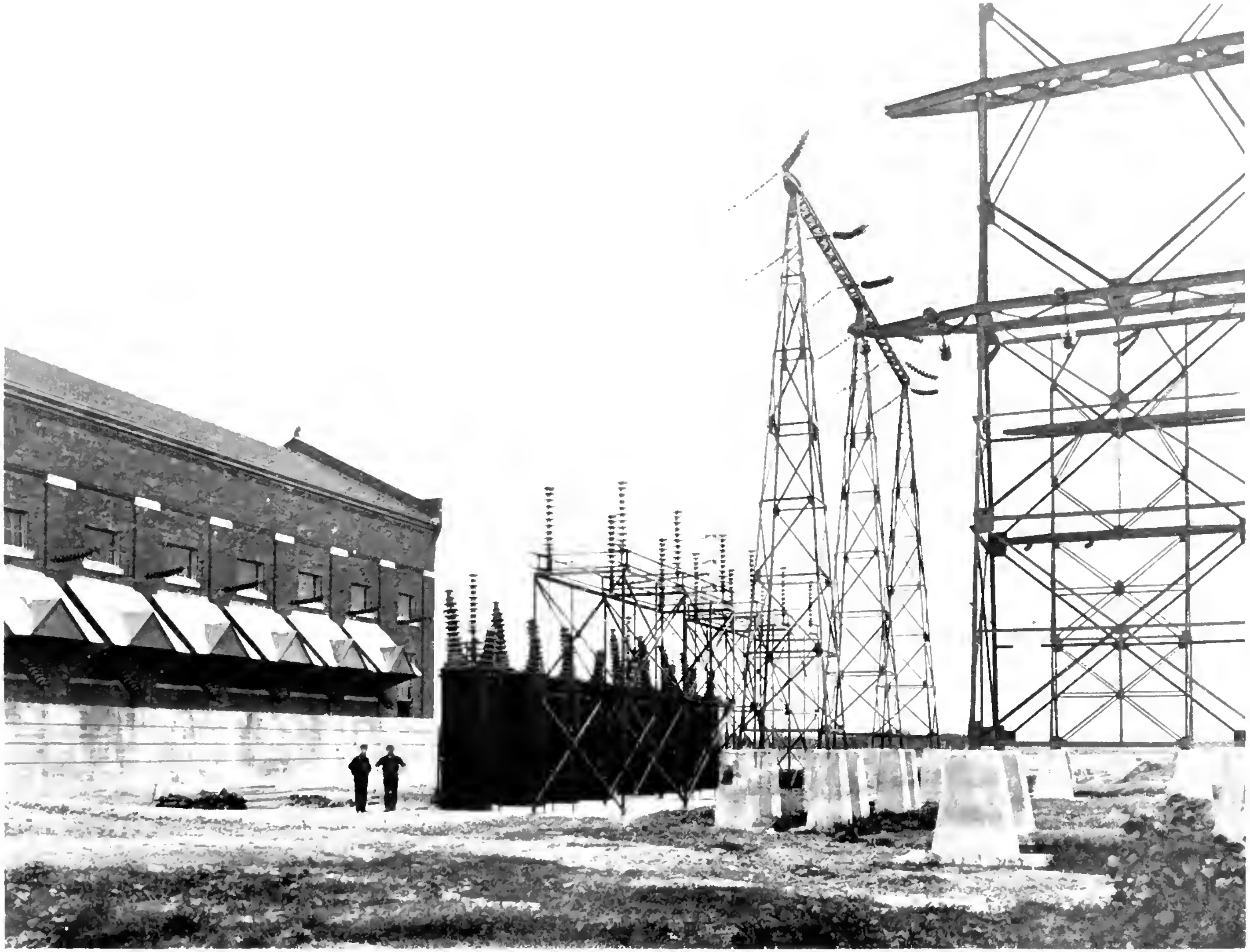


The subject of the protection of transmission lines has been very thoroughly taken care of in the Review of late, and the present issue contains three more articles on the matter, including the final installment of Mr. Wagner's paper on Aluminum Arresters. Supplementing the pictures of arrester installations shown with that article, we publish above a photograph of the largest arrester installation in the world, the 140,000 volt equipment at the Zilwaukee Station of the Eastern Michigan Power Company.

GENERAL ELECTRIC REVIEW

BIRTHDAY THOUGHTS

The General Electric Review appeared for the first time in March, 1903, and with this number therefore we enter on our eleventh year. Following well-established custom we should properly sing here a little hymn of thankfulness and praise—to say nothing of aspiration. Efforts of this kind, however, suffer from the grievous disadvantage that in print they look very cold, and do not in the least serve to convey how really thankful and aspiring are the composers. Nothing on a large scale should be attempted. Let us barely record the fact that we are ten years old; congratulate ourselves that, for a technical paper, this is a passable degree of antiquity; and thank Heaven for whatever measure of good health we are now enjoying.

The March, 1903, Review was in the nature of a trial run—an edition printed for a limited private circulation. Opinion on the scheme in general, and that March number in particular, was gathered; and the next issue made an appearance in June of the same year. Since then the paper has been out, more or less on time, once a month. In this place we cannot enter minutely into our history. Some day, doubtless, it will be written. For the present let the reader take note that this magazine has seen quite a good deal of life, has passed through many times of storm and stress, and is now due to run indefinitely. A Japanese friend the other day sent in a subscription for three years; while an American, working on the coupon plan, succeeded in pushing his own subscription ahead by 45 months. Barring strikes, lock-outs, pestilence, and the collapse of our favorite press, we shall not fall down on these contracts.

ELEPHANTS AND ELECTRICITY FOR FREIGHT-HANDLING

With this issue of the Review we are giving away as a cover-cut a picture of an elephant. When we first saw the photograph from which this engraving was made our instinctive sense of association set us to humming Kipling's "Mandalay":

"Elephints a-pilin' teak,
In the sludgy, squdgy creek,
Where the silence 'ung that 'eavy
You was 'arf afraid to speak!
On the road to Mandalay,
Where the flyin'-fishes play,
An' the dawn comes up like thunder
Outer China 'crost the Bay!"

Our next instinct told us that the picture would look well on the cover of this by-no-means-zoological ten-year-old magazine. But it must not be imagined that we selected it simply because we like elephants; or that the creature depicted on the cover has no connection with anything inside the book. On the contrary. The elephant, in a sense, is the text of one of our leading articles. Readers with long heads may now like to look at the contents-page and see if they can guess which one. "Locating the Friction in our Transportation Systems" is actually the story; and of course the episode of the elephant is but one item in a more or less complicated transportation system—more or less, depending on whether the teak of the Burmese interior is destined for usefulness in Burma itself, in India, in Europe, or in some other more distant part of the globe.

Mr. Rogers' article on page 145 is not the first of his which we have published in the Review calling attention to the greatest defect in nearly every modern freight-transportation system, whether on sea or land. Freight is rushed over continents and oceans by the most efficient locomotives and liners, only to encounter long and wasteful delays at the terminal through the continued use of antiquated freight-handling systems and appliances. Some of these have been handed down from the middle of last century. Some of them have been handed down from the time of the Flood. At present, terminal development on sound, logical and economical lines is practically standing still, although, it is true, several cities in this country have recently awakened to the extent to which they can damage their trade by a further neglect of their terminal problem. It is not only that terminal building activity must be accelerated, since, in many instances, there is no room for new buildings and enlargement. A much more crying necessity is the elimination of obsolete methods and appliances in existing terminals, and the rapid resort to the only service which holds out any substantial prospect of relief from the present confusion and congestion. That is the electric service. Elephants are all right in their way. As the prize event in an up-to-date zoo they can be adequately superseded by nothing that the electrical man can put up. We will go further, and declare that on the Irrawaddy they may be everything that is good and nice, even in freight-handling. But in the modern American terminal they are most wretchedly and unhappily misplaced. Literally they are not commonly employed in the terminal service of this country. Figuratively, and by analogy, they are. The hand-trucking and hand-piling used today are certainly no more efficient than the trunk-method—if as efficient. The elephant method in Burma remains today as it has been through the centuries, and there is reason for the conservatism: elephants on the banks of a Mandalay creek, miles out of reach of any electrical service, still represent real efficiency and economy. The elephant's counterpart in the White Man's industrial country, i.e., the heirloom of the ages, the terminal system which has been handed down from generation to generation while *Mikado* locomotives and *Mauretania* liners have been conceived and perfected on the railroads and on the sea highways, possesses neither excuse nor justification, and needs reforming.

PENSIONS FOR LONG AND FAITHFUL SERVICE

We have received a copy of the *Rules and Regulations* which will govern the administration of the pension scheme recently inaugurated by the General Electric Company. Our notice of the welfare scheme is somewhat belated, as it [illegible] operation last September. It [illegible], however, to make at least brief [illegible] while those who are [illegible] welfare work in general, and [illegible] information in regard to [illegible] last benefit scheme of [illegible] Company, will be able [illegible] on application.

The administration of the pension system is, under the President of the Company, in charge of a Pension Board consisting of five officers or employees of the Company, appointed annually by the Board of Directors to serve for the succeeding year and until their successors are appointed. The duties of this Pension Board are to authorize payment of such pension allowances as are provided for by the regulations; to make and enforce rules for the efficient administration of the system; and, in general, and within limits prescribed by the Directors, to settle all questions which may arise in connection with the administration of the scheme.

All employees of the Company, in whatsoever capacity engaged, are eligible for pensions. Any male employee 70 years of age, and any female employee 60 years of age, who has been twenty or more years in the service of the Company, or of any Company whose business and property have been acquired by the General Electric Company, shall be retired and receive a pension, unless, at the request of the employee and with the approval of the Pension Board, some later date be fixed for such retirement. Similarly, any male employee 65 years of age, and any female employee 55 years of age, who has seen twenty years of service, and who, by reason of age, sickness or other disability is incapacitated from further work, may, at the discretion of the Pension Board, be retired on a pension. The annual amount of such pensions shall equal one per cent of the average yearly wage for the ten years prior to retirement, multiplied by the number of years employed; but it may not exceed $125 a month. Thus, on attaining the age of 70 years, a male employee who had, during the last ten years, been earning an average wage of $1000 a year, and who had been working with the Company for thirty years, would be retired on a pension of $25 a month. The regulations contain, of course, a number of other clauses governing the operation of the system, such as temporary absence during years of service, re-employment, suspension of benefits, discharge rights of the Company, and so on; but the foregoing will serve to convey an adequate idea of the essentials of the scheme.

The first pensioner to receive payment was placed on the list on the first of October last. The first of November saw another beneficiary added; New Year's day another; while several further pensions, we understand, have now been approved and will shortly take effect.

LOCATING THE FRICTION IN OUR TRANSPORTATION SYSTEMS

By R. H. Rogers

Power and Mining Engineering Department, General Electric Company

For a long time Mr. Rogers has specialized in studying freight-handling motions at terminals, and has from time to time sent out some very strong and closely-reasoned papers on the inadequacy of existing terminal freight-handling facilities, and the need for reform by the wider utilization of electrical methods wherever possible. Two of these have appeared in the Review: "Freight Handling as a Field for Electricity" (August, 1911) and "Electric Power in Railway and Marine Terminals" (June, 1912). The present paper is along similar lines. An analysis of the "friction" in our transportation systems shows that friction in handling is the one outstanding reason why our freight traffic to-day costs us five times as much as our National, State, and local taxes combined.—Editor.

Commerce and trade, by means of transportation, equalize the potentials between areas of production and areas of consumption though oceans and continents may intervene. The friction or resistance that is opposed to the free flow of commodities has been greatly reduced in the last few generations; so that, at the present time, distances intervening must be very great or the potential between supply and demand very small, to prevent a flow of freight traffic.

The remaining opposing friction may be divided into that of hauling and that of handling. The amount of traffic annually overcoming this resistance is increasing rapidly for two reasons. First, a few generations ago man's wants were few, and were principally supplied by his own efforts or by exchange in his immediate vicinity; while now our wants are very complex, our self-support is indirect, and we make exchange with the whole world. Second, the friction of hauling has been so reduced by the use of great fast steamships in place of sailing vessels, by the improvement of waterways, by the powerful locomotives, large cars and improved roadbeds, that ocean traffic now costs less than a mill per ton mile, and railroad traffic from three to seven mills per ton mile.

A Rare Sight in New York Harbor, Where Once Grew a Forest of Spars, Ocean Traffic is Now so Heavy That Every Ship, Steam or Sailing, is Under Charter

The results of cheap hauling costs may be seen in the fact that nearly fifteen tons of freight are annually chargeable to every individual in this country; and the per capita tonnage is increasing three times as fast as the population. We can look for no further reduction in hauling costs unless some radical, and as yet unthought-of, change is made available.

On the other hand, why does our freight traffic cost us five times as much as our National, State and local taxes combined? Because of the friction in handling. While increased traffic tends to reduce the cost of hauling, exactly the opposite effect takes place at the terminals where costs per ton are constantly going up. In striking contrast to the swift and smooth passage of a consignment from port to port, or from city to city, is the treatment it receives in the terminals. Here it is subjected to innumerable lifts and lowers, drags and pulls, delays, stoppages and set-backs; until finally it emerges and goes again on its serene way to the ultimate consumer—who, after all, must stand the terminal charge.

The entire commerce of the world by land and sea must repeatedly pass through terminals with only hand labor to help it over these bare spots. If the losses in the machinery of commerce could be clearly segregated, those chargeable to the terminals would stand out in big figures that, in any other machine, would immediately bring every effort to bear upon their reduction to more reasonable amounts. Facts are stubborn things and bear repeating. The terminal cost in large cities on a given shipment exceeds one thousand miles of hauling cost. With marine traffic the condition is still more marked, for the terminal costs at New York and Liverpool exceed the hauling costs of the 3000 mile voyage. It is as though a swift and smooth-running vehicle had to be pushed by hand through frequent and increasing sand pits.

The Best we can do with Animal Help is a Hybrid with Five Expensive Longshoremen to Load, Unload and Guide Him. Contrast this Combination with the Elephant and One Cheap Mahout, Shown on the Cover

Two things are contributing to the rising terminal cost, congestion and a higher wage scale. Expansion of terminals is difficult in large cities; congestion is followed by worse congestion. Wages have increased from $1.00 and $1.25 per day to $2.50 and $3.50, while the laborers have depreciated, at least in intelligence. It recently took three hundred men ten days to unload the following interesting cargo from a ship having a standby charge of $300 per day:

1327 cases curios
756 cases bristles
17 cases hats
33 cases human hair
109 cases horse tails
10 cases ess oil
2 cases portiere
10 cases tobacco
3 cases medicine
64 cases albumen
15 cases rhubarb
500 cases antimony
140 cases canned crabs
135 cases crackers
25728 cases tea
14 cases effects
7 cases pres. ginger
731 cases groceries
2409 bags tea sweepings
5980 bags copra
500 bales cassia
3325 bales hemp
171 bales strawbraid
116 bales sheepskins
1389 bales wool
199 bales bamboo
35 bales goatskins
27 bales goatskin rugs
87 bales hats
168 bales cotton
85 casks ginger
3222 casks wood and nut oil
2391 rolls matting
17828 pcs. copper
103978 mats sugar
14 empty cylinders

At a prominent and well-organized railroad transfer terminal 300 men are employed in re-arranging the contents of about four hundred cars per day, at a labor cost of thirty cents per ton.

Freight-handling offers the greatest field for the profitable application of electrical machinery. In every other large industry hand labor has long been superseded by machinery; while, more recently, in most cases a second transition has taken place, namely the application of electric power to the machines themselves. This latter transition has proved profitable to the users. What then of this great industry in which the change can be made in one step from the hand labor of fifty years ago to the highly efficient electric-driven machine methods of today?

Because of the tremendous bulk of work, concentrated in space and time, that arises in connection with marine traffic, the handling of ships' cargoes is the phase of freight handling that offers the greatest return on an investment of ingenuity, good management and money. Millions of tons of material are moved every day by the crudest kind of labor. On the docks the human worker reigns supreme, congesting traffic by his complex and cumbersome motions. That such a condition should prevail so long is due to the fact that those most deeply involved "cannot see the forest for the trees." As the superintendent of a prominent terminal in New York Harbor said "Some time we may do things better, but we have got along a good many years and I reckon we can stand it a while longer. Whose business is it anyway?" Another thing that has maintained this "before-the-war" condition is the more or less intermittent periods of activity at a given pier or wharf and the multiplicity of interests involved in the traffic. The first tends to show a low load factor for a machine and the second spells divided responsibility.

Besides the multitude of existing marine and railway terminals, many new and great terminals are under construction or projected. The Panama Canal will give a great impetus to commerce, making necessary terminals at the canal and at many Gulf and Pacific ports. The New York State Barge Canal is to be equipped with nearly twenty million dollars worth of terminals, of which the State Engineer and Surveyor says: "At all terminals particular attention will be given to freight-handling devices, to the end that the barge canal terminals may excel in this particular and fix the conditions that they may meet."

The Slow and Laborious Distribution of a Ship's Cargo Limits the Speed of Unloading the Ship. This Picture Shows the Overflow from the Piers. Piling only "Shoulder-high" is the Cause, since Area is used instead of Volume

In conclusion let us quote from a recent address by James J. Hill, who is fully alive to the location of the friction that is get-at-able in our wonderful transportation systems.

"The figures already given show an increase of traffic in a year about five times as great as the increase of equipment, and eleven times the increase of mileage. Yet the machine has been hauling its load because efficiency has been developed. Heavier rails, larger engines, cars of greater capacity, increased train movement and the full utilization of equipment have kept business moving. . . .

"The commerce of the country can escape disaster only by additions to and enlargements of terminals. When the railroad yards are filled with cars that cannot be moved, the railroad loses a portion of its earnings; but the business man loses a larger share of his trade, and the working man his employment."

THE MAXIMUM VOLTAGE GRADIENT IN A SPARK GAP IN TERMS OF THE RADIUS OF CURVATURE OF THE ELECTRODES

By Geo. R. Dean

Professor of Mathematics and Mechanics, School of Mines and Metallurgy, University of Missouri

This article is the outcome of a special line of study followed up in connection with research work on the dielectric strength of air. Values for the dielectric strength of air are usually based on tests of breakdown voltage between metal electrodes spaced at given distances. Whatever the potential and shape of the electrodes, it is necessary to have a means of computing the maximum voltage gradient between them; and most of the methods which have heretofore been proposed have been either highly involved or of limited applicability. Prof. Dean in this article employs only elementary algebra and trigonometry in evolving an exceedingly simple working formula; and shows moreover that the spherical form of electrode may be departed from considerably provided the curvature of the spark point is known. Editor.

Physicists generally attempt to deduce the dielectric strength of air, at a given barometric pressure, from the results of experiments on the disruptive voltages between equal metal electrodes at given distances apart. They calculate the maximum value of the voltage gradient between the electrodes on the assumption that the electric field round them at high voltages is the same as that existing at low voltages. Nearly all experimenters have used equal spherical electrodes. It is therefore necessary to be able to write down at once the value of the maximum voltage gradient between two spheres whatever may be their potentials.

An expression for the gradient was derived by Clark Maxwell, who employed the method of images. His result has been found to be well-nigh useless for computation. It was modified by Poisson, and Kirchhoff derived a [illegible] formula which works well within certain limits. In 1890 Prof. Schuster published a table for the gradient between two spheres when one was at potential V and the other at potential zero. Alexander Russell in his paper on "Dielectric Strength of Air" (Philosophical Magazine, Feb., 1906) derived Kirchhoff's series formula by the method of images, and gives a table of values for [illegible] of [illegible] and radius.

The [illegible] the outcome of an effort to derive a more convenient working formula [illegible] the effect of deviation [illegible] form of the electrod[illegible] By [illegible] equipotential surfaces round [illegible] having equal and opposite [illegible] has derived a very [illegible] of two surfaces having [illegible] and $-\frac{V}{2}$, in terms of the [illegible], the radius of curvature [illegible] on the common axis and [illegible] difference of the surfaces. The maximum difference between the values of the gradient computed by this formula and those computed by Russell's formula is about one-half of one per cent. and occurs in the neighborhood of $x/a = 1.5$, x being the spark-gap and a the radius.

Green proved mathematically that if we suppose an equipotential surface replaced by a conductor having the same boundary as the surface, and if it be electrified so that the surface density is given by the formula

$$\sigma = -\frac{1}{4\pi}\frac{\delta V}{\delta \eta},$$

where $\frac{\delta V}{\delta \eta}$ is the electrostatic force at a point of the surface, due to the charges enclosed by that surface, then the electricity on the surface will be in equilibrium with the charges outside, and will produce the same potential at external points as the charges enclosed originally did. A physical proof of this theorem is given by Alexander Russell in Alternating Currents, Vol. 1, Chap. I.

Consider two equal equipotential surfaces in the field of two particles having equal and opposite charges. Replacing these by conducting surfaces on which the charges $+q$ and $-q$ are distributed, the field outside the surfaces will be identical with that of the original point-charges which are supposed annihilated. The maximum voltage gradient will be just outside the surfaces at the point where they cut the common axis.

The Radius of Curvature of an Equipotential Surface at the Point Where It Cuts the Axis

Referring to the diagram, let A_1, A_2 be the position of the point charges; $x+2z$ the distance between them; P any point on the equipotential surface passing through H_2 which is distant z from A_2; Q_2 the intersection of the normal drawn through P and the axis A_1A_2 produced.

Let F_1 denote the force acting toward A_1 on unit positive charge at P; F_2 the force acting away from A_2; R the resultant; α, the angle between F_1 and R; α_2, the angle between F_2 and R; $a=PQ_2$; θ, the angle between the normal and the axis.

When P moves along the equipotential line toward H_2, Q_2 approaches the center of curvature and $H_2 Q_2$ becomes the radius of curvature.

Let $A_1 P=r_1$, and $A_2 P=r_2$; then

$$F_1=\frac{q}{r_1^2} \quad \text{and} \quad F_2=\frac{q}{r_2^2}.$$

Resolving along the tangent to the equipotential, we have

$$\frac{q}{r^2} sin\ \alpha_1 = \frac{q}{r_2^2} sin\ \alpha_2$$

or

$$\frac{sin\ \alpha_1}{sin\ \alpha_2} = \frac{r_1^2}{r_2^2}. \qquad (1)$$

In the triangle $A_1 PQ_2$, by geometry,

$$\frac{r_1}{sin\ \theta} = \frac{a+x+z}{sin\ \alpha_1}. \qquad (2)$$

In the triangle $A_2 PQ_2$,

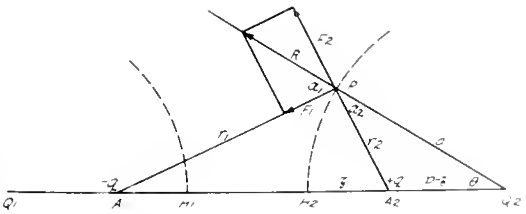
$$\frac{r_2}{sin\ \theta} = \frac{a-z}{sin\ \alpha_2}. \qquad (3)$$

From (2) and (3), by eliminating θ,

$$\frac{r_1}{r_2} = \frac{a+x+z}{a-z}\ \frac{sin\ \alpha_2}{sin\ \alpha_1}. \qquad (4)$$

Substituting the value of $\frac{sin\ \alpha_1}{sin\ \alpha_2}$ from (1), (4) becomes

$$\frac{r_1^3}{r_2^3} = \frac{a+x+z}{a-z}. \qquad (5)$$



When P approaches H_2, the value of $\frac{r_1}{r_2}$ approaches $\frac{x+z}{z}$, and a becomes the radius of curvature. Then

$$\frac{\rho+x+z}{\rho-z} = \frac{(x+z)^3}{z^3}. \qquad (6)$$

Solving for ρ, the radius of curvature,

$$\rho = \frac{z(x+z)\ [z^2+(x+z)^2]}{(x+z)^3-z^3} \qquad (7)$$

Putting $z=nx$, we get

$$\frac{\rho}{x} = \frac{n(n+1)\ [2n(n+1)+1]}{3n(n+1)+1};$$

and S for $n\ (n+1)$,

$$\frac{\rho}{x} = \frac{2S^2+S}{3S+1}. \qquad (8)$$

Arranging as a quadratic in $\frac{1}{S}$, we find that

$$\frac{2}{S} = \frac{x}{\rho}-3\pm\sqrt{\left(\frac{x}{\rho}-3\right)^2+8\frac{x}{\rho}},$$

$$4+\frac{2}{S} = \frac{x}{\rho}+1\pm\sqrt{\left(\frac{x}{\rho}+1\right)^2+8}. \qquad (9)$$

The Voltage Gradient in Terms of the Radius of Curvature

Let $\frac{V}{2}$, $-\frac{V}{2}$, be the potentials at H_2 and H_1, so that the potential difference is V. Then, we have,

$$\frac{V}{2} = \frac{q}{z} - \frac{q}{x+z}$$

$$= q\left[\frac{x}{z(x+z)}\right] \qquad (10)$$

Then for the voltage gradient G at H_2, we have

$$G = \frac{q}{z^2} + \frac{q}{(x+z)^2}$$

$$= q\left[\frac{(x+z)^2+z^2}{z^2(x+z)^2}\right]. \qquad (11)$$

Eliminating q between (10) and (11),

$$\frac{2G}{V} = \frac{(x+z)^2+z^2}{xz(x+z)}.$$

Putting $z=nx$, and $S=n\ (n+1)$, we get

$$\frac{2G}{V} = \frac{2S+1}{Sx} \qquad (12)$$

Then

$$G = \frac{V}{4x}\left(4+\frac{2}{S}\right).$$

Substituting value of $\frac{2}{S}$ from (9).

$$G = \frac{V}{4t}\left[\frac{x}{\rho}+1+\sqrt{\left(\frac{x}{\rho}+1\right)^2+8}\right] \qquad (13)$$

The reason for giving the radical the positive sign is obvious.

Numerical Results

The table below gives the values of the factor

$$f = \frac{1}{4}\left[\frac{x}{\rho}+1+\sqrt{\left(\frac{x}{\rho}+1\right)^2+8}\right]$$

and the corresponding values given in Russell's table.

Barlow's table was used.

$\frac{x}{\rho}$	f (Dean)	f (Russell)	$\frac{x}{\rho}$	f (Dean)	f (Russell)
0.0	1.0000	1.000	3.0	2.2247	2.215
0.1	1.0337	1.034	4.0	2.6861	2.678
0.2	1.0681	1.068	5.0	3.1583	3.151
0.3	1.1032	1.102	6.0	3.6374	3.631
0.4	1.1390	1.137	7.0	4.1213	4.117
0.5	1.1754	1.173	8.0	4.6085	4.601
0.6	1.2124	1.208	9.0	5.0981	5.095
0.7	1.2500	1.245	10.0	5.5895	5.586
0.8	1.2881	1.283	20.0	10.5474	
0.9	1.3268	1.321	30.0	15.5322	
1.0	1.3660	1.359	40.0		
1.5	1.5687	1.559	50.0		
2.0	1.7808	1.770	100.0	50.510	50.510

METHODS OF TESTING ELECTRICAL INSULATIONS, AND THE EFFECT OF VARIABLES ON DISRUPTIVE VOLTAGE

By M. E. Tressler

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This paper, which is based upon the lecture which the author gave to the Pittsfield Class in High Voltage Engineering (referred to also on page 206), considers only the electrical testing of insulation materials. Methods of measuring insulation resistance and disruptive strength are described, followed by a discussion of the effect on disruptive voltage of such factors as thickness of insulation, size and shape of insulating material, temperature, time of application of voltage, and frequency. Permittivity is defined, means of its measurement described, and its values for common insulating materials given. The concluding section deals with energy losses in insulation.—Editor.

In the testing of insulation the prime requisite is to know the use to which the insulation is to be put, or else to have a standard set of tests which will cover all the uses to which the insulation may be applied, the former being preferable. The test of an insulation should include mechanical tests as well as electrical; but in the following article only the electrical tests will be considered, the mechanical tests depending mainly on the use to which the insulation is to be applied. In the very recent past, the testing of an insulation meant to a great extent the determination of its "dielectric strength" without particular attention to such details as the shape and size of the test terminals, the shape of the material tested, the temperature of the material tested, time of application of the electric stress, etc., but at the present time greater attention is paid to these details, and also to other important tests such as energy loss in a given dielectric field, permittivity, and insulation resistance.

INSULATION RESISTANCE

The insulation resistance may be measured in several different ways, e.g., by the use of a "megger," with a Wheatstone bridge, or by the measurement of the current flowing through the insulation at a given voltage, with a galvanometer. All of these methods require the use of direct current.

The "megger" is an indicating instrument and consists of a small constant-speed, constant-voltage, direct current generator with a galvanometer inclosed in the same case. The galvanometer deflections are proportional to the current, but indicate on the scale as a resistance. Virtually the instrument is an ammeter reading backwards $\left(\text{i.e. from Ohm's law } I=\frac{E}{R}\right)$, the resistance being inversely proportional to the current.

The Wheatstone bridge method is familiar to all and hence will need very little explanation here. The ratio of resistance measured to the known resistance in the bridge must of necessity be large; the resistance to be measured is usually in millions of ohms and the resistance in the bridge arms will be in thousands of ohms or less; and hence the accuracy of this method is not very great.

The measurement of current with a galvanometer, and the calculation of the resistance from this and the known voltage, is theoretically the simplest method of measurement of insulation resistance. In using this method an accurate and very sensitive galvanometer must be used. Meters are quite readily obtainable which will measure 1.5×10^{-9} amperes; and hence, by the use of 500 to 600 volts, a resistance as high as 4×10^{-11} ohms can readily be measured.

The Wheatstone bridge may be said to be the most useful for measuring low resistances; the megger for medium high resistances; and the measurement of current with a sensitive galvanometer for very high resistances.

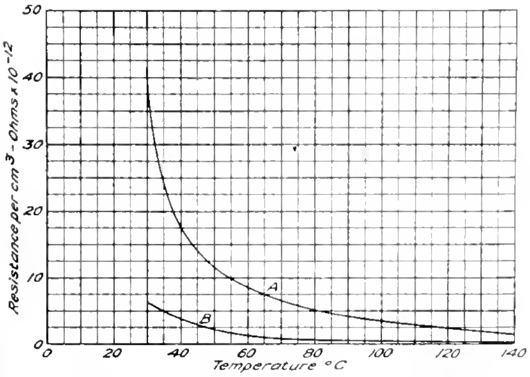

Fig. 1. Insulation Resistance of Transformer Oil

A—Disruptive voltage	= 42	kv. at 25° C.
Viscosity	= 46	sec. at 25° C.
Specific gravity	= .818	at 25° C.
B—Disruptive voltage	= 45	kv. at 25° C.
Viscosity	= 178	sec. at 25° C.
Specific gravity	= .860	at 25° C.

As far as is known at present there is no relation between insulation resistance and puncture voltage of an insulation. For instance, we may have two oils which are very similar in all characteristics, where the puncture voltage is the same, and may yet find that the resistance of one will be six to eight times that of the other. Similarly we may have some fibrous insulation such

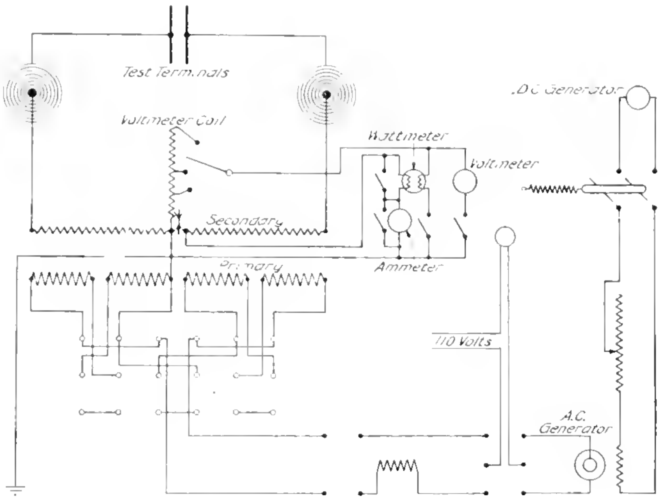

Fig. 2

as paper or pressboard, which under normal conditions will contain several per cent of moisture and consequently have low resistance, and yet find that the puncture voltage will be practically the same as when the material is thoroughly dry and of high insulation resistance.

In measuring insulation resistance very careful temperature measurements should be made, as this resistance usually decreases very rapidly with increasing temperature. This is shown by the curve of insulation resistance plotted against temperature of transformer oil (Fig. 1), the general shape of this curve being the same for practically all solid and liquid insulations.

DISRUPTIVE STRENGTH

The disruptive voltage of a given insulation is determined by subjecting it to an electric stress which may be gradually increased until puncture occurs. The stress is usually applied by placing the insulation between two metal terminals of a given size and shape, these terminals being connected to the high voltage side of a transformer. The most common laboratory method, and one which is usually the most convenient, of obtaining a suitable voltage which can be varied, is to have field control of a generator whose voltage has a sine wave form. Such an apparatus is shown in Fig. 2.

Another method sometimes used where the test requires a considerable amount of energy and the armature reaction due to

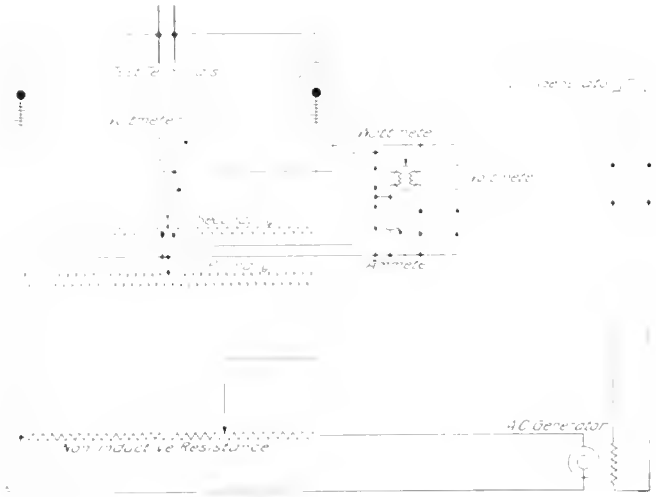

Fig. 3

the increased out-of-phase current produces a distorted voltage wave, is the shunt resistance method where the transformer is tapped off from a constant non-inductive resistance across the generator terminals. (Fig. 3.)

There are a number of ways of measuring the voltage applied to the insulation, such as directly at the generator, through a potential transformer if the voltage is too high, by spark gap in the high voltage side, or by means of a voltmeter-coil placed next the high tension winding and connected either to the transformer and grounded or completely insulated therefrom. The latter method is found the most convenient, for the reason that no potential transformer is required, and the ratio of voltmeter reading to the voltage on the high voltage side does not change with a change from series to parallel or series-parallel connection on the low voltage side of the transformer. This coil is shown in Fig. 2.

In the determination of disruptive strength of an insulation a number of conditions must be taken into consideration, such as the following: thickness of material tested; size and shape of test terminals; shape of material tested; material of test terminals; whether tested in air or oil; temperature of insulation; humidity of atmosphere; length of time of application of voltage; and frequency of voltage. We shall not discuss all of these conditions in this article owing to lack of space and also on account of meagre information on some of the conditions.

Effect of Thickness of Insulation

If an insulation were tested between two infinite planes which would give a uniform flux distribution, it would be expected that the disruptive voltage would increase directly with the thickness. As this is not possible and we must test with terminals which have edges, we would expect that the disruptive voltage would vary other than directly with the thickness. In all insulations the disruptive voltage per unit thickness decreases as the thickness increases; and the equation of disruptive voltage against thickness of material will be similar to:

$$e = e_0 \phi x \qquad (1)$$

where e = disruptive voltage, x = thickness of insulation and e_0 = disruptive strength. The value of e depends upon the shape of the test terminals, their distance apart and probably other factors as well. The method of

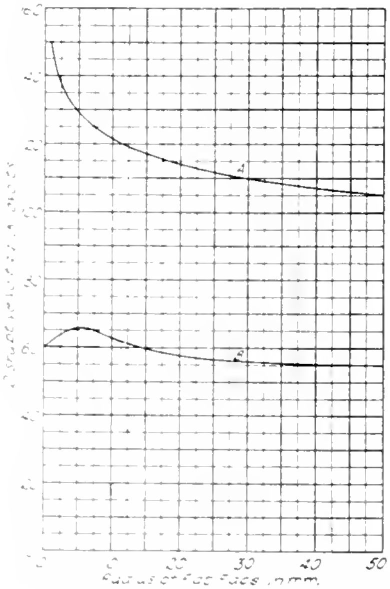

Fig. 4. Curve of Radius of Face vs. Disruptive Voltage. Sample is of 0.03 cm. Varnished Cloth, 10 Layers, Square Edge, Flat Disks. *A* is Probability Curve. *B* is Experimental Curve.

giving the disruptive strength per unit thickness without giving the thickness of piece tested, as is quite common at present, is therefore wrong. This decrease in disruptive voltage per unit thickness with increased thickness is probably due to the increasing effect of non-uniformity of dielectric flux distribution in the insulation as the distance between terminals increases.

A problem similar to this is considered by Mr. Peek in the GENERAL ELECTRIC REVIEW for December, 1912, where he shows that the apparent disruptive strength, g_v of air equals the true disruptive strength, g_o, which is a constant, multiplied by some function of the radius r of the conductor.

$$g_v = g_o \left(1 + \frac{0.301}{\sqrt{r}}\right) \qquad (2)$$

Effect of Size and Shape of Test Terminals

The size and shape of terminal may be practically anything desired, such as needle points, flat disks, spheres, etc. All of these forms, however, may be defined by saying that they are disks with edges rounded to various radii. Thus needle-points may be said to be flat disks with zero diameter of flat face and zero radius at the edge; and spheres to be flat disks with zero diameter of flat face, and radius of sphere equal to the radius of the edge.

In a large number of tests which have been made, it is found that the instantaneous disruptive voltage of a given thickness of material decreases with an increase in the diameter of the terminal. This is to be expected if we consider the probability curve for this condition, assuming that the flux distribution between the terminals is perfectly uniform. In Fig. 4 is shown this curve for ten layers of 0.03 cm. varnished cloth, as calculated from one layer tested between 100 mm. diameter, 5 mm. radius edge, disks. Below the probability curve is shown the curve obtained by experiment for 100 mm. diameter terminals with square edges. Here we readily see that above a certain diameter of test terminal, the general shape of the two curves is very similar. It should be noted that the abscissæ in these curves are plotted as radii of flat face of terminal, and not as areas. The radius was used because it was noted that a very large percentage of the punctures occurred at the edge of the disks where the flux density was the greatest; hence that area over which the punctures were likely to occur was an area proportional to the circumference or, rather, the first power of the radius of the disk, and not the second power of the radius as would have been the case had the punctures occurred uniformly over the face of the disks.

As shown in Fig. 4, the experimental curve is considerably below the calculated curve,

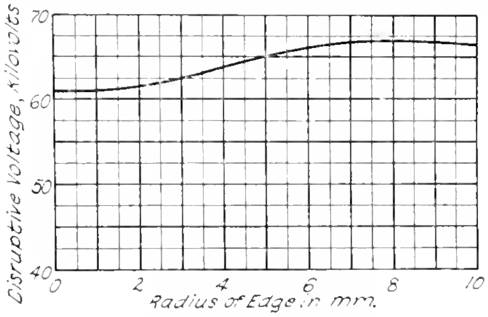

Fig 5. Curve of Radius of Edge vs. Disruptive Voltage. Sample is of 0.03 cm Varnished Cloth 10 Layers. 25 mm. Radius of Flat Face of Terminal

and also ceases to be parallel to the calculated curve below a certain diameter of test terminal. This would indicate that there were other factors beside the radius of disk which affected the experimental results. The only other factor which would be apt to affect the results would be the shape of the edge of the terminals which would tend to make the flux distribution non-uniform, and hence concentrated at the edges.

In Fig. 5 is given a curve of kilovolts to puncture *versus* the radius of the edge of a 5 cm. flat-faced disk, when testing ten thicknesses of varnished cloth. This shows that the disruptive voltage increases with an increase in the radius of the edge of the terminals. The intensity of the stress increases at the edge as the radius of curvature decreases; hence, when the strain at the edge reaches a certain value which is the disruptive strength, rupture occurs.

From the consideration of the two factors above, equation (1) could be modified so that it would take the form

$$e = e_o x \left(1 - \frac{\phi' R x}{\phi'' r}\right) \qquad (3)$$

where e, e_0 and x are the same as before and R = radius of flat face of terminal and r = radius of edge of terminal. By further consideration of the effects of different sizes and shapes of terminals with the results of a series of tests an equation could evidently be derived, from which the disruptive strength could be calculated.

This discussion is based on results from tests which were made in oil.

The general effect of shape of terminal when testing in air is as follows: if needle points are used the flux distribution will be quite concentrated at one point and the corona will be large. This will heat the insulation, thereby changing the results. If spheres are used the same general effect occurs, except that the flux is not so concentrated and the total corona is larger. If flat disks with square corners are used the flux is greatly concentrated at the corners, but the corona and consequent heating are small. If flat disks with rounded edges are used the corona is increased and the flux distribution is more uniform.

If the tests are made in oil a double advantage is obtained: the flux distribution is made more uniform due to the permittivity of oil being nearer to that of the material under test, and the corona is very nearly eliminated. Therefore if the tests are made in air there is little choice between the flat disks with square edges and the disks with round edges, as the beneficial effect of uniform flux distribution with rounded edges is offset by the detrimental effect of increased corona and consequent heat; but, if the tests are made in oil, the flat disks with rounded edges would seem to be preferable, as the corona is nearly eliminated and the flux distribution is more uniform.

Effect of Shape of Material Tested

The tests as given above were all made on flat pieces of insulation. Other definite shapes may be used, such as cylinders. If two concentric cylinders are used as test terminals, the ratio of diameter of outside terminal to that of inside terminal, as calculated, would be 2.718 to give maximum disruptive voltage. In actual test, however, the maximum disruptive voltage is obtained when this ratio is from 3 to 6. This would mean that with a given diameter of outside terminal the diameter of the inside terminal would be smaller than calculated.

We might then assume that the maximum voltage gradient which the insulation could withstand had been reached on the inside terminal, and that corona had appeared which increased the diameter of the inside terminal to the value to give the maximum disruptive voltage. This is hardly probable; as it would mean that if a ratio of 3.5 had been found instead of 2.718 when using an outside terminal 15 cm. in diameter, the thickness of corona would be 0.62 cm. This corona should be visible when testing oil in this manner if the change of ratio is caused by this effect, but as there is no corona visible it is probable that the ratio is not changed in this manner.

Another way in which we might look at it would be to assume that the permittivity of the insulation increased as the voltage gradient increased; and that therefore the layers next the inside terminal would be relieved of part of their stress, and the outer layers receive greater than their proportional voltage, this voltage over the outside layers being such that it is a maximum when the ratio of outside to inside diameter terminal is 3.5. At the present time there are no results available which would prove that the permittivity does increase with increase of voltage gradient; and we must therefore look further for explanation of the results. Again referring to Mr. Peek's paper on the "Nature of Corona," he has shown that to start corona requires a definite amount of stored energy at the point of maximum voltage gradient before disruption actually occurs. Our case may be found to be similar to his in that the voltage gradient at the terminal surface varies; but that at a given distance, depending on the size, shape and distance apart of the terminals, the voltage gradient is a constant for any given material.

Effect of Temperature of Insulation

The disruptive voltage in general varies inversely with the temperature. This is true of practically all solid and a large number of liquid insulations. Several curves are shown of this effect in Fig. 6. The disruptive voltage of each point on the curve was taken while the insulation was at that temperature; and not when the insulation had been heated to that temperature, then cooled to normal temperature and afterwards tested.

Effect of Length of Time of Application of Voltage

The effect of length of time of application of voltage to the insulation is probably an effect of temperature combined with molecular fatigue. Practically all insulations exhibit an energy loss when subjected to a high alternating voltage. This energy loss appears as heat in the insulation; and since, as was shown above, the disruptive voltage is less at a high temperature, it would be expected that the application of low voltage would produce disruption if continued long enough, whereas it would require a higher voltage to produce the same amount of heat if disruption was to occur in a shorter time. (See Fig. 7.) Those insulations which show very small energy loss also show less effect of a long continued application of voltage and of heat.

Effect of Frequency of Voltage

The general effect of increasing the frequency, when an insulation is tested, is to decrease the voltage at which puncture occurs. Over the range of commercial frequencies, say, 25 to 125 cycles, there is little difference in disruptive voltage; but with a range from 100 to 50,000 cycles there would be a noticeable change.

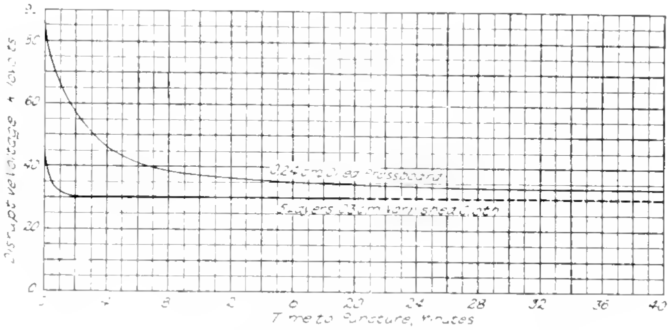

Fig. 7. Curve Showing Effect of Time of Applied Voltage on the Disruptive Voltage

PERMITTIVITY

The measurement of permittivity of an insulation means the determination of the ratio of the capacity of a condenser, with the given insulation as dielectric, to the capacity of the same condenser with air or, rather, a vacuum as dielectric. Practically, air is used instead of a vacuum, the difference being very small. The measurement can be made in a number of different ways, which should give the same result if all conditions could be made as desired.

If a pure sine wave is obtained of a known frequency we can measure the current in a condenser with the given insulation for dielectric, and can compare the results with the same condenser and air dielectric. The ratio of the two gives us the permittivity. This is correct provided there is no appreciable dielectric loss in the insulation such as would also require current but not capacity current, thus making the ratio higher and indicating a greater than the true permittivity. Below is given the equation of capacity current in terms of frequency, capacity, and voltage which will make the explanation somewhat clearer:

$i = 2\pi fce$

i = capacity current

f = frequency

c = capacity

e = voltage

Here it is readily seen that, if the voltage is not a perfect sine wave, the effect of the harmonics is to rapidly increase the capacity current, thereby giving, in the end, erroneous results.

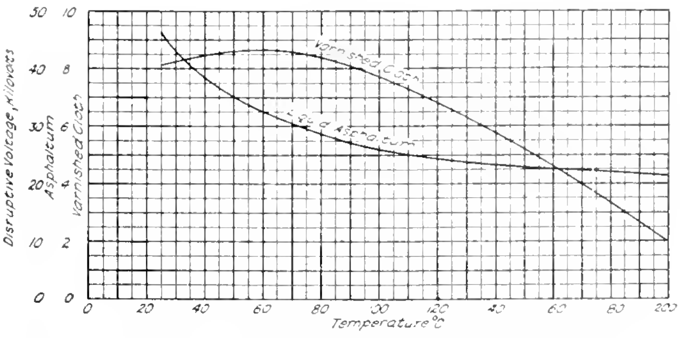

Fig. 6. Curve of Temperature vs. Disruptive Voltage for Asphaltum and Varnished Cloth

Another quite common method of measuring capacity for precision work, is the Maxwell bridge method where a rotating commutator is used for charging and discharging the condenser. balanced against an inductance and resistances. This is too tedious and laborious for ordinary practical use.

For commercial work the Anderson bridge method (Fig. 8) has been found quite satisfactory.

C = capacity to be measured

L = variable inductance

A = resistance

B = resistance

D = resistance

r = resistance

G = galvanometer or detector

Here the condenser is balanced against a variable inductance and resistances, and a buzzer or high-frequency generator is used for charging and discharging the condenser.

In practice a buzzer has been used for producing the pulsating or alternating current. A telephone receiver is used as detector to determine when the potential between x and y is zero or a minimum. The human

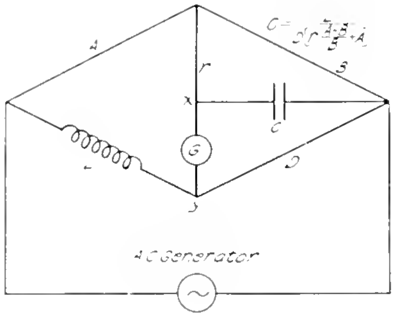

Fig 8 Connections for Anderson Bridge

ear is found to be the most sensitive to sound waves of 600 to 800 vibrations per second. A commutator in consequence has been used which gives a frequency of about 750 cycles per second, in place of the buzzer which was of considerably lower frequency.

A number of factors enter into the measurement of permittivity which have not been considered. One of these is the fact that almost no perfect insulation is obtainable except air, and therefore a current other than the capacity current is flowing, and there is an energy loss. If the loss is equivalent to a resistance loss in parallel with the capacity, the formula, as given in Fig. 8, is not changed; but if it is equivalent to a resistance loss in series the capacity as obtained is affected by the frequency as well as the series resistance. As it is not yet known whether the loss exists as an equivalent series or parallel resistance, or either, the frequency of tests should be given.

A few of the values of permittivity of common insulating materials used for high voltage insulation are given in the adjacent column. The permittivity of the transformer oils vary almost directly with their specific gravity. With the exception of oil, all the results are given to only two places of figures, as it is assumed that this is as close as, if not closer than, the variation in different samples of the same material. Where oil is used the material may be expected to be more uniform.

ENERGY LOSS

Very little is known of the subject of energy losses in insulation at the present time.

Thickness	Permittivity: Dry	Oiled	Varnished
PRESSBOARD			
0.010	3.5	7.0	
0.014	3.9	7.0	3.8
0.030	4.0	7.7	3.8
0.032	3.8	5.8	3.8
0.094	3.3	4.8	3.1
0.125	2.6	4.7	
HORN FIBER			
0.010	2.3	3.8	
0.015	2.4	3.9	
0.020	2.4	5.3	
0.030	2.2	4.1	
0.062	3.2	4.9	
0.125	3.3	4.7	
EXPRESS PAPER			
0.003	2.6	4.1	
0.005	2.9	4.6	
0.010	3.3	5.6	
VARNISHED CLOTH			
0.012 yellow	5.5		
0.012 black	4.5		
TRANSFORMER OIL AT 15 DEG. C			
No. 6	2.24		
No. 8	2.16		
No. 12	2.21		

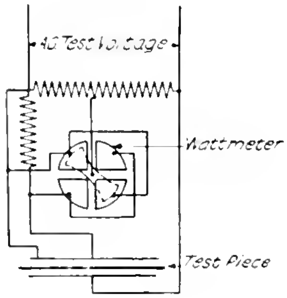

Fig 9 Connections for Electrostatic Wattmeter

These losses only become apparent at very high voltages, in such apparatus as transformers, or at moderately high voltages in such apparatus as cables where a large volume of insulation is subjected to the electric stress. There are many difficulties in measuring these losses, owing to their very small value, very low power-factor and the high voltages at which they become appreciable.

One of the first methods used was with the electrostatic wattmeter (Fig. 9) where, if the voltage is not too high, it may be applied directly between one pair of quadrants and the moving vane. If the voltage is too high the method may be used by tapping off from a resistance shunted across the circuit. The current quadrants would be supplied by the voltage drop over a series resistance.

Another method which has been used is that shown in Fig. 1, in which the voltmeter coil of the transformer is connected directly to the potential coil of the wattmeter; the high tension winding of the transformer is opened at its middle point; and the current coil of the wattmeter placed in series with this winding.

A third method is that with the cathode ray tube (Fig. 10) in which the electrostatic or magnetic fields of a circuit are so connected that the field proportional to the current produces a deflection of the cathode ray in one direction and the field proportional to the voltage in a direction at right angles to this. When both fields act at the same time they cause the cathode ray to trace a figure on a fluorescent screen whose area is proportional to the loss being measured. This method would seem to have several advantages over the other two, in that it gives a graphical idea of how the losses occur and that it requires practically no power to operate. With the cathode ray tube the figures traced on the screen show that during one cycle the current may increase directly with the voltage up to a certain value, where its elastic limit is reached, after which the current increases without further increase of voltage. This is quite similar to the case of a metal bar being placed under tension until it has reached its elastic limit; above which the length increases with very little further increase of stress.

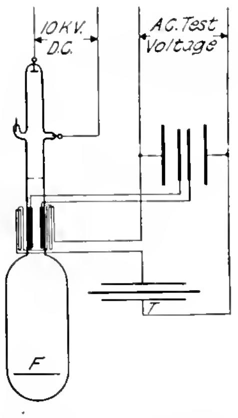

Fig. 10. Cathode Ray Tube
F = Fluorescent screen
T = Test piece

In other cases it is found that the current increases faster than the voltage from zero value. This would be similar to placing under tension a bar of lead or annealed copper, where there is either no well-defined elastic limit or else one that is very low.

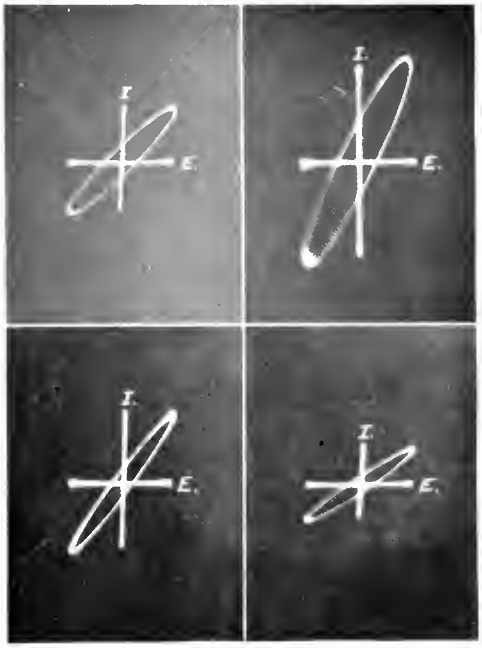

Fig. 11

Fig. 11 shows four figures which represent the energy loss per cycle in several insulating materials at high voltage as obtained with the cathode ray tube. In all of the figures the area and thickness of insulation tested was 507 sq. cm. and 1.25 cm. respectively. The two axes of reference in each figure are the voltage and current and are marked *E* and *I* respectively. *a* represents the energy loss in a sheet of insulation at 31,300 volts, and *b* the energy loss in the same piece of insulation at 37,000 volts. *c* and *d* represent the losses in another kind of insulation at 26,900 and 31,700 volts respectively. It may be noted that the area of *c* is greater than that of *d*, although the voltage is lower and the energy loss is less. This is produced by using condensers of different capacity, so that the voltage to give a deflection of the proper size is obtained; or, in other words, the ratio of voltage on the quadrants of the tube to the voltage on the insulation is different.

ELECTRIC HARDENING FURNACES

By M. Unger

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The requirements essential to the successful hardening of steel tools are: first, to be able to obtain the proper temperature, and to ascertain this temperature practically exactly; second, to prevent too sudden heating, which may cause warping and cracking; and third, to be able to heat the metal uniformly throughout, so that overheating and burning of sharp points and edges are avoided. With the dry heat furnace, comprising the open coal fire and the oil, gas and electrically heated muffled furnaces, constant uniform temperature is practically impossible and the success of the process is dependent almost entirely upon the skill of the workmen; while the externally heated wet baths, represented by the lead bath and the barium and potassium chloride baths, possess respectively the disadvantages of heating the tool too rapidly and a non-uniformity of temperature. The electric furnace described in this article is free from these objectionable features. It is furnished with a compensator by means of which the current can be adjusted to give the correct temperature; while uniform temperature in all parts of the bath is maintained by the thorough circulation effected by the electromagnetic forces produced by the heavy current.—Editor.

The hardening of steel is an art, and for the production of efficient tools and machinery, it is of vital importance that the operation be properly performed. It is, however, a noteworthy fact that the methods of hardening in general use to-day embody practically no radical changes or improvements over those of 50 years ago, and this despite the many defects of these methods. The introduction of electric hardening furnaces, which have recently been perfected and which will be described later in this article, marks a great advance in the art. By means of these furnaces hardening can be carried out on a scientific basis, and the results will be more uniform and satisfactory than it has hitherto been possible to obtain.

No strict definition of steel exists, but as distinguished from iron it may be characterized as containing 0.3 to 2 per cent of carbon, and possessing the property, in all grades but those of lowest carbon content, of becoming hard after being heated and quickly cooled. Such steel is usually termed "carbon steel" to distinguish it from the modern "high speed steel," which in reality is an alloy of iron and such metals as tungsten, chromium, molybdenum, vanadium, etc., in varying proportions and combinations. Depending upon its composition, each steel requires a definite temperature for hardening. For carbon steel this ranges from 750 to 1000 deg. C. and for high speed steel from 1000 to 1300 deg. C.

While the molecular changes that take place in the steel when heated are exceedingly complicated and not yet fully understood, the following principal requirements must be fulfilled in practice in order to give the best results:

1st: It must be possible to produce and maintain constant any temperature that may be required for any particular steel.

2nd: It must be possible to ascertain practically the exact temperature of the heated steel.

3rd: The heating must be uniform throughout, and overheating and burning of edges and sharp points of the tool should be made impossible.

Fig. 1. Electric Hardening Furnaces

4th: The heating must not be too sudden, so as to avoid internal stresses which may cause warping and cracking of the steel.

5th: During heating the steel must be protected from oxidation as much as possible.

6th: The furnace must be efficient and easy to operate.

The above requirements are not fulfilled by any of the standard furnaces in use.

In the so-called "dry heat" furnaces, which include the open coal fire, oil, gas and electrically heated muffle furnaces, it is practically impossible to maintian a uniform heat, and temperature measurements are very deceiving. The operator must therefore be able to judge the temperature from the color of the steel, and after many years of practice may be able to meet with fair success. Adjustments of the temperature in coal, oil and gas furnaces are very unsatisfactory, although they are easier with the electric muffle furnaces. The heating of steel in these furnaces is very slow, but due to the uneven heating it is difficult to avoid warping if the tool is of more or less complicated shape. Oxidation of steel heated in these furnaces cannot be fully avoided, particularly if a long time is required for heating, or if the temperature is very high. In order to obtain satisfactory work with these furnaces, the judgment and skill of the operator are therefore of prime importance.

We will next consider the so-called "wet heat" furnaces, to which belong the lead bath and the metallic salt baths. The heating media are in these cases contained in suitable crucibles, as, for example, graphite or steel pots, which are heated externally, usually by gas or oil. So far as uniformity of temperature is concerned, it should be stated that the lead bath is undoubtedly quite satisfactory, due mainly to the high heat conductivity of lead. The salt bath, consisting usually of barium or potassium chloride, or both, is, however, not so satisfactory, the heat conductivity of the salt being quite low and the natural circulation of the bath not sufficient to assure a uniform temperature throughout. Temperature measurements can easily be obtained, but must be used with caution where the salt bath is concerned. Due to the difficulty of adjusting the oil or gas flames, temperature regulation is not easily obtainable. The greatest objection to the lead bath is the sudden heating of the steel immersed therein, and therefore it cannot be used with good results for anything but small simple tools. Another objection is the tendency of the lead dross to stick to the tool when quenching, thus causing soft spots on the tool. The poisonous nature of the lead fumes is another serious objection. Contrary to common opinion, the heating of tools immersed in the salt bath is not sudden and the reason therefore will be discussed more in detail later. It should be noted that the amount of steel that can be heated in the externally heated salt bath is comparatively small. The reason for this is that when a quantity of cold tools are immersed in the bath its temperature naturally sinks, and if the oil or gas flames are left

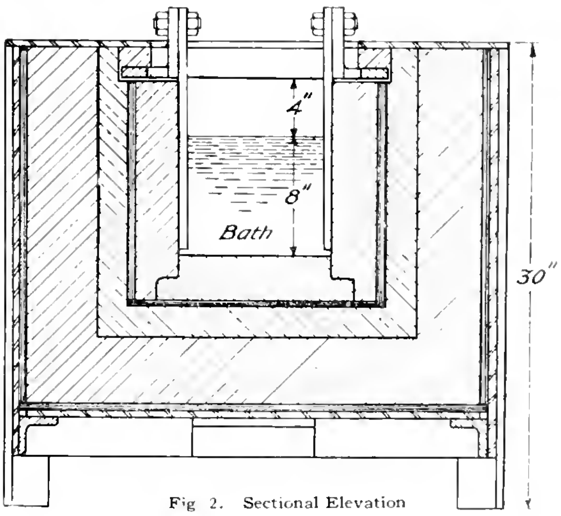

Fig 2. Sectional Elevation of Furnace

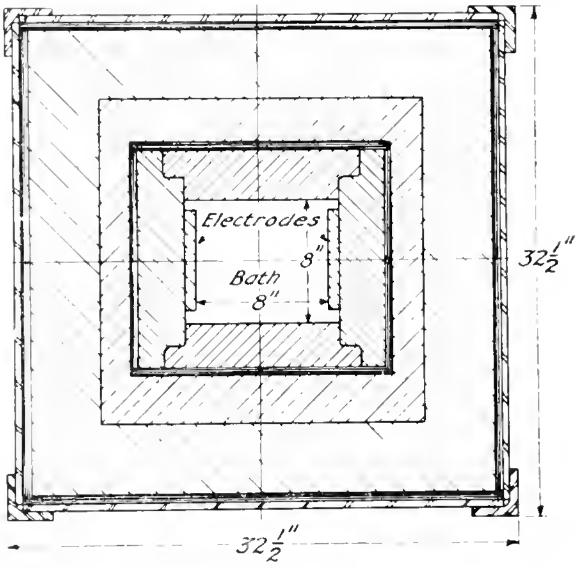

Fig 3. Sectional Plan of Furnace

unchanged it will require quite some time before the proper temperature is again reached. If an attempt were made to increase the heat there would be danger of

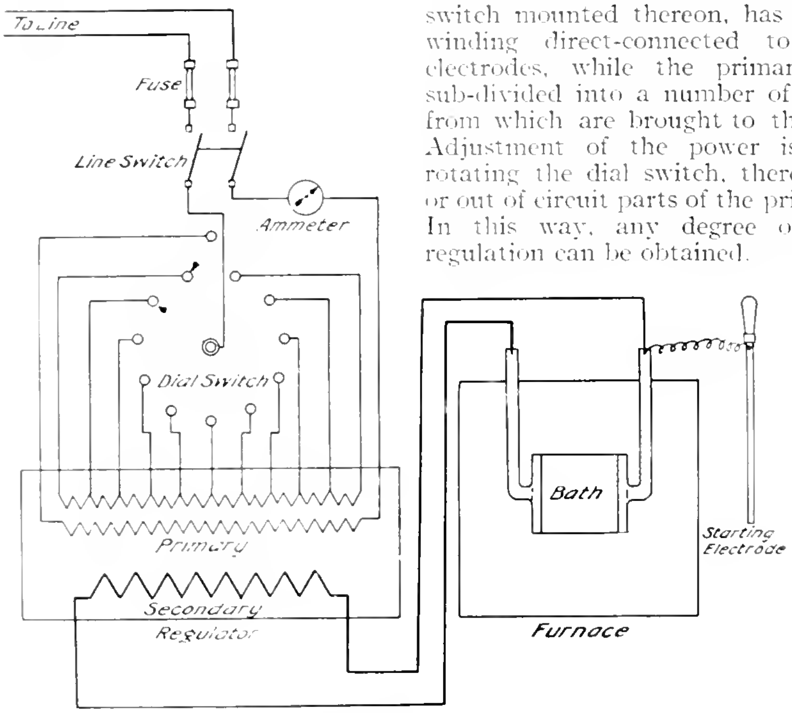

Fig. 4. Diagram of Electric Circuits

local overheating, due to the poor circulation of the bath, as already stated.

To the "wet heat" furnaces also belongs the internally heated salt bath, which, as will be shown, fulfills to a marked degree all the requirements for successful hardening. In these new furnaces, which will be termed "electric hardening furnaces," metallic salts or mixtures thereof are heated by the direct application of electricity, the electric current being allowed to penetrate all parts of the bath.

The crucible or container for the bath is made up of fire bricks, which are surrounded by heat insulating material and supported in a sheet iron case as shown in Figs. 1, 2 and 3. Two iron electrodes, located on opposite sides of the crucible, direct the current through the bath. A suitable regulator, usually of the switch type as shown in the illustrations, is used with the furnace. By means of this regulator the available voltage is stepped down to that required by the furnace, and means are also afforded for regulating the power and consequently the temperature of the bath.

A diagram of connections of the furnace outfit is shown in Fig. 4. The regulator, which consists of a transformer and a dial switch mounted thereon, has the secondary winding direct-connected to the furnace electrodes, while the primary winding is sub-divided into a number of sections, taps from which are brought to the dial switch. Adjustment of the power is obtained by rotating the dial switch, thereby cutting in or out of circuit parts of the primary winding. In this way, any degree of temperature regulation can be obtained.

The kind of salt used in these furnaces depends upon the temperature desired. For hardening high speed steel, barium chloride should be used, while for carbon steel a mixture of barium chloride and potassium chloride is recommended. For still lower

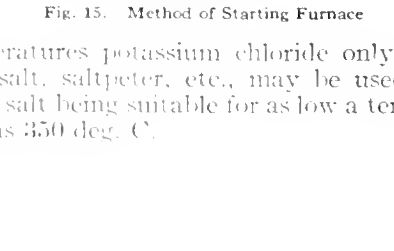

Fig. 15. Method of Starting Furnace

temperatures potassium chloride only, common salt, saltpeter, etc., may be used, this latter salt being suitable for as low a temperature as 350 deg. C.

These salts are non-conductors of current when cold and become conductors of the second class when molten. Means are therefore provided for obtaining a channel of molten conducting salt between the two electrodes, as illustrated in Fig. 5. With a carbon rod pressed between one of the main electrodes and the auxiliary electrode, power is applied and current flows through the carbon, generating heat therein and causing the surrounding salt to melt. The auxiliary electrode may then be moved slowly toward the main electrode to which it is connected, leaving a channel of liquid salt between the two main electrodes. With the power left on, the bath will soon become liquid throughout and any desired temperature, including the very highest used in hardening, can be obtained with precision by adjusting the power through the regulator. The time required for melting all the salt varies from one to two hours, depending upon the size of the bath and the power applied. The temperature of the bath can be accurately measured with a pyrometer, the "fire end" of which is to be immersed in the bath. Several types of pyrometers are available, the most common of which consists of a sensitive milli-voltmeter connected to a thermo-electric couple, or the so-called "fire end." The scale of the indicating voltmeter is calibrated in degrees Centigrade or degrees Fahrenheit, so that direct temperature readings can be made. The thermo couple is usually enclosed in a protecting steel tube, so that its life is quite long. Fig. 6 shows a pyrometer having a portable type of indicating instrument.

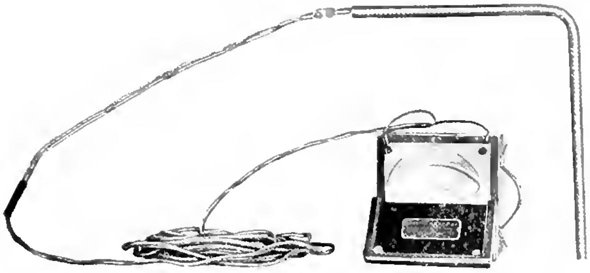

Fig. 6. Pyrometer with Portable Type of Indicating Instrument

The temperature of the bath is absolutely uniform throughout due to the pronounced circulation. This circulation is caused mainly by the electromagnetic forces set up by the heavy current, and in this respect these furnaces have a great advantage over all other "wet heat" furnaces.

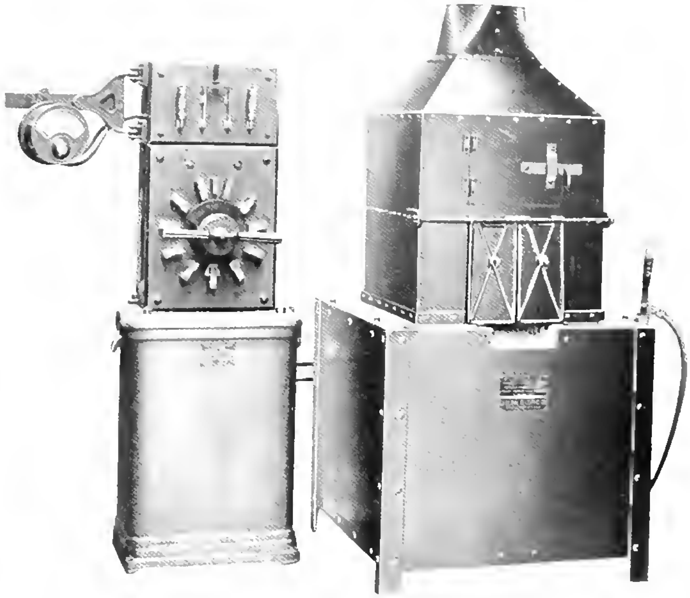

Fig. 7. Furnace for Hardening Carbon Steel

Steel, being heavier than the salt, does not float as in the lead bath, but must be suspended from a steel wire or held in some other suitable way. The tool is left in the bath until it attains the same color and temperature as the bath, after which it is removed and quenched in water or oil as the case may be.

When a tool is placed in the bath it will be noted that the surrounding salt solidifies, say to a thickness of $\frac{1}{32}$ in., and this blanket of salt will melt slowly. This is of great advantage in reducing the shock from sudden heating, the solid salt being a poor conductor of heat. When the tool has finally attained the temperature of the bath and is removed, it will be noted that it is covered with a thin film of the salt, which protects against oxidation; but as soon as the steel strikes the cooling medium the salt chips off, leaving a clean surface. The salt has absolutely no chemical effect upon carbon steel, and if certain precautions are taken there is no difficulty with high speed steel. Blistering or pitting of the surface of the tools has never been observed.

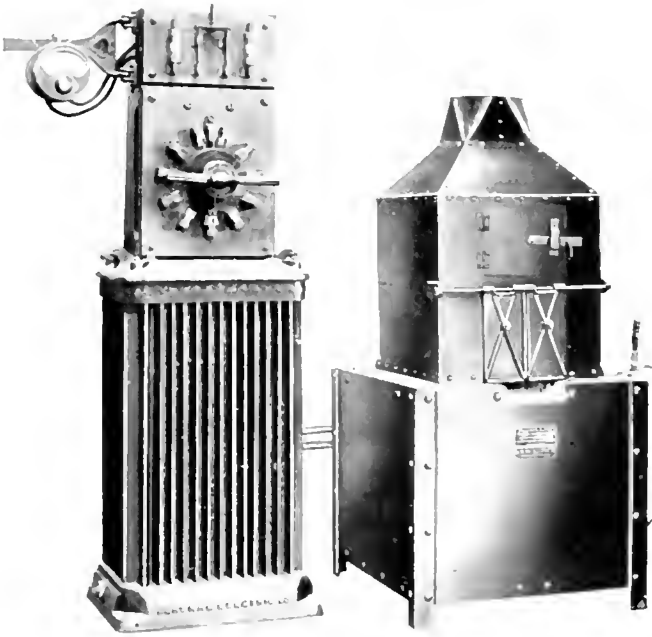

Fig. 8 Furnace for Hardening all Kinds of Steel. May be used for Temperatures as High as 1300 Deg. C.

As long as the tool is covered by the blanket of solid salt no current will penetrate it on account of the non-conducting properties of the solid salt. When this blanket melts the current will go through the tool, but the heat developed thereby will be very small and uniform, except in the case of a tool having a sharp point in close proximity to one of the electrodes. In such a case the current density at this point may be high, causing over-heating. Such difficulties, however, do not take place in practice where the operator has been properly instructed.

When a large tool or a large number of small tools are immersed in the bath its temperature naturally drops a certain amount and if no adjustment is made on the regulator it will require some time before the desired temperature is again reached. However, by applying more power this time can be shortened to suit the requirements. For example: if without changing the power the necessary time for heating the tools is 30 minutes, this can, by increasing the power, be shortened to 5 minutes or even less without any danger of uneven heating of the bath. This furnace can therefore be adapted to very fast production and in this respect is comparable with the lead furnace.

It may be added that the fumes given off by the salts are not considered poisonous; in fact, practically no fumes are given off except at starting, and these are carried off through a hood which is provided. The operation of the furnace is exceedingly simple, no special knowledge of electricity being required. The voltage within the bath is so small that there is absolutely no danger of shocks.

These furnaces operate only on alternating current, direct current being unsuitable on account of the electrolytic effect on the bath. The power is very steady and the power-factor nearly unity, so that this load should prove to be very desirable for central stations.

The upkeep of the furnaces is very low. The loss of salt is small, and is due mostly to its removal with the tools. The electrodes, which are inexpensive and easily replaced, will last about three months if the bath is operated at 800 deg. C., and the crucible will last almost indefinitely. Even at

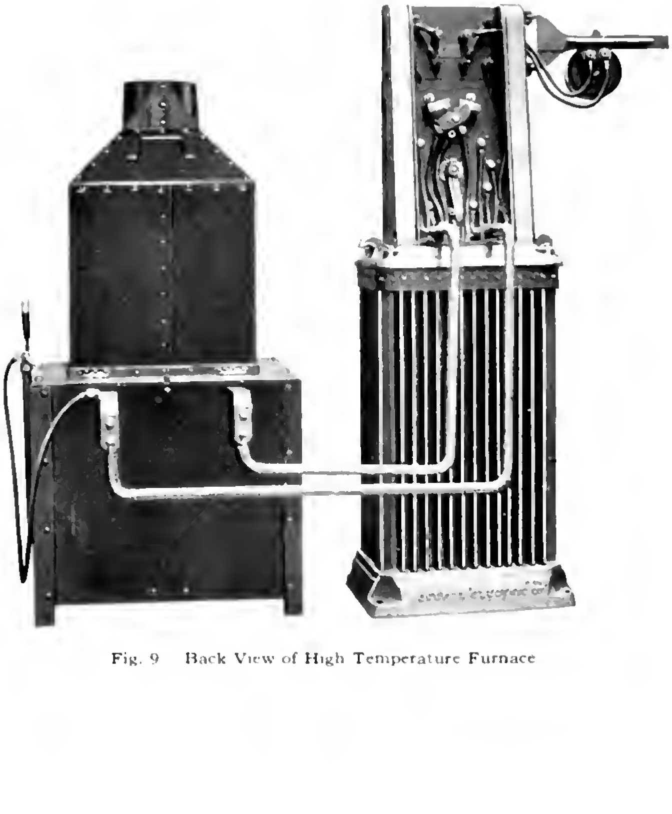

Fig. 9 Back View of High Temperature Furnace

temperatures as high as 1300 deg. C. the crucible will last 6 months or more, and it can then be replaced at a small expense. If cracks should develop in the crucible the salt will flow into them and harden, thus automatically preventing leakage. This is a great advantage over externally heated baths.

So far as the efficiency is concerned, it may be stated that it is very high as compared to the standard type of furnace. In making such comparison, the mistake is often made of comparing the operating cost of furnaces having the same heating space. The only logical basis of comparison is, of course, the number of tools that can be hardened; and then the quality should not be overlooked. In order to make a true comparison a great many other factors must be considered, which, however, are outside the scope of this article.

The electric hardening furnaces can be built in any size, but for ordinary requirements a bath with dimensions of 8 in. by 8 in. by 8 in. has been found quite sufficient. Fig. 7 shows one of these outfits suitable for hardening carbon steels, while the outfit shown in Figs. 8 and 9 is suitable for hardening any kind of steel and may be used for temperatures up to 1300 deg. C.

Quite a number of these furnaces are now in successful operation for hardening all kinds of tools, such as twist drills, reamers, cutters, knives, razor blades, chisels, lathe tools, dies, etc., and it has also been proposed to use this method for heating rivets, bars for forging, etc.

WHAT THE CRANE FOLLOWER SHOULD KNOW OF SLINGING AND MAKING HITCHES

By John Riddell

Mechanical Superintendent, Schenectady Works, General Electric Company

The number of accidents which are likely to occur through the operation of cranes depends on the size of the factory, on the instructions which are issued to crane followers and others regarding the methods which they should follow, and the degree of thoroughness which is realized in seeing that these instructions are rigidly carried out. This article deals with the matter of handling electrical machinery in a strictly practical way. The instructions may be said to be primarily for the benefit of the men on the floor who have actually to do the work. They may also be of service to station engineers and others who have to supervise the assembly and disassembly of machinery in the station; while they will doubtless be of considerable interest to a wider circle of readers who have come only into indirect contact with such matters, but who are on the lookout for further enlightenment on what is, after all, a very important phase of economical factory operation.—Editor.

The handling of heavy machines and parts of machines in a large electrical factory is, of course, a matter of the greatest importance. The apparatus used includes travelling cranes, jib cranes and other machinery; and, during the ordinary working day, has to deal with weights varying between very wide limits. The different cranes may vary in capacity from, say, 3 tons to 100 tons; and the weights of the pieces which have to be handled may be anything from 100 pounds to 100 tons.

Accidents from Cranes

As a general rule, no particular trouble need be expected in handling the larger weights, since, owing to their importance, more care is exercised in making hitches and other preparations, and usually the foreman, or some other leading man, sees that every accident is guarded against. It is from pieces of medium weight and light weight, of which a great many are handled every day, that trouble more often results. The man handling so much of this class of work becomes thoughtless, the slings become chafed and worn, and the chains become crystallized by long use. The last is a frequent cause of trouble. There is a great difference between ropes and slings used for hoisting. In ropes the wear can always be seen by the strands becoming frayed, loose or cut. A chain, outside of a few bruises, will not show any signs of weakness; although actually it may be full of small cracks which cannot be seen by the naked eye, or it may be much crystallized by long use. A chain under these conditions is rapidly becoming weaker with each lift; until it finally gives way, letting something fall on the man who used it, or, as is more frequently the case, on some innocent shop mate.

Fig 1. Clove or Double Half Hitch (Method of Making)

Fig. 2. Timber Hitch

Used principally for hoisting rough lumber.

Fig. 3. Clove or Double Half Hitch

Very useful in the hands of a trained rigger, but, except for hauling, should not be generally used where other slings are available.

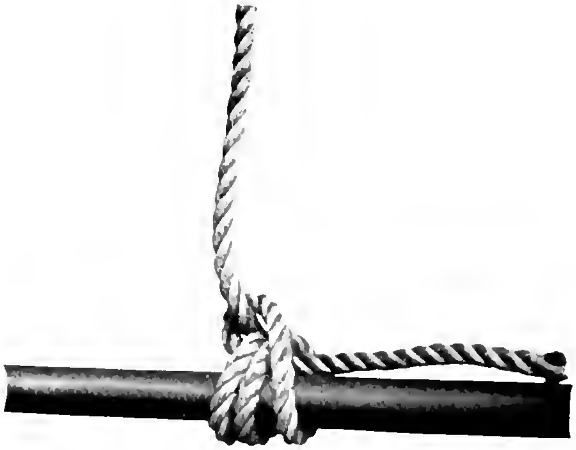

Fig. 4. Studding Sail Hitch

May be used very properly for hoisting timber or such material.

Fig. 5. Timber and Half Hitch

Very useful for hoisting shafts or timbers in a vertical position.

Fig. 6. Blackwall Hitch

Exceedingly useful where material is to be drawn along the floor, or for hauling cars on a level, or where the hitch is to be made quickly, or where a change is frequently required.

Fig. 7. Square or Reef Knot

Used only for joining two ropes together. This knot cannot slip.

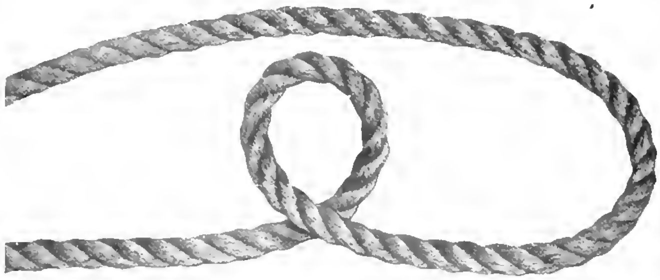

Fig. 8. Bowline Knot

First position necessary in making a bowline knot.

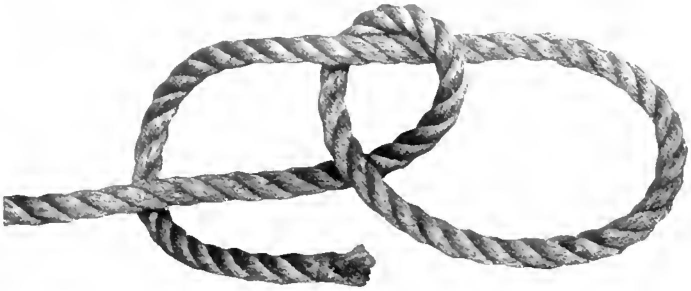

Fig. 9. Bowline Knot

Second position necessary in making a bowline knot.

Fig. 10. Bowline Knot

Third position and completed bowline knot. If properly made this knot cannot slip.

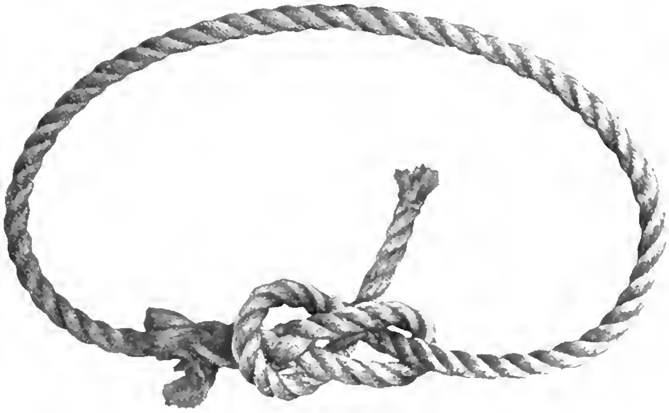

Fig. 11. Sheet Bend in Eye

Generally used for an adjustable sling. It can be adjusted quickly, and is a safe and useful sling in the hands of trained riggers.

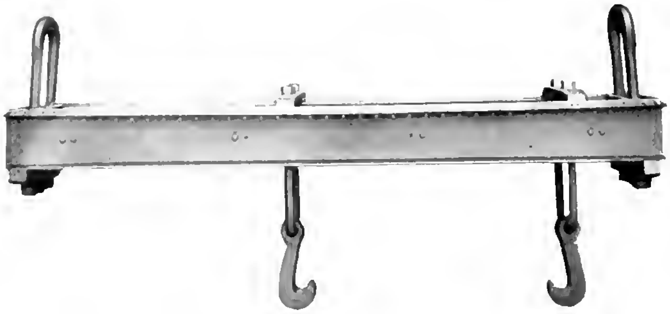

Fig. 12. Equalizer

Used with two cranes of different lifting capacities, when lifting a load of greater weight than the safe capacity of one crane. For example: in the case of a weight of 90 tons, which is to be lifted by two cranes, one having a capacity of 60 tons, and the other a capacity of 30 tons. The hooks of the equalizer should be located so as to bring the center of the weight one-third of the length of the beams away from the end attached to the 60-ton crane. This arrangement brings two-thirds of the weight on the 60-ton crane and one-third of the weight on the 30-ton crane.

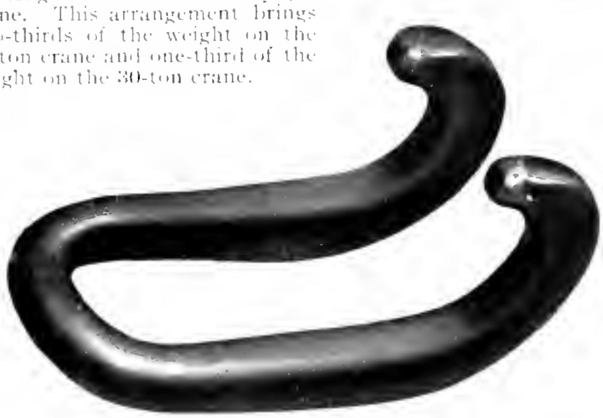

Fig. 13. Double Hook

Used for lifting flat disks or other flanged pieces where the hook can be properly applied. These hooks should never be used on the inside of a hole or bore of any casting where they would be liable to slip, and, while two of them can be safely used in a great many cases, it is preferable to use them in sets of three, equally divided around the circumference of the piece to be lifted.

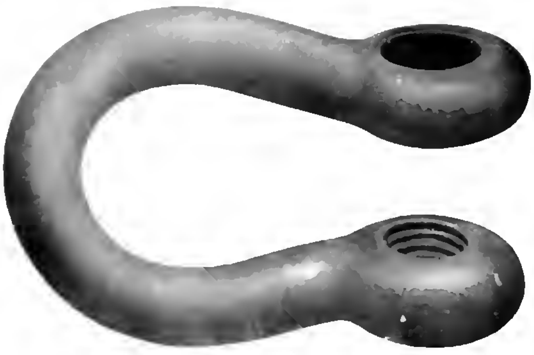

Fig. 14 Shackle

Used where a bolt can be passed through the shackle and a hole or opening in the part to be lifted.

But whether anyone is hurt or not there is always a loss to the factory. Sometimes it may only be a rough casting, but very often it is a piece of finished apparatus on which much time and labor has been spent; and worst of all there is usually urgent need for the apparatus at its destination, and disappointment to follow. Suitable racks should be provided for hanging chains and slings on, and when not in actual use they should be kept on these racks. When not following cranes and making hitches, the followers should be inspecting these slings to detect weaknesses and sorting out the bad ones to have them repaired. These racks also afford a ready means for the head rigger's inspection, who is in charge of all such apparatus, and who should always be consulted when anything of a doubtful character in relation to hoisting comes up.

There are many varieties of hitches and many kinds of knots. Some are useful, others are ornamental, but it is only the useful kind that will be considered in the following pages. A general description will be given of the standard hooks, eyes, clevises, etc., used in general practice. Some knots and hitches will also be shown which are used in special cases, but which are not intended for everyday use in machine shops. They are useful, however, for riggers, millwrights and others handling special machinery and materials, and should be used only by men competent in such work.

Wire Cable Slings

Wire cable slings occupy a very important place in hoisting, and have been found very satisfactory when carefully used. A wire cable sling should never be used singly when hooked by a spliced eye. When the weight is sufficient the cable is liable to untwist, thus allowing the splices to open and slip (see Fig. 17). Such slings should always be used double, and where sharp corners or rough castings exist the cable should be protected by pads (see Fig. 18). Another method of protecting the cable is by two loose metal blocks that should be perfectly free to adjust

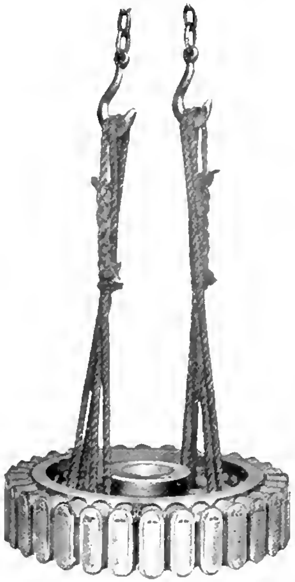

Fig. 15. Proper Way to Lift and Turn Revolving Field (First Position)

A double set of slings should be used on the main hoist to lift the field high enough for turning; padding being used wherever necessary to protect the slings from sharp corners.

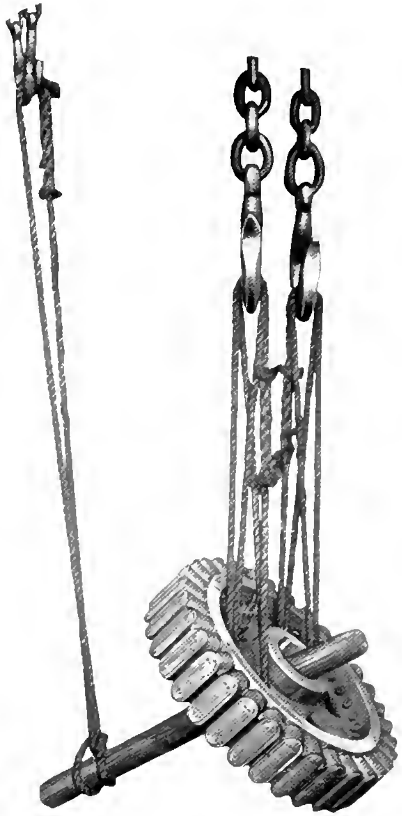

Fig. 16. Proper Way to Lift and Turn Revolving Field (Second Position)

The field having been hoisted high enough for turning, a piece of timber or scantling should be placed through the bore of the field, the other end of the scantling to be connected to the "small hoist" by the sling; then by lifting on the "small hoist" and lowering on the "main hoist" the work is turned over. Great care should be used, especially against chafing or cutting of the slings.

Fig. 17. Single Cable Sling

The use of a single cable sling in this manner is very dangerous. If the load is sufficient, the cable is liable to be untwisted to such an extent that the splices will open, thereby allowing the splices to slip. Padding should be used on all sharp corners to protect the cable.

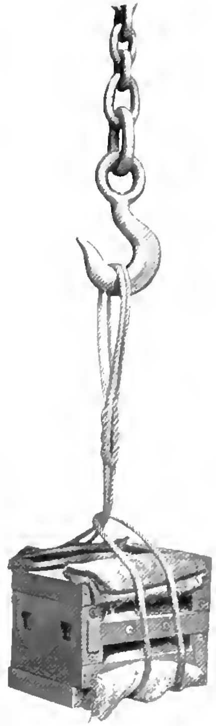

Fig. 18. Double Cable Sling

Right way of using a wire cable sling; pads should be used on all sharp corners to protect cable.

themselves and afford ample protection for the slings so used.

In using slings of any kind, especially rope, care should be taken to see that they are properly laid; i.e. to see that one rope does not lie on top of the other, as this will prevent proper equalization, putting an undue strain on the outer rope. It very often happens, when a rope sling is used double, that the ends of the rope are passed through the doubled part, as when placed around a casting; and, unless this is done carefully, instead of having the strength of two parts of a rope, as supposed, it can be so slipped around the casting, or other piece being lifted, as to actually only have the strength of one part.

Sudden Stoppages of Load

Before lifting heavy loads by means of a crane the crane brakes should always be tested to see that they are in good condition and will hold. Care must be used when lowering loads to limit the speed, which should not exceed the hoisting speed of the crane for the same load. Particular care must be taken to apply the brakes gradually when bringing the load to rest. The ordinary hoisting speed for a 30-ton motor-operated crane is about 18 ft. per minute, and for a 50-ton crane about 12 ft. per minute with the rated load. Stopping the load at such speeds within a distance of 1/8 in. may double the stress on the slings and crane. *This point cannot be emphasized too strongly; as, in more than one instance, serious accidents have resulted from the sudden stopping of cranes while the load was being lowered.*

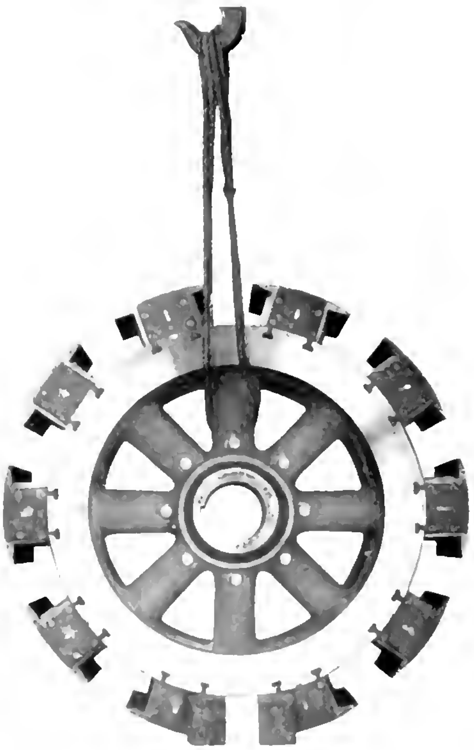

Fig. 19 Improper Method of Making Hitch for Turning Revolving Fields with Two Slings

As the slings are liable to be of different lengths the whole or greater part of the load would come on one sling.

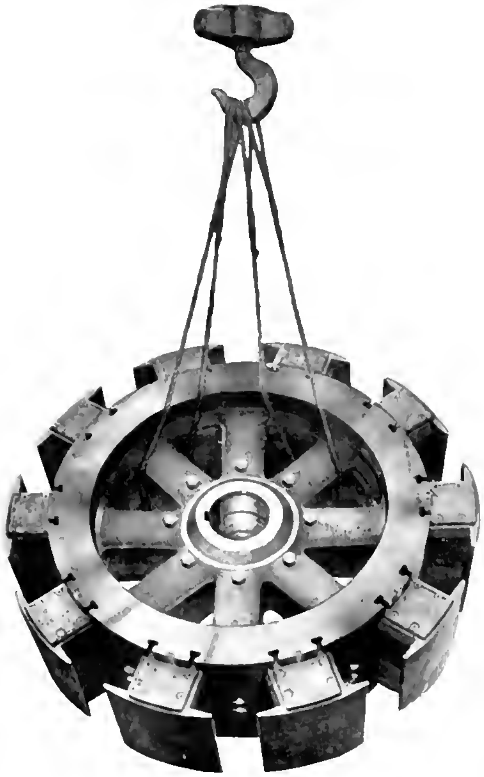

Fig. 20. Proper Method of Making Hitch for Turning Revolving Fields

Slings when used as shown permit of enough slip to equalize or give an equal pull on each part of the sling.

TABLE I

	INCHES A	B	C	Safe Load Lb.
	$\frac{1}{2}$	$1\frac{1}{2}$	$\frac{7}{16}$	1100
	$\frac{9}{16}$	$1\frac{9}{16}$	$\frac{17}{32}$	1500
	$\frac{5}{8}$	$1\frac{11}{16}$	$\frac{5}{8}$	1800
Drop	$\frac{3}{4}$	$1\frac{13}{16}$	$\frac{3}{4}$	2800
forged	$\frac{7}{8}$	$1\frac{15}{16}$	$\frac{13}{16}$	3900
steel.	1	$2\frac{1}{16}$	$\frac{15}{16}$	5100
	$1\frac{1}{4}$	$2\frac{5}{16}$	$1\frac{3}{16}$	8400
	$1\frac{1}{2}$	$2\frac{9}{16}$	$1\frac{3}{8}$	12,200
	$1\frac{3}{4}$	$3\frac{1}{16}$	$1\frac{1}{2}$	16,500
	2	$3\frac{1}{16}$	$1\frac{5}{8}$	21,800
D.B.G. Iron	$1\frac{3}{4}$	3	$1\frac{1}{4}$	10,000
E.L., 28,000	$1\frac{3}{4}$	4	$1\frac{1}{2}$	11,000
Lb. per sq. in.	2	5	$1\frac{3}{4}$	14,000
Welded	$2\frac{1}{4}$	6	2	16,000

Increased Stresses Due to Angle of Slings

When a weight is lifted by two or more slings connected to the crane hook and making an angle with each other, the increase in the stress of the individual slings must be considered. On account of this angle between the two sets of slings the stress on each set

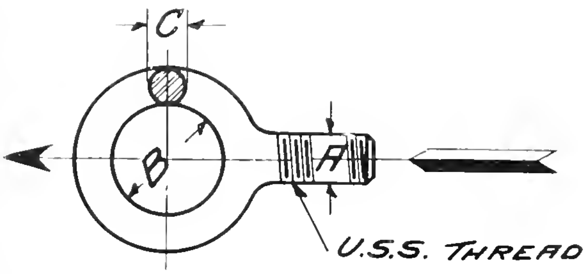

Fig. 21

is greater than half the total load, and increases very rapidly as the angle between the sling and the work is decreased. An angle of 45 degrees between the sling and the work

Fig. 22. Wrong Way of Making a Hitch

This method of making a hitch gives a one part cable, due to sharp bend and loop in sling, as shown by arrows.

Fig. 23. Right Way of Making a Hitch

The friction of the cable around the object giving approximately a two part cable.

Fig. 24. Improper Use of Double Hook

Should never be used as shown.

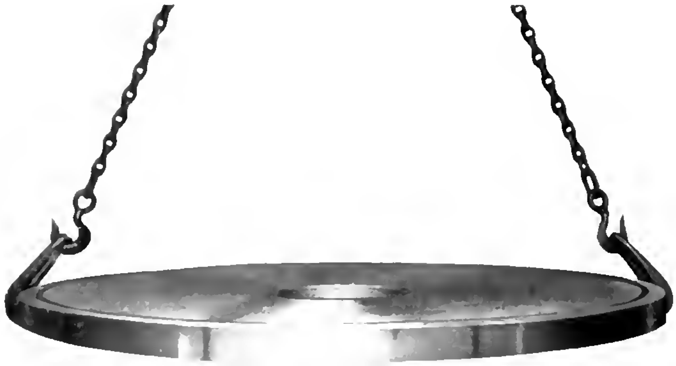

Fig. 25. Two Double Hooks

Correct position when two double hooks are used. Where possible use three hooks.

Fig. 26. Three Double Hooks

Where possible use in preference to two double hooks.

makes the stress in each sling three-fourths of the total weight, and the collapsing force between the two points of attachment to the work is equal to one-half the weight. This collapsing force acts in a direct line between the two points of attachment. If the work is ring-shaped, it would tend to deform the ring. A spreader of sufficient stiffness should be used between these two points to resist this collapsing force. It will be seen that eyebolts are not suitable for attaching the slings to the work unless a spreader is used to relieve them of this side pull, which would put a *heavy bending moment* on the shank of the bolt. Reducing the angle between the sling and the work to 30 degrees makes the stress in each sling equal to the total weight, and the collapsing force is also equal to the total weight. Such a small angle should never be used if avoidable.

Safe Loads for Eyebolts

When it is necessary to use eyebolts for lifting loads no greater strain should be allowed than given in Table I, which gives the safe load in pounds for bolts up to and including $2\frac{1}{4}$ in. diameter. It should be noted that the values given are correct only when the pull is in the direction of the arrow shown in Fig. 21, and when the bolt is in good condition.

It should be understood that, to obtain the greatest strength from an eyebolt, it must fit reasonably tight in the hole into which it is screwed, and the pull applied in a line with the axis of the screw. Eyebolts should never be used if considered the least faulty. They should never be painted when used for miscellaneous lifting, as paint is very apt to cover up flaws. They should be tested occasionally by tapping gently with a hammer, but not sufficient to bend or to otherwise injure them. If it does not impart a good ring one of two things is the reason. It may fit too loosely in the hole, or there may be a flaw.

TABLE II

MANILA ROPE				WIRE CABLE				CHAINS			
Dia. of Rope in In.	Safe Load in Tons			Dia. of Cable in In.	Safe Load in Tons			Dia. of Chain in In.	Safe Load in Tons		
	Single Rope	Two Part	Four Part		Single	Two Part	Four Part		Single Chain	Two Part	Four Part
1/2	1/8	1/4	1/2	1/2	1	2	3 1/2	1/4	1/2	7/8	1 1/2
5/8	1/4	1/2	3/4	5/8	1 3/4	3 1/4	6 1/2	3/8	1	1 3/4	3
3/4	3/8	3/4	1 1/4	3/4	2 1/2	4 1/2	9	1/2	2	3 1/2	6
7/8	1/2	1	2	7/8	3 1/4	6	12	5/8	3	5	9
1	3/4	1 1/2	2 1/2	1	4	8	16	3/4	5	9	15
1 1/4	1	2	3	1 1/4	6	12	24	7/8	6	10 1/2	18
1 1/2	1 1/4	2 1/2	4	1 1/2	10	19	36	1	8	14	24
1 3/4	2	4	6	1 3/4	13	25	48	1 1/8	11	19	33
2	2 1/2	5	8	2	16	32	60	1 1/4	13	23	39
2 1/4	3 1/2	6 1/2	11					1 1/2	18	32	54
2 1/2	4 1/2	8	13								

[On page 166 it is stated that wire cable slings should never be used singly when hooked by spliced eye, as shown in Fig 17, because of the liability of the cable to untwist and thus allow the splice to slip. The illustrations on this page show the use of two slings in which the hitch is made, by means of the spliced eye. Here, however, there is no chance for the cable to untwist and in such cases the use of this hitch is justifiable.]

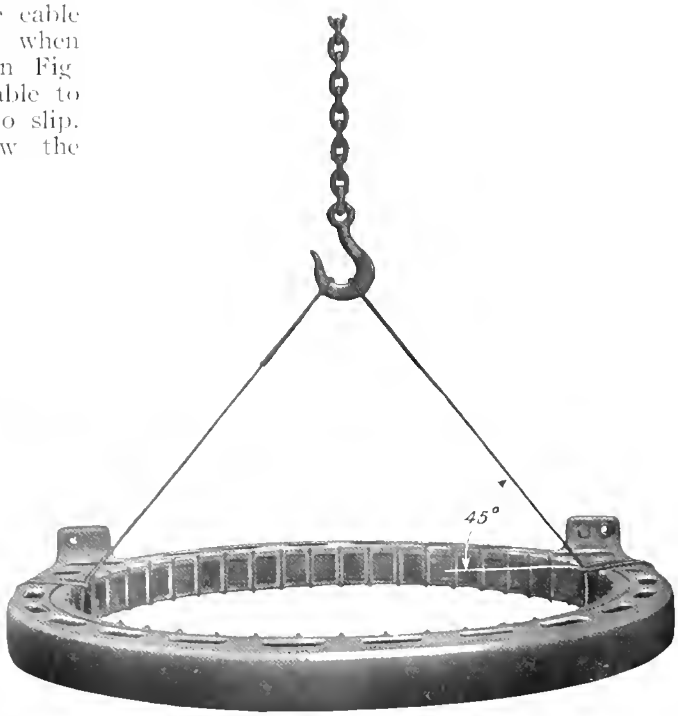

Fig. 28. 45 Deg. Angle Sling (Right Way)

In lifting work of this nature the angle of the slings should never be less than 45 degrees. The manner of making hitch to be as shown.

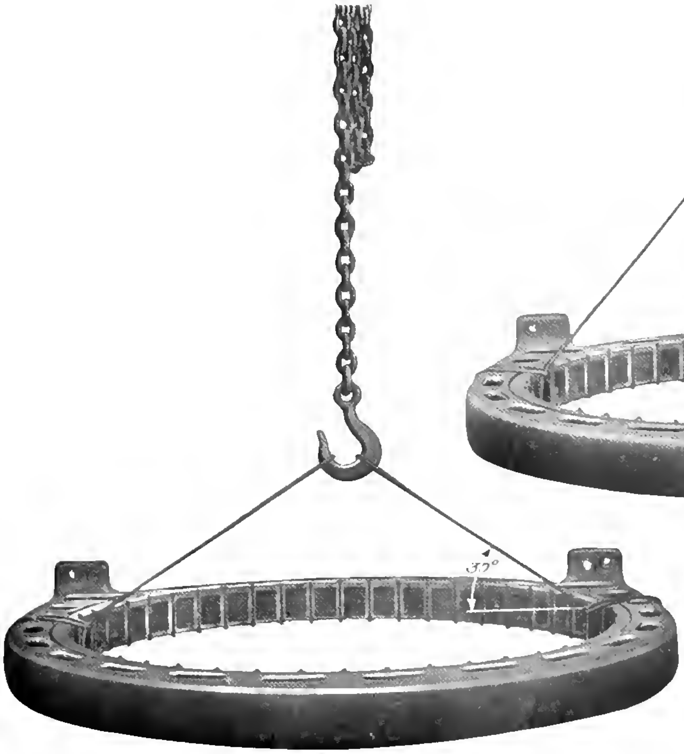

Fig. 27. 30 Deg Angle Sling (Wrong Way)

If it can be avoided, hitches, with a small angle between the slings and the work, should never be used, as the stress in the slings or the collapsing force on the work may reach the breaking point.

TABLE III
WEIGHTS OF VARIOUS MATERIALS

Material	Weight per Cu. Ft. in Lb.	Weight per Cu. In. in Lb.
Cast iron	450	0.26
Steel	489	0.28
Copper	552	0.32
Lead	709	0.41
WOOD		
Ash	45	
Pine	38	
Concrete	155	
Stone	180	
Earth	72 to 110	
Brick	100 to 150	
Mortar	100	
Marble	180	

SHAFTS

Diameter in In.	Weight of Shafting in Lb. per Lineal Ft.
6	95
8	169
10	264
12	368
14	517
16	676

Where a bolt is to be used for anything like its maximum load it should be screwed in tight with a bar and given a gentle tap with a bar or hammer to see if it imparts a solid feeling. If not, it should not be used.

Safe Load on Ropes and Chains

Table II gives the safe loads which may be put on manila rope, wire cables, and chains. The first column gives the diameter of the rope or chain, the second column gives the safe load which the rope or chain is to carry singly. In a sling where the strain is carried by two ropes or chains, the loads given in the third column should be used. In a sling where four parts of the rope or chain carry the load, the figures in the fourth column should be used. Figures are in tons of 2000 lb. each.

The loads for manila rope should be used only when the rope is in fairly good condition; when badly chafed or worn the load should be reduced in proportion.

As there are a great many different kinds of material to handle in the various parts of a factory, and in order to familiarize those engaged in the actual handling of these materials, a short table of the weights of the various materials is given (see Table III). The weights of cast iron, steel, copper and lead are given in pounds per cubic foot. The weights of wood, concrete, stone, earth, brick, mortar and marble are also given in pounds per cubic foot. A great deal of shafting is also handled. The weight of shafts is given per lineal foot, or so many

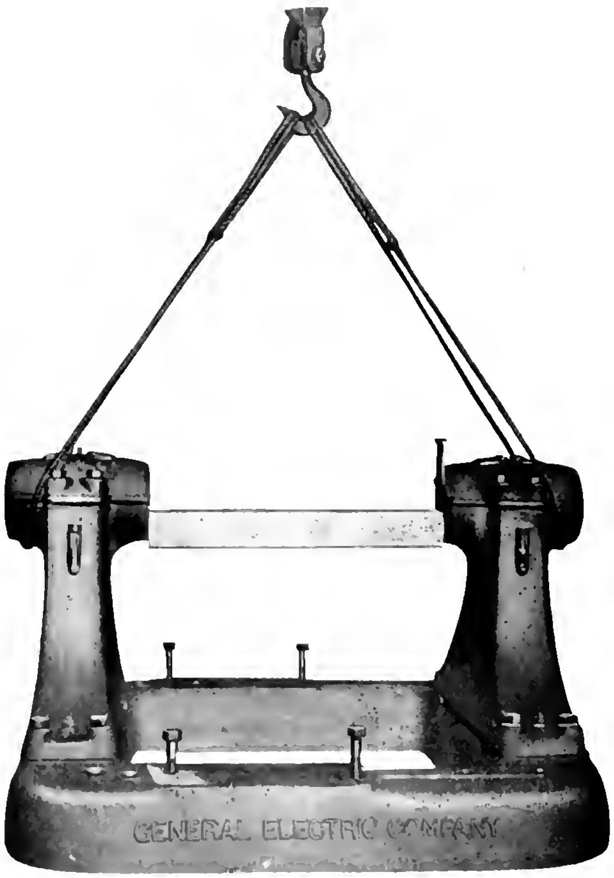

Fig. 29. Lifting a Base with Standards

Frequently a base and standard are lifted and no provision is made for any lateral strains that may occur; tending to place an unnecessary strain on the bolts fastening the standards to the base. When such a lift is to be made, a piece of timber should be placed between the bearings to relieve the strain, as shown.

pounds per each foot in length. All that is necessary to find the weight of any piece of shafting, knowing the weight per foot, is to multiply the weight by the number of feet in length, which will give the net result in pounds to be lifted. For instance, a piece of shafting 16 in. in diameter, 1 ft. long, weighs 676 lb. A piece of shafting of this same diameter and 16 ft. long would weigh 10,816 lb. Provision in this case should be made for lifting at least six tons.

A wood or lag screw, when made in the form of an eyebolt, should never be used to hang any hoisting tackle on. Wherever possible the safest way to hang such tackle is by passing the shank of an eyebolt through the floor or beam, properly protecting the wood by a large plate washer and nut. It frequently happens that a chain or rope sling can be used by passing it over a properly secured timber. There are several good ways of doing things, and many wrong ways. Care should always be used to see that they are done in a good way. Case after case might be enumerated; but enough has been said to enable any person entrusted with this work to be able to decide on a proper method, and the proper slings or other apparatus to be used. Where he is in doubt as to the weights to be lifted or methods employed, he should seek advice from those qualified to give it. For the guidance of those engaged in handling or lifting pieces it is also suggested and urged that all irregular shaped castings, and in fact, all castings weighing over a ton, should have the gross weight marked in plain figures. It is always safer to over-estimate a weight than to under-estimate it; and it is always safer to use slings of ample lifting capacity than those about which one is in doubt.

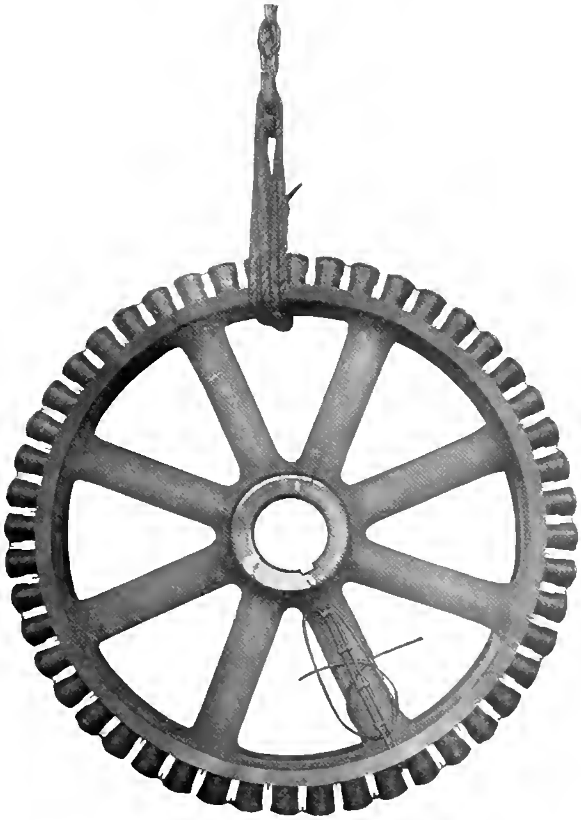

Fig. 30. Lifting Revolving Field (Wrong Way)

When the slings are used between two arms the entire strain of lifting, coming in one segment, would, if the weight were great enough, crack or break the piece.

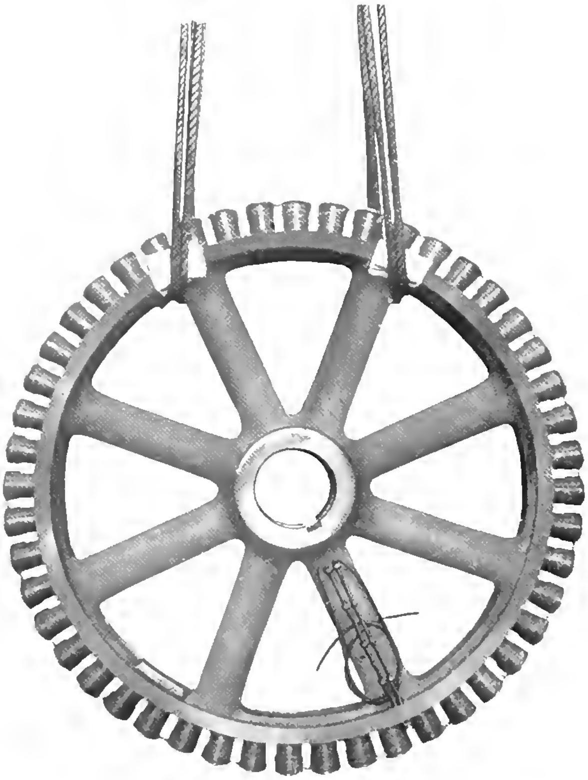

Fig. 31. Lifting Revolving Field (Right Way)

Two or more double slings should be used, depending upon the weight, the slings to be placed behind two adjacent arms and protected by means of padding.

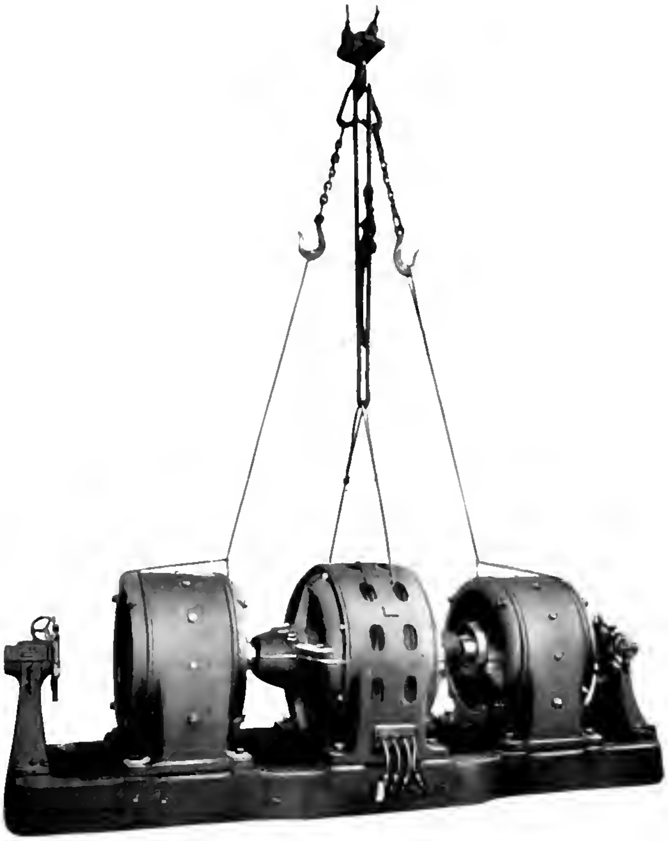

Fig. 32. Lifting Motor-Generator Sets Wrong Way

In this case there are a number of sharp corners unprotected while the manila rope sling passes through the loop of the wire cable, and the arrangement of the outside slings do not permit of an even distribution of the load.

Other defects besides those in lifting apparatus will occasionally be discovered, such as a cracked arm of a flywheel, or other similar piece. If this defect is discovered by the person originally handling the piece, he should call his superior's attention to it immediately upon making such discovery.

Those engaged in this important class of work should also have some idea of the strength of materials. They should know how the strains will be set up in such materials, and also know how to apply slings for lifting, as illustrated in some of the cuts accompanying this article. They should know that using too small an angle on the slings, as in the case of a field ring, would tend to pull the sides together; and that, in the case of a revolving field where the sling is applied between a pair of arms instead of around adjacent arms, the tendency would be to break out a portion of the ring (See Figs. 30 and 31.) These things are all matters of judgment and the importance of appointing proper persons to have charge of this work cannot be urged too strongly.

A reduction in the number of crane accidents can only be effected by extreme vigilance. The loss of material in the past has been very great. The suffering to humanity caused by thoughtlessness has been as great. If proper care is exercised such accidents can be almost totally avoided.

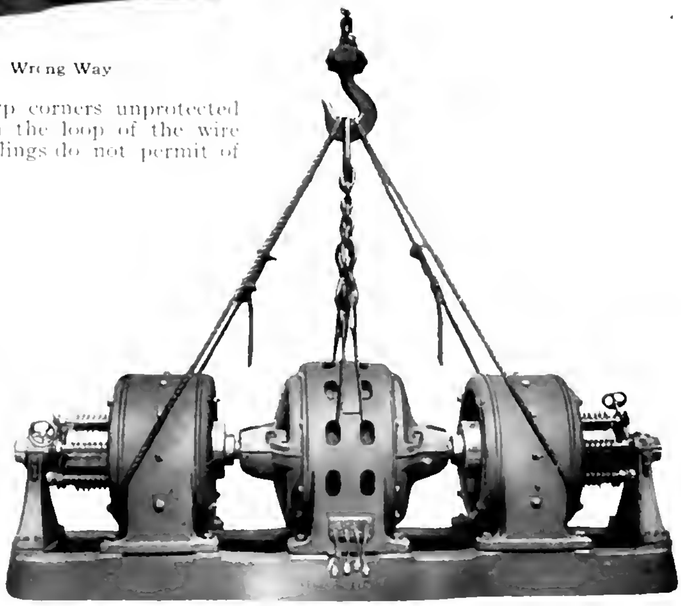

Fig. 33. Lifting Motor Generator Sets Right Way

ELECTRIC SIGN LIGHTING WITH TUNGSTEN LAMPS

By O. P. Anderson

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The purpose of this article is not primarily to show the benefits to be gained in the volume of light and greater economy of operation of tungsten lamps, for these subjects have been previously taken up and discussed with great thoroughness and convincing detail, in the journals more intimately associated with the commercial end of central station business, but to furnish specific information for utilizing the new lamps to the best advantage electrically. It in turn gives a description of the various types of lamps on the market, and instructions as to their selection for any special conditions. Specific directions (including diagrams and tables) as to the number of lamps, layout of circuits, and sizes of wire, applying both to re-equipping of old carbon lamp signs and to design of new signs, conclude the article. Editor.

There are today approximately 80,000 electric signs in this country. Assuming an average of 100 lamps per sign, this make a total of approximately 8,000,000 sign lamps in actual service. From these figures the importance of this business in dollars and cents can readily be calculated. Although it may be seen that the revenue from electric signs is already extensive, these figures represent only a small percentage of possible business. In fact, the surface has as yet only been scratched. Before the advent of the drawn wire tungsten sign lamp a number of central stations believed they had reached the "saturation point" with electric signs. The saturation point may have been approached with carbon lamps in a few cases, but this condition has now been changed. The tungsten lamp has opened almost unlimited fields for the use of electric lamps for advertising purposes.

Merchants today know the value of electric sign advertising, as is evidenced by the large number of signs which border our principal thoroughfares. Owing to the extreme flexibility of design made possible by the use of incandescent lamps, the sign can be made as plain or fancy as desired. The dealers are satisfied that this is the most efficient method of advertising; that it will attract and compel attention when all other methods fail; that, in fact, it is the most profitable investment they can make. Their only objection has been the cost of operating the old carbon lamps.

Every merchant is in a position to spend a certain percentage of his gross receipts for advertising, including electric signs; but the cost of operating a representative sign with carbon lamps has, in many cases, exceeded that sum, and hence the merchant was compelled to forego the sign. The carbon lamp, however, is now obsolete, it being either efficient nor attractive. Its place has been taken by the efficient tungsten sign lamp, which removes every objection that any merchant might have had against the old carbon lamp.

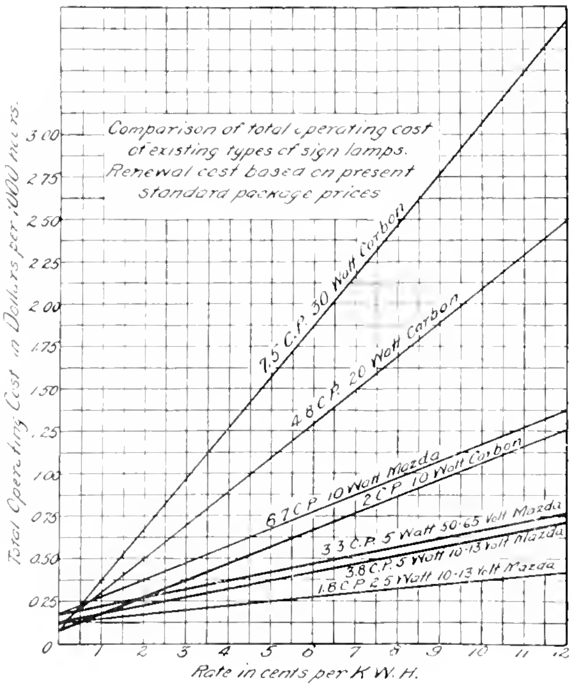


Fig. 1

Fig. 1 gives the comparison of the total operating cost of various types of sign lamps. In these curves the renewal cost is assumed to be the present standard package price. It will be seen that there is no longer any excuse for the continued use of carbon sign lamps.

Fig. 2 gives theoretically the conditions which are produced with tungsten lamps. It will be seen that as the operating cost decreases, due to the use of high efficiency tungsten lamps, there is a material increase

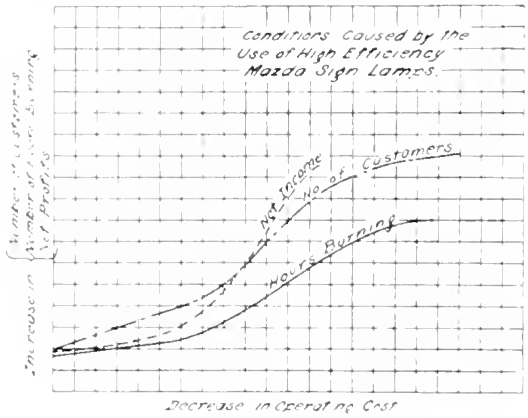


Fig. 2

in the number of consumers. In addition to this the reduction in operating cost makes it possible for existing consumers to burn their signs longer for the same expense, thus getting more advertising, and at the same time greatly improving the load factor of the central station. The gross income to a central station varies with the product of the operating cost per hour, the number of consumers and the number of hours burning. The increase in the number of hours burning and number of consumers will more than offset a decrease in operating cost, the result being a material increase in income to the central station. Therefore, by reducing the operating cost a small amount, it is possible to considerably increase the net profits to the central station, and at the same time give the customer more and better advertising for the same amount of money.

There are a large number of carbon signs throughout the country which are not operated at all, or, at best, only a very short time each night. Clearly this is not profitable business for the central station, nor does it give the merchant results in proportion to his investment. Therefore everything seems to indicate that it is both to the advantage of the central station and merchant that tungsten lamps be used.

Figs. 3, 4, 5 and 6 show the types of tungsten sign lamps in use at the present time and Table 1 gives their qualifications. It is now possible to use these lamps on any standard lighting circuit, whether alternating or direct current. The filaments in all tungsten low voltage sign lamps are now made of wire of exactly the same diameter. This means that when these lamps are connected in series and necessarily take the same current they will operate at the same current density and efficiency in watts per candle. This makes it possible to get nearly as good results from series as from multiple operation.

TABLE 1—Sizes and Characteristics of Tungsten Sign Lamps

Rated and Average Watt	Type of Lamp	Efficiency		Candle-Power		Average Total Life in Hours	Bulb	
		Watts Per Candle	Lumens per Watt	Mean Horizontal	Mean Spherical		Diameter in In.	Length Overall in In.
10 to 13 Volts								
2.5	Fig. 4	1.33	7.46	1.8	1.4	2000	$1\frac{3}{4}$	$3\frac{3}{8}$
5.0	Fig. 4	1.33	7.46	3.8	3.0	2000	$1\frac{3}{4}$	$3\frac{3}{8}$
5.0	Fig. 3	1.33	7.46	3.8	3.0	2000	$1\frac{9}{16}$	$3\frac{1}{4}$
50 to 65 Volts								
5	Fig. 5	1.5	6.62	3.3	2.6	2000	$1\frac{3}{4}$	$3\frac{3}{8}$
100 to 130 Volts								
10	Fig. 6	1.5	6.62	6.7	5.3	2000	$1\frac{3}{4}$	$3\frac{3}{8}$

Since the diameter of the wire is the same through the entire voltage range, namely, 10 to 13 volts, it is evident that there will be a slight variation in the watts consumed, due to variation in voltage. This is to be desired, however, since the normal amperes are constant. It is therefore possible to operate with entire success a 10 volt lamp in series with 9 and 11 volt lamps. However, this is not recommended as it will be responsible for either an increase or decrease in the efficiency at which all the lamps are operated. In order that there may be no misunderstanding regarding which is, and which is not, the correct way to operate these lamps, each type of lamp will be described separately and recommendations made accordingly.

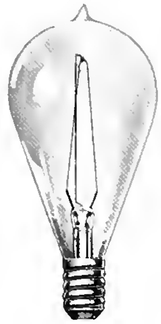
10 to 13 Volt Lamps

Since these lamps are made for 10 to 13 volts they necessarily have a comparatively short and thick filament which makes them very rugged and able to withstand severe service.

In cities supplied with alternating current it is always recommended that these lamps be used in connection with a transformer. The expense of the transformer is justified since by its use the best possible performance is secured through multiple operation. It is poor economy, therefore, to wire even small signs in series under these conditions. It is a very simple matter to change over old carbon signs to accommodate these lamps, as it is only necessary to insert a transformer between the service wires and the sign. Care, however, should be taken to see that the size of wire in the sign is heavy enough to carry, without excessive voltage drop, the increased current consumed by the low voltage lamps. The problem of voltage drop will be taken up later in this article.

In the past these 10 to 13-volt sign lamps have been a perplexing problem to central stations supplying only direct current. Although many have wired these lamps ten in series with good results, others have had only indifferent success. The difficulty has been largely due to a system of wiring which would permit ten lamps to go out whenever one failed. Since, therefore, the success of series systems of wiring with 10 to 13-volt lamps has been questionable, it is no longer recommended for new sign lamps, especially in view of the fact that the 100 to 130-volt and 50 to 60-volt sign lamps make it possible to employ a better system of wiring. However, should a sign be already wired in series, very good results may be obtained by using carefully selected series sign lamps, the present method of selection allowing every one of the lamps in each series to burn at exactly the same efficiency, when consuming the same current. Under no conditions should lamps of different manufacture be operated in the same series.

Although the straight series method of wiring may now be considered obsolete, the multiple series method may still be used with satisfactory results under certain conditions. These conditions are that the sign which is so wired should contain not less than 100 lamps and also that the burnouts be promptly replaced. In Fig. 7 is shown this method of wiring. It is evident that the failure of one

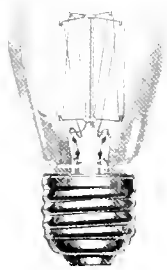


5 Watts
10 to 13 Volts

Fig. 3

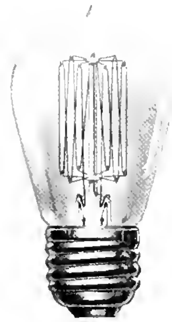
2.5 and 5 Watts
10 to 13 Volts

Fig. 4



5 Watts
50 to 65 Volts

Fig. 5



10 Watts
100 to 130 Volts

Fig. 6

lamp will cause the remaining lamps in that group to operate at an increased voltage which will of course shorten their life. This increase in voltage varies with the number of lamps which are connected in multiple and becomes less with an increase in the

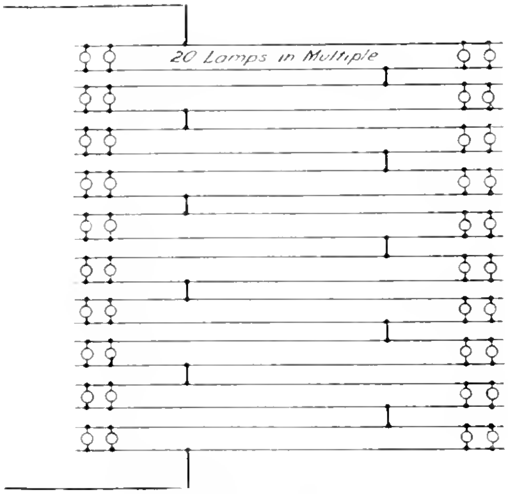


Fig. 7. Multiple-Series Wiring for Sign Lamps, Using 10 Volt Lamps

number of lamps. A sign containing from 200 to 300 lamps should give good results when so wired, provided it is maintained properly.

Tables 2, 3 and 4 take up in detail the various operating conditions of lamps wired in multiple-series. We have in Table 2 a sign containing 200 10-volt, 5-watt lamps, which is wired with ten multiple groups in series, each containing twenty lamps as shown in Fig. 7. It is assumed in this case that all the failures are confined to one multiple group, this being the worst possible condition. Column 1 gives the number of lamps which have failed in one group of lamps. Column 3 gives the percentage increase in voltage on the remaining lamps in this group, while column 4 gives a decrease in voltage on the lamps in the remaining nine multiple groups, due to the failure of lamps in first group.

It can be seen that the failure of one lamp will cause the voltage on the remaining lamps of that group to increase $8\frac{1}{2}$ per cent. Knowing the effect of increasing voltage on the life of lamps it can be readily seen that all burn outs should be replaced at once.

In Table 3 the same sign is assumed to be wired, but as shown in Fig. 8. In this case 20-volt lamps are used and are accordingly wired five groups in series, with each group containing 40 lamps. It can be seen in this case that the failure of one lamp will cause the voltage on the remaining lamps in that group to increase only $3\frac{1}{2}$ per cent as compared with $8\frac{1}{2}$ per cent in the former case.

TABLE 2—200 Lamps in Sign, 20 10-Volt, 5 Watt Lamps in Each Multiple Group, 10 Groups in Series

Lamps Burned Out in One Multiple Group		Percent Increase in Voltage on Remaining Lamps in Multiple with Burnouts	Percent Decrease in Voltage on Remaining Lamps in Groups with All Lamps Burning
Number	Percent of one Group		
1	5	8.5	0.9
2	10	17.5	1.9
3	15	28.0	3.1
4	20	40.0	4.5
5	25	53.0	6.0

TABLE 3—200 Lamps in Sign, 40 20-Volt, 5 Watt Lamps in Each Multiple Group, 5 Groups in Series

Lamps Burned Out in One Multiple Group		Percent Increase in Voltage on Remaining Lamps in Multiple with Burnouts	Percent Decrease in Voltage on the Remaining Lamps in Groups with All Lamps Burning
Number	Percent of one Group		
1	2.5	3.5	0.9
2	5.0	7.5	1.8
3	7.5	11.0	2.8
4	10.0	15.0	3.8
5	12.5	20.0	4.8

TABLE 4—200 Lamps in Sign, 100 50-Volt, 5 Watt Lamps in Each Multiple Group, 2 Groups in Series

Lamps Burned Out in One Multiple Group		Percent Increase in Voltage on Remaining Lamps in Multiple with Burnouts	Percent Decrease in Voltage on the Remaining Lamps in Groups with All Lamps Burning
Number	Percent of one Group		
1	1	0.6	0.6
2	2	1.7	1.7
3	3	2.3	2.3
4	4	3.7	3.7
5	5	4.2	4.2

It is evident, therefore, that with a fixed number of sockets, a more favorable condition results from using higher voltage lamps, with a corresponding decrease in the number of groups which are connected in series and an increase in the number of lamps in each multiple group. Hence, conditions will be improved still further by using 50 to 65 volt tungsten sign lamps, wired in multiple-series with two groups connected in series.

In Table 4 we have assumed the sign to be wired with two groups in series, each group containing 100-50 volt, 5 watt, tungsten lamps as shown in Fig. 9. The failure of one lamp in this case causes the voltage on the remaining 99 to increase only 0.6 per cent. The failure of 5 lamps will be responsible for an increase of only 4.2 per cent in voltage, and therefore will not produce any appreciable detrimental effect on the performance of the remainder of the lamps. It is very evident, therefore, that this last system is a vast improvement over the two previous ones, and it may be said therefore that where a sign contains less than 100 lamps, 50 to 65 volt lamps should be used, wired in multiple-series.

50 to 65 Volt Lamps, Two in Series

These lamps will be of great assistance in the sign lighting field, especially for direct current districts. The method of wiring this lamp will be the same on alternating current and direct current circuits. The lamps may be either wired two in series or in multiple-series. In a double face sign it is suggested that each side be wired in multiple, and the two sides placed in series, thus making the condition of operation practically similar to straight multiple. If it is desired to wire two lamps in series it is recommended that the lamps be staggered

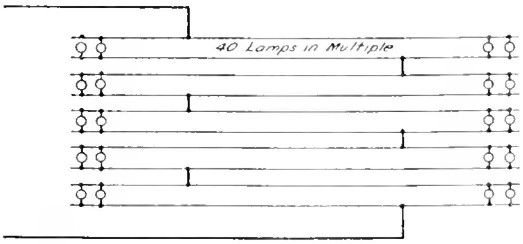


Fig. 8. Multiple-Series Wiring, Using 20-Volt Lamps

so that the failure of one lamp will not cause two adjacent lamps to go out. With a double face sign, by wiring one lamp on one side in series with a lamp on the other side, the failure of one lamp will only cause one lamp on each side to go out, and it can readily be seen that with a reasonable amount of care such a sign can always be kept in good condition.

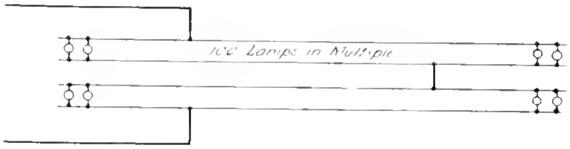


Fig. 9. Multiple-Series Wiring, Using 50-Volt Lamps

The old signs containing 100 to 130 volt carbon lamps can, in the majority of cases, be re-wired very simply, so as to accommodate these lamps. If it is a double face sign the change can be made by simply connecting one side of the sign in series with the other side at the cutout box. If it is a single face sign, or a double face sign with an equal number of balance circuits, the change can be made by connecting in series two circuits which contain an equal number of lamps. Such changes have been made in a number of cases with satisfaction.

100 to 130 Volt, 10-Watt Lamps

The introduction of these lamps has made possible the simplest and most satisfactory method of operating sign lamps, viz., in straight multiple on standard lighting circuits. Their use means the elimination of a transformer, which will mean a considerable saving in the initial cost. Fig. 10 shows the performance of a sign containing about 400 of these lamps which have burned in excess of 2000 hours, giving an average life of 1800 hours, with 60 per cent of the original lamps still in service. The results given in other places, under different conditions, have shown up equally well.

These lamps should prove a blessing to central stations supplying direct current, who have heretofore objected to the series system of wiring. They make it possible to change over all old carbon signs to this lamp without any re-wiring and also to so equip all new signs. In fact there is no logical reason why any new sign should not be supplied with tungsten lamps.

Wiring

The wiring of tungsten sign lamps is very important, especially that of the 10 to 13-volt lamps. It is very essential that the size of the wire be calculated very carefully in order that the Fire Underwriters' rules are not violated, and also in order that the voltage drop be not excessive. According to the Fire Underwriters' rules: "Where wire not inferior in size and insulation to approved No. 14 B.&S. gauge is used, connected direct to standard sockets or receptacles, 1320 watts may be dependent upon final cutout."

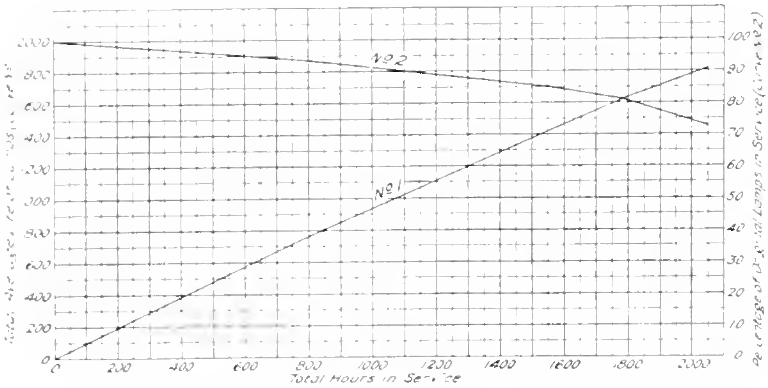


Fig. 10 Performance Curves of a Sign Containing 400 100-Volt Lamps

Table 5 shows the carrying capacity of wires as approved by the National Board of Fire Underwriters, and also the number of tungsten sign lamps, used in multiple, that they may safely carry. It can be seen from this table that the carrying capacity of the wires is the governing feature with low voltage lamps.

With 10 to 13 volt lamps it is very essential that the voltage drop in all cases be less than one-half volt. This is evident, since if a larger drop be allowed the percentage drop would be so high that the appearance of the sign would be affected. For instance, a drop of one volt means a drop of 10 per cent, which is entirely too much for satisfactory service.

Table 6 gives the number of lamps that can be operated on each of four different sizes of wire with a voltage drop not exceeding one-half volt. Table 7 gives the maximum number of 5 watt, 10 to 13 volt lamps, wired in multiple, that can be supplied from feeders having the size and length in the table, with a drop not exceeding 0.2 volts.

With the 100 to 130 volt 10-watt, and the 50 to 65 volt 5-watt lamps, the ampere rating is very small, and hence the governing feature of the wiring will be the 1320 watts which is imposed by the National Board of Fire Underwriters. With 10 to 13-volt lamps wired in multiple, it is, however, necessary to calculate very carefully the size of wire to be used in each particular sign. Knowing the current to be carried, it is a fairly simple matter to determine the size of wire to use by referring to the given wiring tables.

There are several methods of connecting the feeders to the circuits when lamps are wired in multiple that will greatly affect the performance of the lamps. This subject has not been given the attention it deserves, and as a result a number of signs are not operating under the best possible conditions.

In Fig. 11, A, B, C and D, are shown four representative ways that feeders may be connected to tungsten sign lamps which are wired in multiple. It can be readily seen that the expense and convenience of wiring will be about the same in each case, and hence it is simply a problem of calculating which will give the most satisfactory performance.

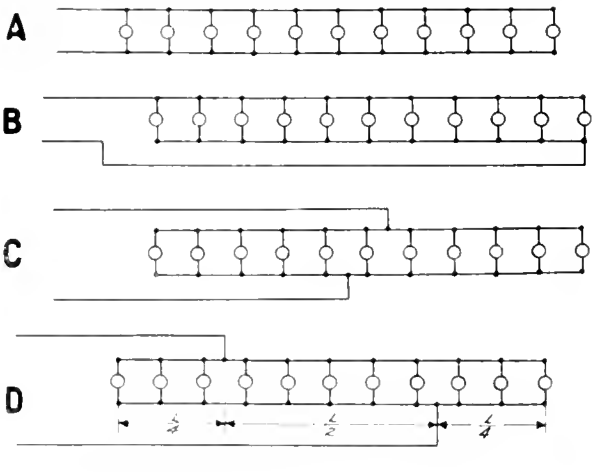


Fig. 11. Methods of Connecting Feeders to Signs Wired in Multiple

TABLE 5—Capacity in amperes of various sizes of copper wire, and number of 5 and 10-watt lamps that may be operated in multiple thereon.

B.&S. Gauge	Rubber Insulation Amperes	No. 5-Watt 10-13 Volts	No. 5-Watt 50-65 Volts	No. 10-Watt 100-130 Volts
14	12	27	137	137
12	17	38	195	*
10	24	55	275	
8	33	76	*	
6	46	106		
5	54	124		
4	65	149		
3	76	175		
2	90	207		
1	107	246		
0	127	*		

* Exceeds the 1320 watts as allowed by National Board of Fire Underwriters.

TABLE 6—Number of 5 watt, 10 to 13-volt lamps that may be operated on each of four sizes of copper wire with a voltage drop not exceeding ½ volt.

Spacing of Lamps in Inches	Size of Wire (B.&S.) 14	12	10	8
3	48*	68*	96*	132*
6	48*	68*	88	112
8	47	60	75	97
10	42	54	68	86
12	38	49	62	79
16	33	42	54	68
20	29	38	48	61

TABLE 7—Number of 5 watt, 10 to 13-volt lamps wired in multiple that can be supplied from feeders of the various sizes and lengths given, with a drop not exceeding 0.2 volts.

Combined Length of Pair of Feeders	Size of Feeder (B.&S.) 10	8	6	4	2
3	64*	92*	130*	184*	262*
4	50	77	125	184*	262*
5	40	62	100	158	254
6	33	53	84	135	210
8	25	40	63	101	160
10	20	31	50	79	127
15	13	21	33	53	85
20	10	15	25	39	63
30	7	10	17	26	42

* These limits cannot be passed without exceeding the safe carrying capacity of the wires.

The table gives simply comparative results, it being assumed that the maximum voltage drop in system A is unity.

Wiring System	Minimum Drop	Average Drop	Maximum Drop	Maximum Voltage Difference
A	0	.667	1.000	1.000
B	.500	.667	.750	.2500
C	0	.167	.250	.250
D	.250	.292	.312	.062

System A

It is assumed that the drop at the end of the circuit is unity, this being used as the basis for comparison. The minimum drop is, of course, zero, since the lamps at that end of the circuit receive full voltage. The maximum difference in voltage between the two extreme lamps will be equal to the maximum drop or unity. In this system of wiring, therefore, the lamps in different positions will operate at voltages which differ greatly.

System B

From the table it is seen that the maximum drop in this case (which is at the middle lamp) is only three-quarters of system A. The minimum voltage drop is higher, however, being one-half. It is evident, therefore, that no lamp in this system receives full voltage. Although the average voltage drop is the same in systems A and B, system B is much the better, since the maximum voltage difference is only one-quarter of that in system A. This means that when so wired the lamps will operate at a more uniform voltage and give more uniform results.

System C

System C is an improvement over B, since its maximum and average voltage drops are less. This system of wiring will therefore consume less energy than that of the other two systems.

System D

This system is a modification of C. The feeders in this case are connected at a distance from each end equal to one-fourth of the total length of the circuit. Although the maximum and average drops are greater than in system C, its maximum voltage difference is considerably less, and hence from the lamp performance standpoint it is much more desirable. For all practical purposes it can be said that all the lamps will operate at the same voltage in this case.

It is therefore recommended that system D be used in all cases of multiple wiring. Since this is a very simple method there is no reason why all multiple signs cannot be wired this way in the future. It will be responsible for a longer lamp life, and the general appearance will be improved since they will all operate at approximately the same efficiency.

Sign lighting is now on a very firm and stable basis. City authorities are very favorably inclined toward it, as it is responsible for lighter and brighter streets, without any additional expense to the tax payers. The merchants are pleased, since they are getting more and better advertising without additional expense. A wonderful advance has been made in the art of manufacturing signs, and as a result sign companies are now erecting better and more artistic signs than ever before. In fact, the present conditions are very favorable for a big increase in the sign lighting industry.

COMPARISON OF THREE METHODS OF STARTING SQUIRREL-CAGE INDUCTION MOTORS

By Campbell Macmillan

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In this article the relative magnitude of the disturbances produced on a distribution system by starting induction motors by means of a compensator, a balanced rheostat, or an unbalanced rheostat is analyzed from several points of view. It is often argued in favor of the balanced rheostat that it permits the terminal voltage on the motor to rise as the current decreases with increase of speed, while the compensator maintains practically a constant voltage during acceleration. Thus at first sight the rheostat might appear to give the more desirable results, but a consideration of the starting characteristics of the induction motor will show these advantages to be largely superficial. From a number of tests, the results of which are plotted to curves, it was found that the compensator gives the most satisfactory starting conditions, both as regards the amount of current necessary for a given value of torque, and the actual power taken from the line.—Editor.

Squirrel cage induction motors may be started up from the line by the use of any one of the three following devices: (1) compensators, or auto-transformers, (2) primary rheostats (balanced), (3) primary rheostats (unbalanced) (e.g., with a two-phase rheostat for a three-phase motor).

In selecting one of these three methods for starting the motor, two conflicting factors must be considered. These factors are (1) the desire for the most effective device for the purpose, which is to ensure minimum disturbance due to starting, and, (2) the desire for a device of minimum cost. Insufficient attention is often paid to the first factor. Objectionable results usually manifest themselves as disturbances on the supply system, causing fluctuation of e.m.f. with consequent irregularities in the behavior of lamps and other apparatus connected to the same electrical network. These disturbances are primarily due to the large currents taken by induction motors, especially those of the squirrel cage type, during the operation of starting, but the immediate causes of fluctuation of line voltage are different in different networks. *First*, if the starting currents constitute a large percentage of the total current in the feeder supplying the motor which is being started, the additional volts lost in the resistance of the feeder may affect other apparatus at the outer end of the same feeder; *second*, the excessive currents may affect the regulation of generators and transformers in power station or sub-station; *third*, the excessive power taken from the lines may overload the prime movers driving the generators which supply the power.

These immediate causes of voltage fluctuation are by no means equally probable. The offending motor may take power which is a considerable percentage of the whole amount supplied by the feeder or local transformer to which it is connected. It is less likely that its demands should constitute a disturbing percentage of the total output of the generators, and still less probable that the prime mover should be affected by the percentage variation of its load due to the motor. The relative importance of these three types of disturbance is, however, somewhat modified by the low power-factor of the induction motor at the moment of starting. The large wattless currents taken from the line may have a much more deleterious effect on regulation of generators than corresponding amounts of energy current. This fact has been made the basis of a contention in favor of rheostats, which are cheaper than compensators and are quite as effective in reducing the wattless current taken from the line for any required value of starting torque. This contention assumes that the effect of the energy component of the current is practically unimportant, and therefore, that both devices perform the essential function of a starter equally well.

If the effect on generators only is considered, this contention may be justified as approximately true; but the effect on feeders depends on the values of total current, and wherever the latter effect is considerable the compensator possesses decided advantages over the rheostat. The same is also true in those cases, probably rarer, in which the capacity of prime movers is overtaxed by the percentage additional load due to motor starting conditions.

From the above, it will be readily seen that the amount of the advantage which may be obtained by the use of a compensator depends upon the characteristics of the supply system with which the motor is connected, and can only be estimated when these characteristics are known. When they are unknown the safer policy is to install a compensator, which takes care of the greater number of contingencies. It may be admitted that cases will arise in practice in which the special advantages accruing from the use of a compensator cannot be realized to such an extent as to justify its greater cost. In order to assist decision in such doubtful cases, some calculations have been prepared, and curves plotted, comparing the joint characteristics of a typical motor with compensator, and the same motor with equivalent rheostats.)

Before commenting on these curves, which refer to conditions at the moment of starting only, it may be well to note certain differences of behavior during the period of acceleration. *First*, advantage has been claimed for the rheostat on account of the fact that it permits the terminal voltage of the motor to rise as the current decreases, while the compensator maintains practically a constant voltage during acceleration. At first sight this would seem to constitute a desirable automatic feature, but its value is almost entirely cancelled by the peculiar nature of the induction motor torque-speed and current-speed curves. These curves show that the current diminishes very little, and the torque increases considerably, during the period of acceleration, so that the provision of sufficient starting torque guarantees more than ample accelerating torque, without the slight automatic increase of terminal voltage obtained when a rheostat is used. *Second*, another feature, which is sometimes desirable in starting operations, may be more conveniently embodied in a rheostat than in a compensator. By providing greater resistance, greater capacity, and a larger number of switch contacts, the rheostat may be arranged to increase the current to the value required for starting, in a succession of easy stages. In this way the increment of current per step may be limited to any specified value, but in practice, the operator who starts the motor cannot generally be relied upon to use the precautions necessary to take advantage of this feature. He will, more frequently, swing the switch over at once to the point at which the motor starts up. For this reason, the extra cost of a rheostatic starter with extra capacity and switch points, is not usually justified. For the same reason, the practice of furnishing more than one starting position in compensators has been almost entirely abandoned.

The objections to the use of primary balanced rheostats and still greater objections to primary unbalanced rheostats—are indicated in the accompanying curves, which embody some data selected from a large number of test results on typical motors, compensators and rheostats. The curve, Fig. 1, shows the maximum current taken in the three cases, in terms of the required starting torque. The motor was a six-pole, 20 h.p., 1200 r.p.m., 440 volt machine. Inspection of the curves shows, for example, that in order to obtain full load torque with compensator, the starting current is 260 per cent full load current. With balanced rheostat, the corresponding value of current is 380 per cent, and with unbalanced rheostat 475 per cent. The nearest compensator tap, 70 per cent, would give 107 per cent of the required torque with 275 per cent full load current.

In practice it is found that, for a compensator of this size, four taps give ample freedom of choice in adapting the starting torque of any particular motor to the load against which it is to start up. In smaller compensators three taps are found to be sufficient. If the tap chosen provides a starting torque somewhat in excess of the

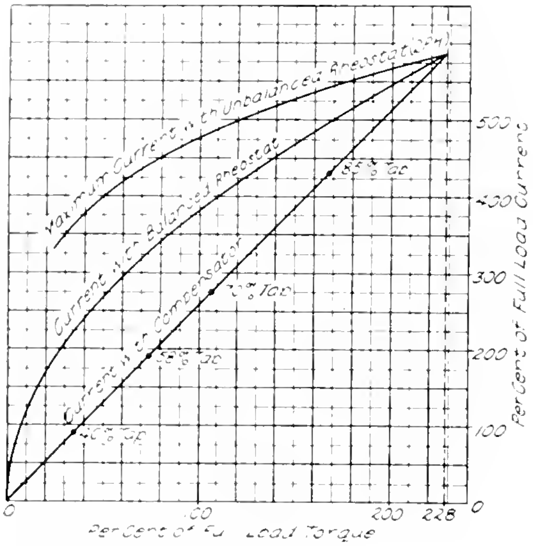

Fig. ' Per cent Full Load Current for Various Values in per cent of Full Load Torque Observed on 20 h p., 440 Volt Motor when Started with Balanced Rheostat, Unbalanced Rheostat and Compensator

minimum required, the balance of torque simply goes to reduce the period of acceleration.

Calculations were also made to compare the power taken from the line at the moment of starting with the three different types of starting device. When rheostats are used, the maximum combined losses in motors and rheostats at the moment of starting occur when the starting torque required is equal to about 150 per cent of the rated full load torque of the motor. In this case the combined losses amount to about 400 per cent of the rated load of the motor. Of this amount about 225 per cent is absorbed by the motor alone, this of course remaining the same whether rheostats or compensators are used. In the latter case the additional losses of the compensators amount to about 18 per cent and in rheostats to about 175 per cent. The losses due to the compensator alone reach a maximum when the starting torque required is about 110 per cent of full load torque, in which case they may amount to about 20 per cent of the rated load of the motor. These last figures form the best basis of comparison when the effect of starting conditions upon the prime movers is being considered. All other effects of the starting operation upon the supply network are best indicated by reference to the curves of current input.

These energy losses in the compensator do not constitute a drawback. They simply indicate that every compensator also acts to a certain extent as a starting rheostat, which is admittedly almost equally effective. It is, in this instance, especially free from criticism in that it constitutes such a small proportion of the losses of the whole device. The wattless kv-a. taken by the compensator in the form of magnetizing current and additional reactance is obtained from the line as an additional wattless current and is admittedly of a deleterious nature, but is practically negligible on account of its relatively small value.

In the compensator used in these tests the magnetizing current at full line volts is 2.25 amperes,—less than 10 per cent of rated full load current of motor, or less than 1.6 per cent of short circuit current of motor. The reactance of the compensator was so low that no consistent values could be deduced from impedance readings with the best available testing instruments. It may therefore be neglected without attempting to obtain its exact values for the different compensator taps, and the comparison of compensator and rheostat made without any reference to the volt-amperes consumed by compensator reactance.

SOME INCORRECT METHODS OF TESTING MULTIGAP LIGHTNING ARRESTERS

By E. E. F. Creighton

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Modern lightning arresters, represented by the aluminum cell and multigap types, are the outcome of practically numberless experiments and tests which have been made for the purpose of determining the best design and most suitable materials to be employed in their construction, and to establish beyond question the fact that they will accomplish the protection that they are intended to give. It would be difficult to conceive a test that would show some characteristic of an arrester, working under anything like the conditions of service encountered in actual practice, that has not been made by the manufacturer time and again.* These facts should be borne in mind when testing an arrester, and care should be taken to see that no influencing factors of an unnatural character are present; for in most cases where the observed performance has been found to differ from the specified characteristics of the unit, an analysis of the methods of conducting the test has disclosed some disturbing element. This article relates some tests that have been inappropriately applied to multigap arresters, and explains wherein they are wrong.—Editor.

From time to time lightning arresters are subjected to tests which result in the condemnation of the unit. Some of the tests applied to arresters to determine their value have about the same relative efficiency as might be expected from employing direct current for testing an alternating current motor. In engineering literature on all subjects, the instructions are of the nature of advising what to do, and there is very little information on the other side, i.e., what not to do. This arises partially from the fact that no one can foretell the previous experience of the man who will test the electrical device, and what view points he will take. In consequence, if one were to undertake to write up a complete set of instructions of what not to do, he might have to include all sorts of absurd instructions covering operations which no one would ever think of doing. It would seem of interest, however, to review some of the tests that have actually been applied to lightning arresters and show why they are not applicable.

The compression chamber lightning arrester, which has recently been put on the market, has been subjected to a number of different kinds of tests with the object of determining its efficiency before adopting it. One of these tests was as follows: An arrester designed for 2300 volts was connected to a large generator and step-up transformer, and the potential gradually increased until it reached 6600 volts. At this potential the arrester failed, causing the circuit-breaker to open, and from this test the arrester was condemned as being useless.

The question might be pertinently asked: Why does this not show the weakness of the arrester? What the test does show is that a lightning arrester, having applied to it a generator potential sufficient to spark over its gaps, will absorb enough energy to destroy itself. In this case the arrester is operating,

*In order to give some idea of the exhaustive series of tests that have been conducted by the manufacturer in the development of lightning arresters, we reprint here, as an addendum to the article, portions of a paper prepared by Messrs. Creighton and Shover for the May, 1912, meeting of the A.I.E.E., in which are listed briefly some experiments that were made in connection with the perfection of the compression chamber multigap arrester, a comparatively new type. The principles of this arrester are in many respects the same as those of the well known graded shunt multigap arrester—the finished product of an immense amount of previous investigation. In the laboratories the principal forms of lightning can be reproduced at will and tests devised to give knowledge of every factor and characteristic. Nothing must be left to chance. Tests were made to determine:

1. If gaps enclosed by hollow cylindrical spacers, which determine a certain gap length between electrodes, will extinguish the dynamic arc without destroying the enclosing spacer.

Tests were made using hollow cylindrical spacers of different lengths and different inside diameters. Tests proved the arrangement to be practical and efficient.

2. The minimum gap length permissible to prevent bridging of the gaps by molten metal thrown from the arc crater during discharge, under conditions noted in (1). (Standard lightning arrester electrode metal used in test.)

3. The possibility of using punched sheet metal electrodes versus solid metal electrodes of like material for efficiency and durability.

4. If discharge faces on the electrodes should be smooth or knurled.

5. The material to be used for spacers.

Many materials were tried among which were fiber (treated and untreated), hard rubber, glass and porcelain.

6. Form and size of discharge face of the electrodes.

7. Inside diameter of porcelain spacer to insure no assistance to dynamic arc in holding across the gap.

8. Length of porcelain spacer to obviate any possibility of deposit from material thrown off by the arc to form a conducting surface from one electrode to the other thereby short circuiting the gap.

The length was determined at 17/32 in. (5.5 mm.) 9000 consecutive discharges on a 2300-volt circuit, using sealed gap units, failed to render the surface of the spacer conductive.

9. Leakage factor of porcelain spacer 17/32 in. (5.5 mm.) long.

The leakage factor for this spacer as found by test on a 60-cycle circuit is 6350 volts effective not as a lightning arrester but as a rheostat. In practice, the generator potential on this arrester would never be 6600 volts applied, and the arrester would never be called on to carry continuously the current resulting from an application of such a potential.

The application of 6600 volts potential is perfectly justifiable, and determines one of the characteristics of the arrester that must be known, viz., its spark potential at 60 cycles. However, when such a spark potential is determined, some means must be used either to limit the current or to limit its time of application. One way of doing this would be to use a fuse made up of resistance wire about 3 mils in diameter, and another way would be to use a transformer of small capacity, in circuit with which is a delicately set, quick acting circuit-breaker. The determination of the spark potential of the lightning arrester can then be made without damaging it in test.

The spark potential is only one characteristic of several important ones. Resistance in series with the arrester must be of such a nature as to give a large current discharge when a lightning discharge takes place over the arrester. From one standpoint, the less the resistance in the arrester the better is the arrester for discharging lightning. From the standpoint of the foregoing test, however, the less resistance there is in the arrester the more quickly and violently will it be destroyed by the test; therefore, such a false test as described above would show the best arrester to the greatest disadvantage. Under this test a very poor arrester, having high resistance, would appear to be an exceedingly good arrester.

Another case of erroneous test arose from using a transformer of too small capacity. Although the test was actually made by several people independently, it might be considered in the light of a development of the suggestions made in the foregoing test. It was suggested above that in order to determine the spark potential of the arrester a limited capacity of transformer or a limited discharge should be used, so as not to damage the arrester. Several tests of spark potential have been made in which a potential transformer was used, the potential being measured by a voltmeter on the low voltage side of the transformer and the high voltage leads being connected directly to the compression chamber lightning arrester. Since the arrester is entirely enclosed in a porcelain tube, it was impossible to determine when a discharge over the gaps took place. The spark potential of the arrester was about 7000 volts. The potential by conversion figured out 15,000

10. The value of resistance to be used in series with the gaps on a 2300-volt circuit.

A number of tests were made by varying the number of gaps from two to six, also varying the resistance from ten to one hundred ohms.

A test was run using a minimum number of gaps (2) and a minimum amount of resistance (10 ohms).

A typical test is shown by the use of three gaps with a 23 ohm resistance rod in series, all of which were enclosed in a porcelain tube. The arrester was sparked over by the use of a static machine.

At the end of 100 discharges taken at intervals of five seconds the temperature rise of the tube above the air was 23 degrees Cent. No damage was done to the arrester and no fuses were blown.

11. The effect of water in the containing tube on the operation of the arrester.

The tube was supported in a vertical position with the line end (top) open and only a small hole in the opposite, or ground end. The arrester was then connected across the 2300-volt circuit using one strand of five-mil boker wire for a series fuse. The test was started using one drop of water every ten seconds and run for 70 minutes.

Most of the water was evaporated.

Boker wire changed for a 20 ampere fuse. Flow of water increased to one drop every 7 seconds, the arrester being subjected to a static discharge every two minutes. Test run 45 minutes; operation of the arrester was normal.

Flow of water increased to 85 drops per minute and run for 15 minutes. No trouble developed.

Flow of water increased to a tiny stream. Some steam given off. No fuses blown. Temperature of the tube 28 degrees Cent. above the air.

Flow of water increased to one pint per minute. No trouble developed. Temperature of tube decreased to 15 degrees Cent. above the air. No fuses blown.

Several porcelain spacers were soaked in water for two days. The effect on spark potential of the gap using these spacers was not material.

12. The rectifying power of various metals and alloys in form of sheet metal electrodes, as now used in the arresters, and also in form of our standard lightning arrester cylinders.

The amount of zinc volatilized during the life of the sheet metal electrodes is minute. Measurements were taken before and after 500 discharges, at 100 ampere discharge rate, applied to the gaps. The result was a gain of two milligrams in one electrode and a loss of 3 milligrams in a total of three others. This amount was too small to be accurately measured with the available balances.

13. Many tests were made which can be mentioned only in a general way. Among them were:

Tests to determine the length, size and form of the antennae.

Tests to determine the equivalent-needle-gap under various conditions, by use of the static machine, Tesla coil, induction coil, 60 cycles, quick break, direct impulse and lightning generator.

Tests to determine per cent surge; per cent spark potential, etc.

Many oscillograms have been taken at critical points in different tests and on endurance runs.

14. Curves were run to show the following:

a. Minimum length of antenna to be used. Minimum length of antenna to give the maximum capacity effect was determined at 87.5 per cent of the total length of number of gaps used.

b. Spark over potential of containing tube. Tube both wet and dry. Test made only to limits of 10,000-volt arrester (50 gaps). Antenna at 87.5 per cent of length of gap safe. Spark over potential to support when dry 100,000 volts. Spark over volts and nothing apparently took place in the arrester. The question arises: What was wrong with this test? What actually took place was that at 7000 volts (approximately), the gaps of the arrester were bridged by a spark and the potential of the transformer was thrown directly onto the resistance rod. The current from a transformer of only 200 watts capacity is too small to injure the resistance rod; yet the current in the high voltage coil of the transformer was sufficient to drop its potential, due to its regulation. The resistance of such a small transformer is necessarily high, and therefore the ohmic drop through this resistance would be considerable as compared to the ohmic drop through the resistance of the lightning arrester. In fact, the resistance of the lightning arrester is negligible as compared to the resistance of the high tension coil. Therefore, since the arrester sparked over, it short-circuited the transformer for all the peaks of potential which rose above 7000 volts, this being the spark potential of the arrester. On the low voltage side of the testing transformer no indication was given on the voltmeter of the conditions of short circuit on the high potential side, and the potential was therefore greatly increased. On the false assumption that the ratio of potentials was the same as the ratio of the number of turns in the primary and secondary of the transformer, the result was an apparent 15,000 volts on the lightning arrester. The actual potential on the arrester was, however, never greater than the spark potential, which was approximately 7000 volts.

How can the foregoing test be made to give correct results? There are two ways that are immediately applicable: First, if a small ammeter is placed in series with the primary of the transformer it will indicate the excitation current only, up to the potential that will cause a spark over the arrester. When the arrester sparks, however, there will be a sudden increase in current due to the short-circuit on the high tension side. The potential applied to the low voltage coil at the instant at which the current increases will give, when multiplied by the ratio of transformation, the spark potential of the arrester. Second, if a step-down transformer is used on the high tension side it will give the actual potential applied to the lightning arrester, as this transformer will not be affected by the short-circuit current of the step-up transformer.

Another test of a lightning arrester which gave false results was conducted as follows: Instead of measuring the spark potential

potential to support when wet 80,000 volts. Factor of safety is 8.

c. Spark potential of gaps for high voltage arresters; gaps varied; antenna 87.5 per cent total length of gaps. Fifty gaps spark over at 21,000 volts at 60 cycles.

d. Antenna surrounding containing tube versus ½ in. (1.2 cm.) strips on opposite sides. Antenna surrounding tube requires less spark potential than ½ in. (1.2 cm.) strips. 6.4 per cent less for 4 gaps to 6.8 per cent less for 50 gaps.

e. Spark potential using antennæ versus no antennæ. Removing the antennæ raises the spark potential 100 per cent.

f. Spark potential, with antennæ, using single tube versus two tubes in series. Using two tubes in series raises the spark potential about 20 per cent. Therefore, all the gaps for one leg of an arrester should be assembled in one tube if at all possible so to do.

g. Spark potential tests: Antennæ connected to grounded end versus antennæ connected to line end of arrester. The antennæ connected to the line end of the arrester raises the spark potential of the arrester about 10 per cent for low voltages and from 15 to 20 per cent for higher voltages (10,000-volt arrester).

Endurance of the Arrester to Withstand Rapid Strokes. In order to determine the strength of the arrester to withstand rapid successive discharges, an arrester had applied at its terminals, 170 per cent of its dynamic potential. The discharges were made through the gaps by means of an induction coil. This induction coil was operated from a make and break contact which made thirty strokes per second. An oscillograph was placed in series with the arrester in order to measure the number of strokes applied to it. Forty-five strokes were applied during 1.5 seconds without causing any damage to the arrester. The greatest known number of successive strokes from lightning in a second is shown by some photographs. This number is only a fraction of the number applied to the arrester. Tests made in connection with Mr. J. A. Clay on the Animas Water Power Company's line, 1907, showed that nearly every stroke of lightning consisted of a succession of discharges, and that the usual number lay in the range of 3 to 9. Sometimes these are distributed over an entire second, but usually they occupy only a very small fraction of a second. As already stated, the limit of the number of discharges is set by the heating of the resistance rod. If the successive discharges are spread out with several seconds between, then the radiation from the resistance rod is sufficient to give the arrester a very long life for such discharges. The actual limit for one of these rods is 50,000 joules, which corresponds to the normal dynamic discharge current for ¼ sec. on one type of resistance rod.

Life of the Arrester. In order to determine whether it would be desirable to leave the arrester open at the top so that the gap units could be replaced after they had worn out, a number of life runs were made on the 2300-volt compression chamber arrester to determine how frequently such a change would need to be made. The result showed that the life of the arrester was so great that it was entirely unnecessary to make any provisions for changing the gaps. For example, discharges were applied to the arrester with intervals of one minute between. These discharges were continued up to 9000. The arrester was tested with the oscillograph at about every 2000 discharges to determine its condition, and the spark potential by the ratio of transformation of the step-up transformer or that of the step-down transformer, it was measured by a gap in parallel with the lightning arrester. Measuring potentials by means of a needle-gap across the lines is a method that has been thoroughly standardized, yet it does not apply to the measurement of potentials applied to multigap arresters. The reason for this will be explained later, after describing the test.

The arrester in question was designed for a 4000 volt circuit and when tested by means of a needle-gap in parallel, the spark potential as taken from the A.I.E.E. curve was 18,000 volts. It is evident that if the lightning arrester had such a spark potential it would give a very poor protection to the transformer. The arrester was returned to the laboratory and tested out, where it was found that the spark potential was actually 11,000 volts. By putting a needle-gap in parallel, however, and interpreting the result by the A.I.E.E. curve, the potential obtained in the original test by the user was checked. Here, then, is a lightning arrester which has an actual spark potential of 11,000 volts, and by a standard method of measurement has an indicated spark potential of 18,000 volts. To the experimenter, this condition is puzzling and if he has confidence in the applicability of the standard method it makes a discouraging outlook for the arrester.

The fact of the matter is that the standard method is not applicable to the measurement of the spark potentials of multigap lightning arresters. Everyone who has noticed multigap arresters installed on high potential circuits has seen the activity of the end gaps in all the phases; sometimes as many as half a dozen gaps will be sparking continuously. This same effect takes place on all multigap arresters previous to the final spark that takes place over all the gaps simultaneously. These little end-gap sparks set up very high frequency oscillations, the frequency being of the order of a billion cycles per second. The high frequency is carried over the conductors to the needle point and there produces a brush discharge, which is equivalent to covering a fraction of the gap length by a conductor. Therefore at the same applied potential it is necessary to open up the needle-gap.

If the needle-gap method of measuring potential is to be used, it is necessary to avoid the effect of the brush discharge at the gap. It is well known that a gap with spherical electrodes having a diameter of the same order as the gap length will not brush discharge previous to the passage of the spark. In the application of the sphere-gap it is of course necessary to calibrate it in terms of the ratio of transformation and voltmeter reading.

was taken. Both these tests showed that the arrester was at all times of the run in as good a condition as at the beginning. The rectifying power of the gaps was the same, and the spark potential of the arrester, even after the 9000 discharges, remained constant. In other words, these discharges did not burn away sufficient metal from the surface of the electrodes to increase the spark potential, although a dynamic potential of 70 per cent above normal was applied to the arrester. The insulation between electrodes, measured by a "megger," was far above 2000 megohms,—practically infinite. When a gap unit was split open a considerable deposit of soft grayish material was found on the walls of the chamber and around the gap, but this material was non-conducting.

Tests of Arresters Protecting Transformers. These tests were made in the laboratory with artificial lightning. An explanation is due at the outset that one cannot reproduce in the laboratory all the forms of lightning that occur from the elements, yet certain forms of laboratory tests along this line of endeavor are not to be despised. In this case we produced an artificial lightning stroke at the terminals of the transformer, of sufficient strength to puncture the insulation between primary and secondary. All we can say of this lightning stroke is that it was of unusual strength as compared to the ones which ordinarily occur on a 2300-volt line. A large number of transformers, both new and old, were available for testing the protective value of the lightning arrester.

The following set of tests is illustrative of the statements regarding the protective value of the arrester. A 2300-volt transformer was placed in parallel with a lightning arrester and subjected to the discharges of artificial lightning. Three thousand discharges were made and no damage occurred to the transformer. The arrester was then removed and the transformer punctured between primary and secondary on the very first discharge. The question next arose whether the transformer had not been damaged by the 3000 discharges, so another transformer was placed in circuit without the lightning arrester. The first discharge of artificial lightning punctured the transformer between primary and secondary. Again another transformer with the same insulation was placed in parallel with a lightning arrester and subjected to successive discharges. After 3500 discharges had passed, it was decided that no damage could be done to the transformer while protected by the arrester and the arrester was removed. Again, as before, on the very first discharge without protection, the transformer failed.

These tests tell us that the lightning arrester will give protection against strokes that will damage the transformer. They do not tell us that the arrester will give protection against all strokes, since it is conceivable that a lightning stroke may have a rate of discharge such that an ohmic drop across the resistance rod might be sufficient to give a dangerous potential across the terminals of the transformer. On the other hand, to offset this possibility, there is always a limited spark potential around the bushing on the transformer and it is only necessary to make this spark potential somewhat lower than the spark potential between primary and secondary in order to minimize the dangers of even a direct stroke.

THE ARCING GROUND SUPPRESSOR, AND ITS APPLICATIONS

By R. H. Marvin

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This article, which is the first we have published dealing exclusively with the arcing ground suppressor and its uses, indicates its field of application; shows the difference in its construction for overhead and underground systems; and explains, with diagram, the operating cycle. The best position at which to locate an arcing ground suppressor on a system is discussed and the reasons stated why the most effective protection is obtained by its location at the power house. The concluding paragraphs summarize the advantages and limitations of this apparatus.—Editor.

Grounds on transmission systems are frequently the cause of interruptions and damages to apparatus. On overhead lines the arc to ground breaks insulators and burns off lines. On cable systems the arc to ground quickly burns to the other conductors, causing a short-circuit. In addition to these troubles due to the heat of the arc, the rapid make-and-break of the arc sets up high-frequency disturbances which are very dangerous to the system and connected apparatus. They also cause great annoyance by practically interrupting communication over all parallel telephone lines. The arcing ground suppressor removes, or minimizes, these troubles, short-circuiting and extinguishing the arc by a switch which automatically closes and grounds the grounded phase at the power house. Its use is limited to non-grounded systems; but these are now becoming the usual practice from their many advantages, in most cases, over grounded systems. The arcing ground suppressor gives them, in addition, the advantages formerly claimed for the grounded neutral systems, such as freedom from high frequency disturbances.

The arcing ground suppressor as built for three-phase service comprises the following parts (see Fig. 1): (a) three single-pole, motor-operated, oil-switches for grounding the system. These are provided with interlocking relays to prevent more than one switch being closed at a time. For use with overhead systems each switch is equipped with the second stroke lock device described more fully later. For cable systems this is omitted. The oil-switches are provided with the usual remote control switches with red and green lights to be placed on the station switchboard. (b) Three single-pole, single-throw disconnecting switches for disconnecting the oil-switches. (c) A phase selective relay for detecting the grounded phase and operating the proper oil-switch. This relay is of a magnetic type, and is supplied with current from three potential transformers, having connected fuses. Such a relay is shown in Fig. 2.

These parts as shown in Fig. 1 are connected as follows: Each phase on the power house high-tension bus is connected to ground through one of the oil-switches. The phase selective relay is also connected to the bus. This relay is so constructed that when a ground occurs on the system it closes a contact and trips the oil-switch closed on the grounded phase. Normally all three oil-switches are open and the interlocking relays render it impossible to close more than one switch at a time, as this would give a short-circuit. An important feature of the oil-switches is that the circuit is closed first through an auxiliary contact and a resistance in the oil-pot. An instant later the main contacts are closed and the resistances cut out. In this way the circuit is always made and broken through a resistance, and this resistance is of such a value as to prevent high frequency oscillations.

Location on System

It is for many reasons best to locate the arcing ground suppressor at the power house rather than at the sub-station. The class of assistants at the power house are usually more familiar with switching apparatus and better able to give it proper attention. The power house will always have a direct current supply from the exciter for operating the switches and relays. The more important switching operations in case of grounds and short-circuits being performed at the power house, it is well to have the arcing ground suppressor under the immediate observation of the operator there. For electrical reasons it is also advisable to have the arcing ground suppressor as close to the source of power as possible. It may therefore be said that the arcing ground suppressor should be connected directly to the high-tension bus in the power house.

It should be noted that only one arcing ground suppressor is necessary, or should be used on the system. Cases where there are several widely-separated power houses on a system should receive more special attention in order that the best location of the suppressor may be determined. The current flowing in the arc to ground, and in the suppressor switch when closed, is the charging current due to the capacity of the entire system to ground. This current has no relation to the power transmitted by the system; and depends only upon the voltage and frequency and the total length of lines.

Operation on Overhead Lines

With overhead lines a large proportion of the grounds are due to the insulators arcing over from lightning or some momentary high potential. Such an arc, if allowed to continue, soon cracks the insulators or burns off the line, causing interruption of service; while if the arc is immediately extinguished this damage is prevented.

The arcing ground suppressor as built for overhead systems is, therefore, made to operate as follows: Referring to Fig. 1, suppose a ground due to any cause appears on the system. This unbalances the potential to ground; and the phase selective relay closes the contact controlling the oil-switch on the grounded phase. The phase selective relay does not operate the oil-switch directly, but simply energizes the interlocking relay. The interlocking relay closes and trips the oil-switch closed. The interlocking relays are each provided with three contacts; one contact trips its own oil-switch, and the other two open the tripping circuits of the other two oil-switches. It is thus impossible to

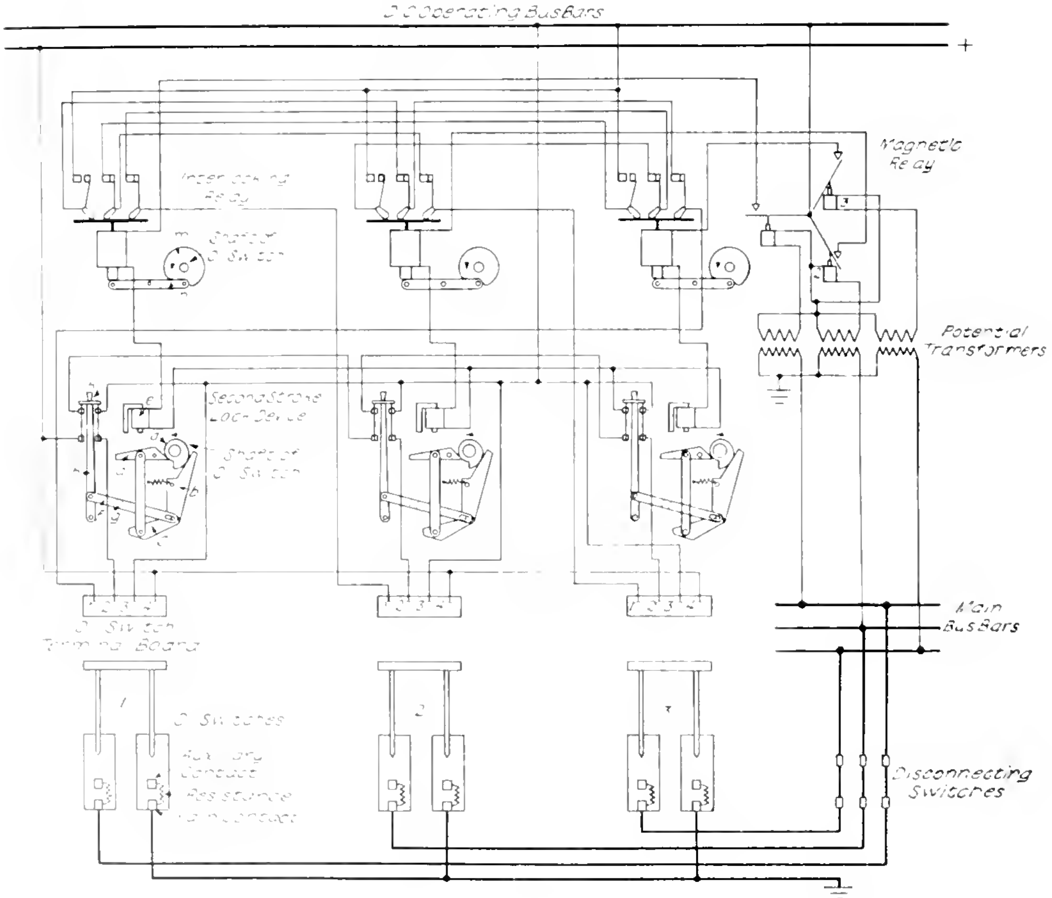


Fig. 1 Connections and Arrangements of Parts of Arcing Ground Suppressor for Three-Phase Systems

have more than one oil-switch closed at a time. Consider now the action of the second stroke lock device. The magnet *e* is in series with the interlocking relay coil, and is, therefore, energized when the phase selective relay closes. This magnet has a short range of pull, and cannot pull up its armature, *d*, but will hold the armature when it is in contact. As the switch closes, the cam, *a*, on its shaft moves over the lever *b*, and catch *c*. The pivot between *b* and *c* slides freely in the slotted end of link *f*. The oil-switch having closed, and the motor having wound up the spring, it at once opens again, as the opening control circuit is closed through switch *k*. As the switch opens, cam *a* moves lever *d* up to magnet *e*. If the ground has been cleared and the phase selective relay has opened, the magnet *e* is not energized, and lever *d* drops back to its normal position when the cam has passed.

This is the cycle of operations when the ground is caused by an arc-over on an insulator. The arc is extinguished as soon as the switch closes, and the system is clear. But if the ground is of a permanent nature, such as a broken line or a punctured insulator, the phase selective relay remains closed, and *d* is held up by the magnet. The motor winds up the spring, and, the relay being still closed, the oil-switch closes a second time. This time the catch *c*, being held up, engages block *g* on link *f*, pushes over lever *h*, and opens switch *k*. Switch *k* being open, the oil-switch remains closed. At the same time the other blade of *k* opens the circuit through magnet *e* and the interlocking relay. This is necessary as these coils are not designed to stay permanently on the circuit. The oil-switch now remains closed until the trouble is removed, after which the operator opens it by closing the switch *k*. The switch *k* is closed from the switchboard by a magnet. This magnet and the wiring to the switchboard, including the signal lamps, have been omitted from Fig. 1 for the sake of simplicity.

This method has the double advantage of extinguishing arc-overs on insulators automatically and without interruption to service; and also provides a safe and solid connection to ground when the fault is of such a nature that the line is touching the ground or so near to it that normal line voltage could start an arc. From the fact that the oil-switch remains closed on its second stroke until opened by the attendant, the attachment to the switch causing this cycle of operations is called the second stroke lock device. The use of the arcing ground suppressor is limited to metal tower lines, as on a wood pole line the resistance of the pole is liable to prevent sufficient current flowing to ground to reduce the potential sufficiently to operate the relay.

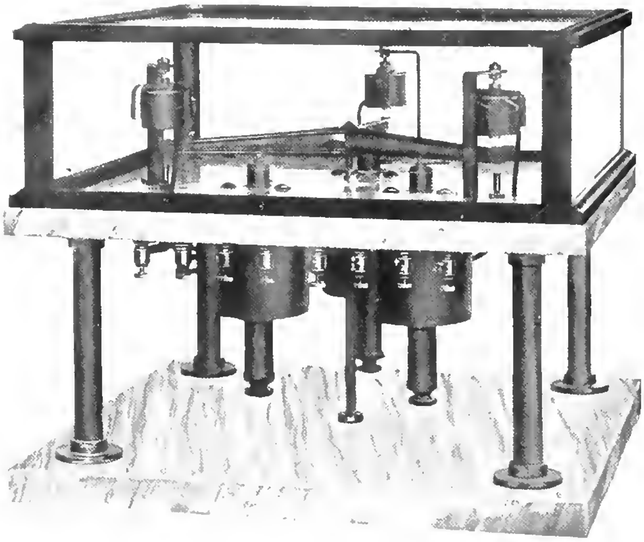


Fig. 2. Three-Phase Selective Relay for Arcing Ground Suppressor

Operation on Cable Systems

In a cable the distance of a conductor from the sheath is usually so small that any puncture of the insulation means a permanent fault. On this account it is not advisable to have the arcing ground suppressor open after once closing. Therefore, with cable systems the second stroke lock device is omitted. The operation is then as follows: When the phase selective relay operates due to a ground on the system the switch closes, grounding the phase and remaining closed. This extinguishes the arc at the fault in the cable. The switchboard attendant, seeing the arcing ground suppressor closed, can then remove the defective cable from service for repairs. The arcing ground suppressor, while it cannot prevent or remedy a breakdown on the cable, does prevent the arc spreading to other phases and causing a short-circuit, or damaging adjacent cables. By suppressing the arc at the fault it also eliminates the high-frequency disturbances. These are at present a serious source of trouble, weakening or puncturing the cables at other points. In a cable system having many cables it is advisable also to install a faulty feeder localizer, a device recently developed for showing the damaged cable, so that the operator can tell at once which cable is defective, and remove it from service.

Limitations of the Arcing Ground Suppressor

The arcing ground suppressor, like any other piece of apparatus, has certain limitations. It should not be used on grounded neutral systems. It cannot clear short-circuits and is intentionally so made as not to operate at such times. A different type of device is necessary to suppress short-circuits. Neither is it recommended for the protection of insulators mounted on wooden cross-arms and poles.

Applications of the Arcing Ground Suppressors

The arcing ground suppressor will prevent breakage and destruction of line insulators and transformer and switch terminals by arcs to ground, and will prevent line wires being burned off by arcs to ground. It will extinguish an arc to ground and restore the system to its normal condition without interrupting the service, and without attention from the operator. On cable systems it minimizes the injury due to a puncture in the cable, and prevents the trouble from spreading. By giving a solid and definite connection to ground it suppresses high-frequency surges on both cable and overhead lines which are liable to injure the lines and connected apparatus.

THE CONSTRUCTION, INSTALLATION AND MAINTENANCE OF ALUMINUM ARRESTERS AND THEIR AUXILIARIES

PART III

By R. T. Wagner

Supply Department, General Electric Company

Part I of this paper (January, 1913) was concerned chiefly with the principles and characteristics of the aluminum arrester. Part II took up the matters of location, installing, wiring, connecting up, placing in service, daily charging, maintenance, etc. Part III, which concludes Mr. Wagner's paper, introduces this month some of the auxiliaries used with aluminum arresters, and deals with the construction, functions and installation of the charging current indicator, the discharge recorder, and choke coils.—Editor.

Charging Current Indicator

The charging current indicator is a device for measuring the current taken by an aluminum arrester when being charged. It consists of a small portable ammeter mounted near the end of a specially constructed switch stick. The stick is beveled off on the ammeter end and contains two brass contacts insulated from each other and connected by short flexible leads to the ammeter. A spring ammeter jack, fastened to the arrester, is so designed that when the above mentioned stick is inserted in the jack the ammeter is in series with one leg of the arrester, thereby allowing the current to be measured.

See Figs. 20, 21, 22 and 23 for indicators for the different forms of aluminum arresters. When the charging current indicators are used it is necessary to eliminate all arcing in the arrester circuit. Therefore, short-circuiting contacts should be installed on the horn gaps, if they are not already in use. See Figs. 18 and 19. If a discharge recorder is part of the arrester equipment the recorder spark gaps must be short-circuited by clips provided for that purpose, before the charging current is measured. All arcing at the horn gaps must be eliminated before inserting the ammeter pole in the ammeter jack, otherwise the ammeter is liable to injury.

The use of the charging current indicator is to determine the condition of the cone stacks of aluminum arresters, it being well known that the charging current varies with the condition of the films on the cones and should not go beyond certain values depending on the frequency of the circuit. For arresters in good condition this current value should be approximately 0.25 of an ampere on 25-cycle circuits, 0.3 of an ampere on 40-cycle circuits and 0.4 of an ampere on 60-cycle circuits. Should these values rise to double value the arrester should be charged more frequently and the current measured regularly until it is down to normal. Should additional charging fail to reduce the current or should the current go still higher, the cone should be taken out and inspected for pitting, poor films and deteriorated electrolyte.

The charging current indicator is designed for the full line of standard alternating current aluminum arresters for voltages from 1000 to 115,000 volts. It is very easily attached to these standard arresters and can generally be installed without difficulty on any special alternating current aluminum lightning

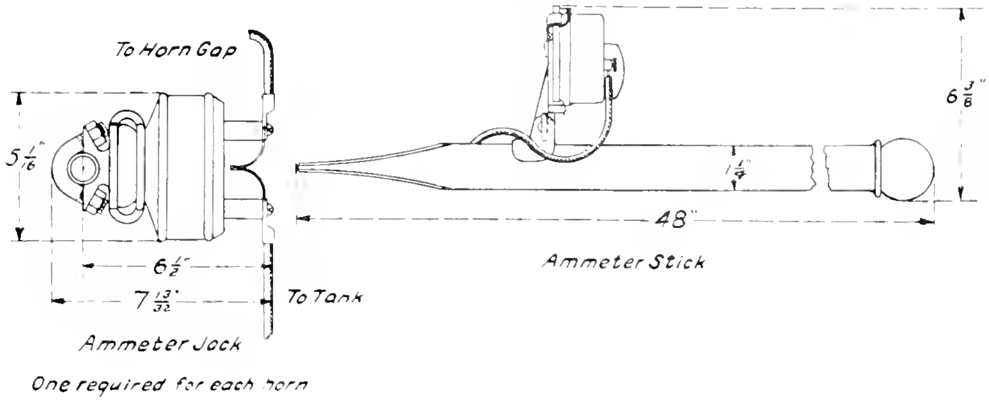
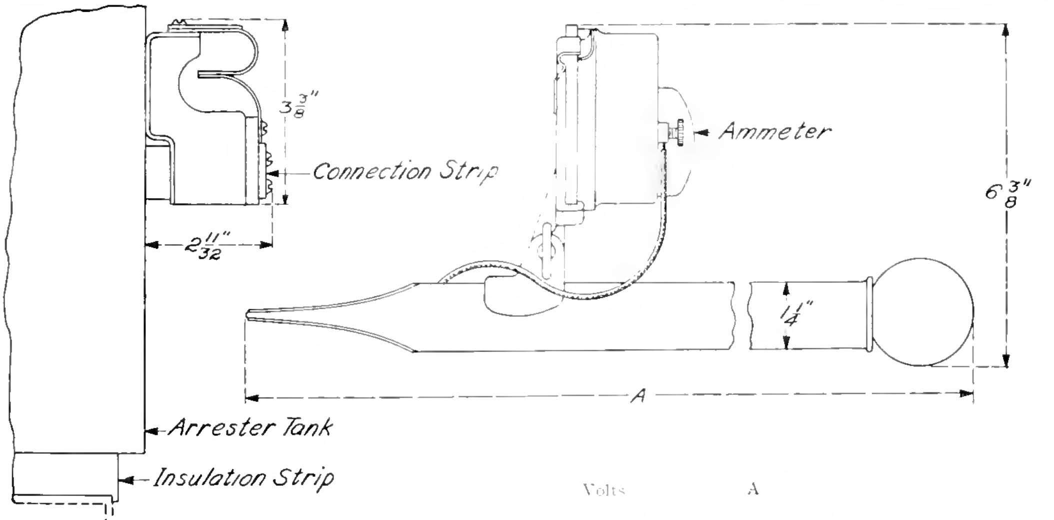


Fig. 20. Charging Current Indicator, 1000-7250 Volts

arrester. For arresters between 7250 and 75,000 volts the ammeter jacks are mounted directly on the arrester tanks. The copper strip connecting the tanks together near the bottom should first be removed. The tanks should then be tilted sufficiently to place under them the treated wooden insulating strips, to insulate them from the "Z" bar rack on non-grounded neutral circuit arresters, and from the ground on grounded neutral circuit arresters. The spring ammeter jacks should next be attached to the lugs on the tanks from which the copper connecting strip has been removed. In order to do this the slotted head plugs must be removed from the jacks in order to get at the recessed screw heads. When screwed securely to the lugs, the plugs should be replaced and the copper connecting strip should be screwed to the front plates of the jacks. See Fig. 21.

In the case of single tank arresters for 2500 to 6600 volts, the ammeter jack is mounted on a porcelain insulator supported on the pipe framework. One jack is connected in series with each horn gap between the horn gap and cone stack. The pipe and clamps for supporting the ammeter jacks should be fastened in a horizontal position at the top of the pipe framework. The ammeter jacks and supporting insulators should then be clamped to this pipe with the jacks accessible from the front, each jack in front of but slightly lower



Volts	A
7,250–16,100	48 in.
16,100–48,250	73 in.
48,250–75,000	96 in.

Fig 21. Charging Current Indicator, 7250-75,000 Volts

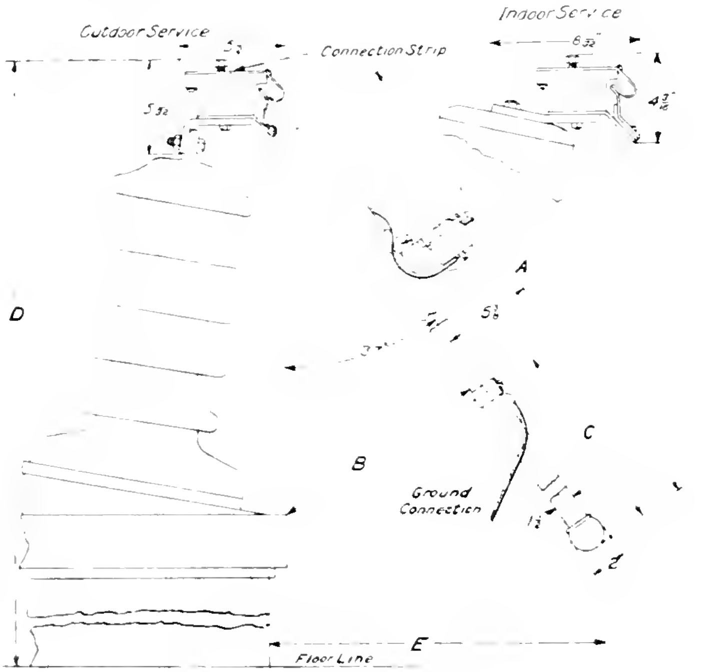
than its corresponding horn gap. The top contact of each jack should then be connected to its corresponding horn gap and the lower contact to the proper tank connections. See Fig. 20.

With the oval tank arresters for 75,000 to 145,000 volts provision is made for mounting the ammeter jack on the top of the multiplex bushing on each tank. The connection strips should first be removed and then the jack can be attached to the top of each bushing as shown in Fig. 22. The connection strips should then be re-installed so as to connect together the top terminal of all the ammeter jacks.

In using the charging current indicator, the horn gap should first be closed until the flexible strips make perfect contact and all arcing is eliminated. This is very important as the smallest possible arc will make the readings unreliable. The horn gaps should be held in this position while the ammeter stick has been inserted into each jack and the current read. Should the arrester have a transfer device, the horn gaps should be opened until the transfer device has been changed, when they should again be closed and readings taken on the two tanks to which the transfer device is connected. (See Fig. 23.) If the arrester is equipped with a discharge recorder the four spark gaps should be short-circuited to eliminate all arcing while the readings are being taken. The short circuit across the gaps should of course be removed, when the readings are completed.

It is recommended that the charging current be read once a week and the readings filed with the station records. Should the arrester at any time indicate by the arc at the horn that the charging current is apparently above normal or if for any other reason it is suspected that the arrester is not in proper condition, the charging current should be read at once.

The operator should not touch or get too near the ammeter, tanks or insulating rack when using the charging current indicator as they are at the Y voltage of the system and are therefore dangerous.



OUTDOOR SERVICE

Volts	A	B (Min.)	C	D	E (Min.)
75,000- 95,000	102 in.	22 in.	48 in.	133 in.	62 1/4 in.
95,000- 115,000	132 in.	20 in.	66 in.	148 in.	75 1/2 in.
115,000- 145,000	136 in.	20 1/2 in.	96 in.	190 in.	105 in.

INDOOR SERVICE

Volts	A	B (Min.)	C	D	E (Min.)
75,000- 95,000	102 in.	14 3/4 in.	48 in.	119 in.	62 7/8 in.
95,000- 115,000	132 in.	15 1/4 in.	66 in.	137 1/2 in.	76 7/8 in.

Fig. 22. Charging Current Indicator for Arresters, 75,000-145,000 Volts

Discharge Recorder

The discharge recorder is a device for recording all discharges which take place through the arrester on which it is installed. It consists essentially of four insulated spark points mounted radially to a copper drum thereby forming four spark gaps through which a strip of paper from a roll is caused to pass by means of clock-work. The four spark points are connected to the three line legs and the ground leg of the arrester so that all discharges must arc from the spark points through the paper to the drum. See Fig. 24.

The clock is an eight day movement and is provided with a regulator to increase or decrease its speed and a lever by which it may be stopped and started as desired. A friction clutch is placed between the clock and drum so that the drum may be revolved by hand in either direction without injury to the clock. Should the friction require any adjustment, the clutch can be reached by removing the clock casing. Adjustment is made by loosening or tightening the nut and lock nut on the end of the main drum shaft.

On arresters below 7250 volts, the discharge recorder is mounted on the pipe framework which supports the horn gap; and is connected to the cone stack by a three conductor cable on arresters for grounded neutral circuits, and a four conductor cable on arresters for non-grounded neutral circuits. The cable is taken into the tank through an additional bushing in the cover and is connected to the cone stack by the terminals riveted to the edge of the cones. The short-circuiting strips which are ordinarily connected to these terminals to form the neutral or multiplex connection of the arrester must be removed. No electrolyte should ever be put into the

Fig. 23. Method of Using Charging Current Indicator

two cells from which the short-circuiting strips have been removed.

On arresters for voltages between 7250 and 75,000 the discharge recorder is mounted on a cast iron base bolted to the "Z" bar support on non-grounded neutral circuit arresters, and on strap iron brackets which stand on the floor on grounded neutral circuit arresters. In both cases, connections from the tanks to the terminal block of the instrument are made with copper strip supplied for the purpose. Treated wooden strips are furnished with all arresters to be placed

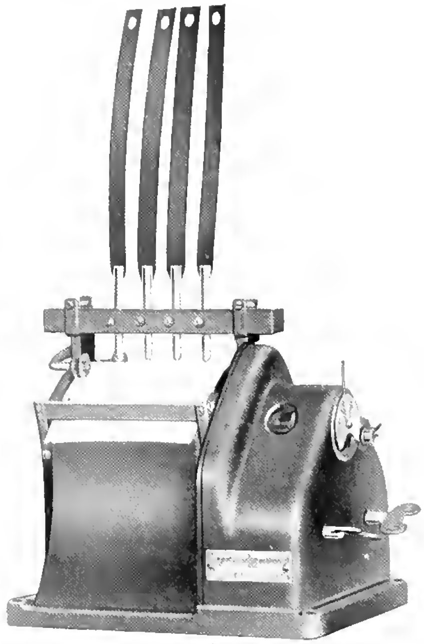


Fig. 24. Discharge Recorder

under the tanks to insulate them from the rack on arresters for non-grounded neutral circuits and from the ground on arresters for grounded neutral circuits. Insulating joints are supplied for the tie rods on 60,000 and 70,000 volt arresters. This insulation is necessary to direct the discharge through the recorder.

After mounting and connecting up the instrument a paper roll should be placed in the knurled screw centers on the lower part of the frame. The centers should be adjusted so as to bring the perforation in the paper in line with the teeth on the drum and to allow the roll to revolve freely. The paper should then be led over the main drum and under the tearing off strip. After putting in the paper the spark gaps should be adjusted so that the paper will just pass under the spark points without touching them. Both springs of the clock should be wound at least once a week, but since the torque of the clock is maintained at a more uniform value and the rate is somewhat better if the spring is not allowed to become completely unwound, it is recommended that the clock be wound twice a week. In setting the paper to the proper time, the drum should be moved a little ahead of the proper point and then backwards until correct so that the backlash of the gears will be taken up. The spark points and drum should be examined from time to time and filed smooth if burned by discharges. The insulation block holding the spark points is made movable so that should the surface of the drum become badly pitted the spark points can be moved over a fresh surface. The gaps should be kept as small as possible without interfering with the movement of the paper.

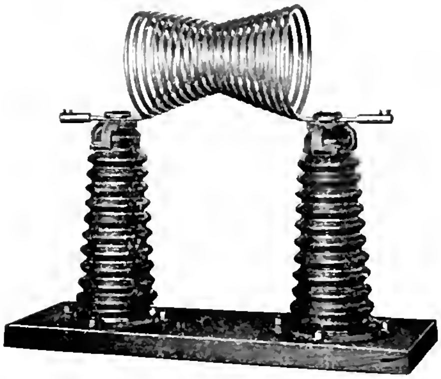


Fig 25. Hour Glass Choke Coil, 45 000 Volts

Should any trouble be experienced in getting the instrument to run satisfactorily, all parts should be gone over carefully to see that there is no excessive friction. The clock casing should be removed and the alignment of the clock and drum shafts should be examined. It sometimes happens that the clock is jarred out of line during shipment thus causing the gears to mesh with excessive friction.

Each roll of paper contains about 60 ft., equivalent to a thirty days supply at the standard rate of feed of one inch per hour. It is recommended, however, that the paper be torn off every 24 hours to be examined and filed with the other daily station records. By this plan, the condition and operation of the arresters is ascertained daily and troubles on either the arrester or the line can be noted and stopped before any damage results. Great care should be taken when examining the paper for discharges, for many of them make such minute punctures that they can only be seen by holding the paper before a strong light. A small quantity of high grade oil, preferably watch oil, should be put on all bearings occasionally. It is important never to touch the discharge recorder without first disconnecting the arrester from the line by means of the revolving horn gaps or removing the fuses. It is also recommended, after opening the horn gaps or fuses, that the four spark points should be grounded. This is necessary as the tanks retain a condenser charge for a short time after each discharge which may result in a dangerous shock to the operator. This ground connection should always be removed before resetting horn gaps to the normal operating position.

Choke Coils

Opinions on the design of choke coils for use with lightning arresters vary considerably Some engineers recommend the use of very large choke coils, but while large choke coils of high inductance do choke back the high frequency currents better than smaller coils of less inductance, they cost more, and under many conditions they are a menace to the insulation unless the lightning arresters are installed on both sides of them. Part of the functions of the choke coil are performed by the end turns of a transformer and extra insulation is invariably installed in all power transformers built in recent years. The choice of choke coils must be influenced by the condition of insulation in the transformers as well as by the cost, potential regulation, and nature of the lightning protection required.

Fig. 26. Hour Glass Choke Coils, 110,000 Volts

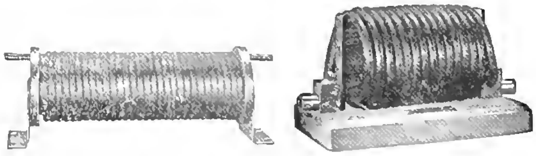
The primary objects of the choke coil should be:

(*a*) To hold back the lightning disturbance from the transformer or generator until the lightning arrester discharges to earth. If there is no lightning arrester the choke coil evidently cannot perform this function.

(*b*) To lower the frequency of the oscillation, so that whatever charge gets through the choke coil will be of a frequency too low to cause a serious drop of potential around the first turns of the end coil in either generator or transformer. Another way of expressing this is from the standpoint of wave-front: a steep wave-front piles up the potential when it meets an inductance. The second function of the choke coil is, then, to smooth out the wave-front of the surge.

It seems best to consider the choke coil as an auxiliary to the lightning arrester. * There seems to be no justification for the expense of a very large choke coil. If it has an inductance equal to that of several end turns it wi'l reduce the wave front of the surge by more than a corresponding value. For example, if there is no choke coil at all, the full strain of a steep wave front will fall on the end turn. If a choke coil of inductance equal to the end turn is placed in series, this strain will be reduced to one-half. If the choke coil has an inductance equal to six turns, the strain on the end turn will be reduced to about one-seventh. Since the value of such an inductance in a choke coil will make its time constant greater than the dielectric spark-lag of a modern arrester, the arrester will be in full operation to relieve the strain before the charge can get through the choke coil.

In the case of a choke coil the principal electrical condition to be avoided is that of resonance. The coil should be so arranged that if continual surges are set up in the circuit, a resonant voltage due to the presence of the choke coil cannot build up at the transformer or generator terminals. This factor is the menace to the insulation mentioned above. Another way of stating the condition is as follows: Arrange the choke coil in such a way as not to prevent surges originating in a transformer from passing to the lightning arrester.



4600 Volts 6600 Volts

Fig. 27. Low Voltage Choke Coils

Another electrical condition to be avoided in a choke coil is internal static capacity between adjacent turns, since this lowers the effectiveness of the coil.

Two types of choke coils, depending upon the voltage, are shown in Figs. 25, 26 and 27. Those for use on circuits not exceeding 6600 volts are made of several turns of insulated wire, while for voltages above 6600 the hour glass type with air insulated turns is used and the coil is mounted on a steel, slate or marble base. The hour-glass type has the following advantages on high voltages:

First. Should there be any arcing between adjacent turns the coils will reinsulate themselves.

Second. They are mechanically strong, and sagging is prevented by tapering the coils toward the center turns.

Third. The insulating supports can be best designed for the strains which they have to withstand.

* A very clear treatment of the genesis and the functions of the transformer choke coil is given in Dr. Steinmetz's paper in the December, 1912, REVIEW, "Abnormal Strains in Transformers." On pages 737 and 738 excessive voltage strains are analyzed; and a simple theoretical discussion shows how the transformer may be guarded against them by the combination of effective arresters and suitable choke coils.—EDITOR.

LIMITS OF FORM FACTOR OF WAVES UNDER A. I. E. E. STANDARDIZATION RULES

By Taylor Reed

Standardizing Laboratory, General Electric Company

The sine wave is the wave form recognized as standard by the A.I.E.E., and in the Standardization Rules of this Society limits are set for the allowable deviation from the equivalent sine wave of peaked and flat top waves. The effective values of voltage or current as read on indicating instruments do not give a correct representation of the average, or mean, values. Some important engineering factors depend upon the average values. For instance, the flux density and consequent hysteresis loss and heating in transformer cores, is a function of the average voltage, not of the effective, and for a given voltmeter reading may be considerably too low if tested on a peaked wave. Hence the necessity for keeping within certain well defined limits. In this article the author has calculated and plotted the limiting peaked and flat top waves that comply with the above mentioned rules.—Editor.

The sections of the A.I.E.E. standardization rules relating to the deviation of waves from sine wave are:

79. The sine wave should be considered as standard, except where a difference in the wave form from the sinusoidal is inherent in the apparatus.

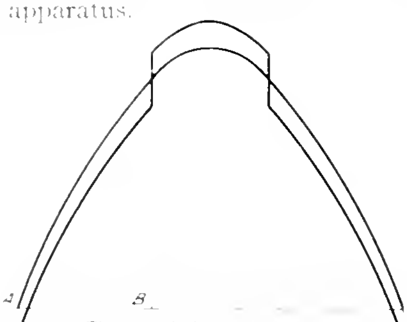


Fig. 1. Limiting Peaked Wave

80. A maximum deviation of the wave from sinusoidal shape not exceeding 10 per cent is permissible, except when otherwise specified.

5h. Form factor of an alternating wave. The ratio of the root-mean-square to the arithmetical mean ordinate of a wave, taken without regard to sign, is called its form factor.

5i The equivalent sine wave is a sine wave having the same frequency and the same r.m.s. value as the actual wave.

5j. The deviation of wave form from the sinusoidal is determined by superposing upon the actual wave (as determined by oscillograph), the equivalent sine wave of equal length, in such a manner as to give the least difference, and then dividing the maximum difference between corresponding ordinates by the maximum value of the equivalent sine wave.

The limiting peaked wave satisfying these requirements is a wave which from the vertex to a certain point (*B*, Fig. 1) is higher than the equivalent sine wave by 10 per cent of the maximum of the sine wave, and then lower than the sine wave by 10 per cent from this point to its axis, or zero; the position of the point of change of ordinate *B* being fixed by the effective value, which is equal to that of the sine wave.

The position of the point of change of ordinate (*B*, Fig. 1) may be computed by approximation. Assuming it to be 60 deg. along the curve, the effective, or r.m.s.,

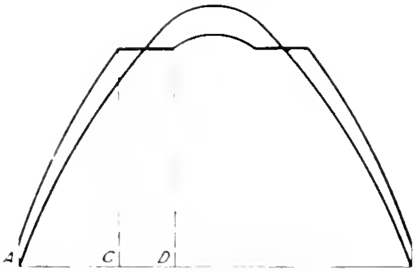


Fig. 2. Limiting Flat Topped Wave

value of the wave is found to be 0.714; assuming 65 deg. the r.m.s. is 0.701; assuming 62.5 deg. the r.m.s. is 0.707, or that of the sine wave. The position of the point of change of ordinate is accordingly 62.5 deg. (Table I).

This case is directly integrable. Representing the angle of the point of change of ordinate of the wave (*B*, Fig. 1) by θ, the effective, or r.m.s., value of this wave is equal to that of the equivalent sine wave. [Equations on opposite page.]

The form factor for this wave is computed to be 1.182 (Table I).

The small portions of the peaked wave below the zero line (Fig. 1) have been taken negative. If the rules (5h) are interpreted to require that they should be reckoned positive the value of the form factor is slightly lower. The average value is then 0.604, and the form factor is then 1.171.

The limiting flat-topped wave satisfying these requirements is a wave which, from the vertex to a certain point (*D*, Fig. 2) is lower than the equivalent sine wave by 10 per cent of the maximum of the sine wave, then horizontal to a point (*C*) 10 per cent above

$$\frac{2}{\pi}\left(\int_0^{\beta}\left(\sin\theta-\frac{10}{100}\right)^2 d\theta+\int_{\beta}^{\frac{\pi}{2}}\left(\sin\theta+\frac{10}{100}\right)^2 d\theta\right)=\frac{2}{\pi}\int_0^{\frac{\pi}{2}}\sin^2\theta d\theta$$

$$\int_0^{\beta}\left(\sin^2\theta+\frac{1}{100}-\frac{2}{10}\sin\theta\right)d\theta+\int_{\beta}^{\frac{\pi}{2}}\left(\sin^2\theta+\frac{1}{100}+\frac{2}{10}\sin\theta\right)d\theta=\int_0^{\frac{\pi}{2}}\sin^2\theta d\theta$$

$$\left[\frac{1}{2}\theta-\frac{1}{4}\sin 2\theta+\frac{1}{100}\theta\right]_0^{\beta}+\left[\frac{2}{10}\cos\theta\right]_0^{\beta}+\left[\frac{1}{2}\theta-\frac{1}{4}\sin 2\theta+\frac{1}{100}\theta\right]_{\beta}^{\frac{\pi}{2}}-\left[\frac{2}{10}\cos\theta\right]_{\beta}^{\frac{\pi}{2}}=\frac{\pi}{4}$$

$$\left[\frac{1}{2}\theta-\frac{1}{4}\sin 2\theta+\frac{1}{100}\theta\right]_0^{\frac{\pi}{2}}+\left[\frac{2}{10}\cos\theta\right]_0^{\beta}-\left[\frac{2}{10}\cos\theta\right]_{\beta}^{\frac{\pi}{2}}=\frac{\pi}{4}$$

$$\frac{\pi}{4}+\frac{\pi}{200}+\frac{2}{10}\cos\beta-\frac{2}{10}+\frac{2}{10}\cos\beta=\frac{\pi}{4}$$

$$\frac{4}{10}\cos\beta=\frac{2}{10}-\frac{\pi}{200}$$

$\cos\beta=.461$, nearly

$\beta=62.5$ deg., nearly.

TABLE I

For 0 – 62.5 deg., $y=\sin x-0.10$
For 62.5 – 90 deg., $y=\sin x+0.10$

Deg.	Sine	y	y^2
2.5	0.044	–0.056	0.003
7.5	0.130	0.030	0.001
12.5	0.216	0.116	0.013
17.5	0.301	0.201	0.040
22.5	0.383	0.283	0.080
27.5	0.462	0.362	0.131
32.5	0.537	0.437	0.191
37.5	0.609	0.509	0.259
42.5	0.676	0.576	0.332
47.5	0.737	0.637	0.406
52.5	0.793	0.693	0.480
57.5	0.843	0.743	0.552
a (62.5)	(0.887)	(0.987)	(0.974)
b (62.5)	(0.887)	(0.787)	(0.619)
62.5	0.887	0.887	0.787
67.5	0.924	1.024	1.049
72.5	0.954	1.054	1.111
77.5	0.976	1.076	1.156
82.5	0.991	1.091	1.190
87.5	0.999	1.099	1.208
			a (9.176)
			b (8.821)
		10.762	8.989
			a (0.510)
			b (0.491)
			0.4994
			a (0.714)
			b (0.701)
		0.592	0.707
Form factor		1.182	

(a) Approximation, at 60 deg.
For 0-60 deg., $y=\sin x-0.10$
For 60-90 deg., $y=\sin x+0.10$

(b) Approximation, at 65 deg.
For 0-65 deg., $y=\sin x-0.10$
For 65-90 deg., $y=\sin x+0.10$

TABLE II

For $y=0-0.84$, $y=\sin x+0.10$
For $y=0.84-1.00$, $y=\sin x-0.10$

Deg.	Sine	y	y^2
2.5	0.044	0.144	0.021
7.5	0.130	0.230	0.053
12.5	0.216	0.316	0.100
17.5	0.301	0.401	0.161
22.5	0.383	0.483	0.233
27.5	0.462	0.562	0.316
32.5	0.537	0.637	0.406
37.5	0.609	0.709	0.503
42.5	0.676	0.776	0.602
47.5	0.737	0.832	0.692
52.5	0.793	0.840	0.706
57.5	0.843	0.840	0.706
62.5	0.887	0.840	0.706
67.5	0.924	0.840	0.706
72.5	0.954	0.854	0.729
77.5	0.976	0.876	0.767
82.5	0.991	0.891	0.794
87.5	0.999	0.899	0.808
		11.970	9.009
			0.5005
		0.665	0.707
Form factor		1.064	

the sine wave, and then 10 per cent above the sine wave to its axis, or zero; the height or ordinate of the horizontal portion (*CD*) being fixed by the effective value, which is equal to that of the sine wave.

Computing by approximation the ordinate of the horizontal portion of the wave (*CD*) in the same manner as for the preceding case, the effective, or r.m.s., value of the wave is found to be 0.707, or that of the sine wave, when the ordinate of the horizontal portion of the wave (*CD*) is 0.84 (Table II).

This case is not readily integrable by the process employed in the preceding case.

The form factor for this wave is computed to be 1.064 (Table II).

The form factors of waves complying with A.I.E.E. Standardization Rules (79, 80, 5h-j) are within the limits 1.064 and 1.182

THE STANDARD-UNIT SWITCHBOARD

By D. S. Morgan

In Charge of Publicity, Switchboard Department, General Electric Company

The standard-unit idea in switchboard production is being very extensively advertised, as its realization is full of profit to the producer, as well as being generally susceptible of all the talking-points which appeal most strongly to the consumer—simplicity and facility of ordering, reduced outlay, and of course very rapid shipments. The achievement represents the greatest single step forward which has yet been made in switchboard production, though not in switchboard engineering, since the panel unit was first built; and careful note should be made of its significance by students of electrical landmarks. This article discusses the commercial factors which made the standard-unit board possible; and illustrates the working out of the scheme by solving the control requirements of three typical installations, varying in size and functions.—Editor.

Simultaneously with the great increase in number and size of electric power installations that have come into existence during the last decade, there has been a gradual yet sure transition from intricate and troublesome to simple and satisfactory control and distribution systems. There has been and is yet a gradual tendency for engineers to get further and further away from the use of special or untried switchboard apparatus, and to thus eliminate the various difficulties that such apparatus was liable to introduce. And not only have the devices, which go to make up the switchboard, been themselves improved; but their selection has been more judicious as their limitations and the conditions which they are designed to meet have become generally better understood.

During this period of progression, efforts have been continually made to simplify the equipment, to reduce it to a minimum consistent with satisfactory service, and to arrange so that space is used to the best advantage. Instruments have become more nearly uniform in size and appearance, circuit-breakers and oil-switches have been given certain specified ratings and duties, connection bars, busses, etc., are mounted where possible in the same relative positions; and the whole effect is that continuity of service has become more and more closely approached. It is probably no exaggeration to say, however, that the most distinct advance in switchboard production which has been made since the panel system was first developed has been the evolution of the standard-unit switchboard. This means the segregation of the individual panels required in the varied fields of electrification, into salient classes, from which can be produced, with facility and without loss of time, a standard-unit switchboard special in that with judicious selection and grouping of panels it will meet any special requirements; standard in that its constituent parts are standard.

Let us consider for a moment what the switchboard is and what it has to do. The switchboard is the connecting link between the source of electric power and its point of application; and consists of switching, metering and protective devices mounted on insulating supports. Its duties consist in the measurement, control and distribution of electric power, and in protecting connected machinery against the disastrous effects resulting from abnormal electrical conditions. If any of the equipment used on a certain panel has been developed for that particular installation, or the position it occupies is different from the usual location, the panel is special. If the devices are of usual construction, and mounted in a certain uniform manner, the panel is standard. Although the use of standard apparatus and arrangement is rapidly increasing because of the numerous evident advantages, there are still a great number of people who believe nearly every installation requires special treatment and also special switchboard equipment. This assumption is by no means correct. It is a fact that many power developments are, and will continue to be, unique in one or several particulars; but this condition is without question the exception when considering the entire field of operation, and among the immense number of new or changed developments maturing every year, but a small percentage necessitate the use or arrangement of devices in ways other than have often been used before.

In the evolution of the standard-unit switchboard there may be said to be three salient steps: First, the analysis of the entire field of switchboard activity and the classification of recurrent conditions into groups differing only in slight details, such as the number of generator or feeder circuits and differences in voltage or magnitude of current; second, the design of the simplest line of panels to meet the conditions in each of these separate groups; finally, and probably the most important step, the listing of these groups so that any engineer, familiar with the conditions in his plant for which a complete switchboard is required, can himself effect a synthetic design of a group of panels suited to the needs of his particular case. The standard-unit panels coming under this classification embrace practically the entire field of operation of small and medium-sized plants up to 600 volts direct current, and 2300 volts alternating current. In order to illustrate how this method of switchboard production is to-day being actually applied in commercial tran-

Fig. 1

Simple Standard Panel for Control and Indication of Output of a Small D.C. Generator

sactions, we may consider a few typical instances in which requirements, which at first glance may appear special, can be met by the provision of a standard-unit board.

Case 1. Medium sized farm with water power available

Assume a prosperous farm, on which there is a little water power which can be developed for furnishing power for the small implements

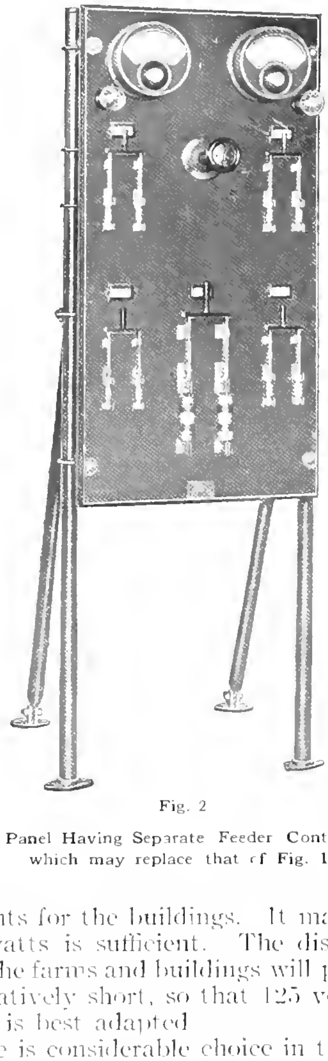


Fig. 2

Standard Panel Having Separate Feeder Control Switches, which may replace that of Fig. 1

and lights for the buildings. It may be that 2 kilowatts is sufficient. The distance between the farms and buildings will perhaps be comparatively short, so that 125 volts direct current is best adapted.

There is considerable choice in the switchboard equipment to meet these conditions. If it is simply a case of passing the Underwriter's requirements, and protecting the generator without trying to maintain constant voltage on the lamps, or to run the plant at its best efficiency, a rheostat and double-pole, single-throw lever switch with fuses mounted on a base would suffice. The saving in cost of such an equipment would, however, probably be offset in a short time by the low efficiency obtained. The lights would be dim and unsatisfactory, or too bright with short life, and an improvement could be made by selecting a panel similar to the above with a voltmeter added. The equipment would be still better if an ammeter

Fig. 3

Standard Panel Similar to that of Fig. 2 but having Circuit-Breakers in Feeders Instead of Knife Switches and Fuses

were furnished, which would tell the load on the system at all times, and thus assist in preventing interruptions to the service due to overloads and the blowing of fuses. A standard unit switchboard, which would take care of the conditions as outlined above, is shown in Fig. 1.

Now, if it is desired to have four feeder circuits, the panel (Fig. 1) can be used with fuses installed at each branch where it leaves the main circuit. It is, however, easy to imagine that trouble on one branch might put the entire equipment out of commission until the fault was located and corrected. Separate switches in each feeder circuit would provide means of disconnecting any one circuit, and localizing the trouble without interfering with the remainder of the system. The panel shown in Fig. 2 would meet the conditions. The installation could be still improved by using such a panel as is shown in Fig. 3 in which the fuses and feeder switches are replaced by small circuit breakers.

Case II. Small manufacturing plant

We shall next consider an installation on a little more extensive scale—a small manufacturing plant with one 50-kw. and one 100-kw. 125-volt direct current generators to be run in multiple, and furnish power to three power and four lighting circuits. The standard-unit switchboard shown in Fig. 4 contains all necessary equipment. The three power circuits will be protected by circuit breakers and the lighting circuits by fuses. A standard-unit direct current 250-volt installation to take care of two 250-kw. and one 50-kw. generators, two 300-amp., two 200-amp. and two 100 amp. feeder circuits, is shown in Fig. 5.

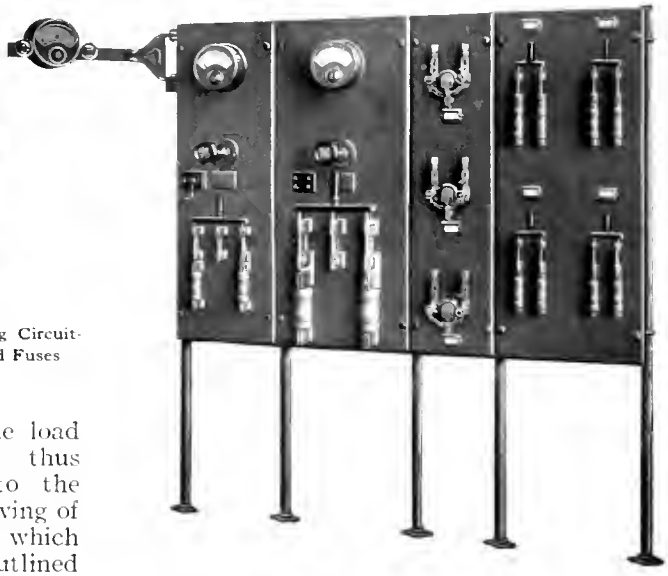


Fig. 4

Switchboard Made Up of Standard-Unit Panels to Take Care of One 50 Kw. and One 100 Kw., 125 Volt D.C. Generators, Three Power and Four Lighting Circuits

Case III. Medium-sized central station

For the last illustration of the use of standard-unit switchboard panels, let us consider a more difficult case. Let this be a 2300-volt alternating current medium-sized central station supplying light and power. The equipment consists of two alternating current generators; with one-engine driven and one induction motor-driven exciter; a generator voltage regulator; two three-phase power circuits; and one single-phase lighting circuit controlled by a feeder regulator. The switchboard (Fig. 6) would take care of this installation. It is composed entirely of standard unit panels and contains the following equipment: two exciter panels; one combined automatic voltage regulator and induction motor panel; two generator panels; two power panels; and one lighting panel.

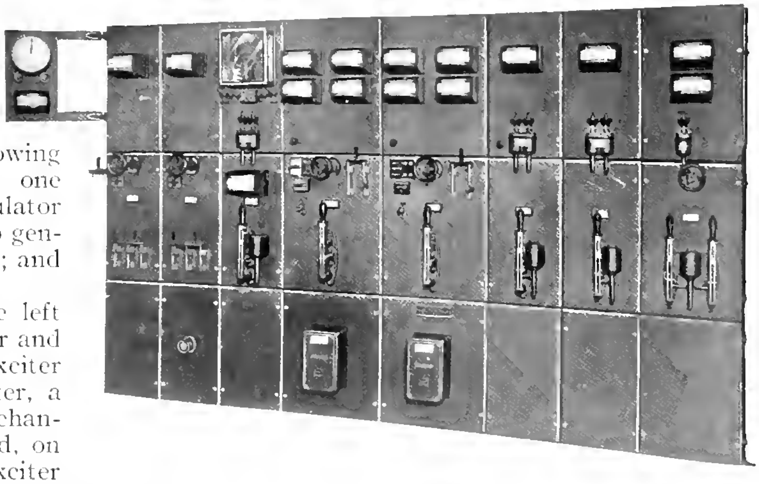


Fig. 6

Standard-Unit Switchboard for Two 2300 Volt A.C. Generators, One Engine Driven and One Motor Driven Exciter, a Generator Voltage Regulator, Two Three-Phase Power Circuits and One Single-Phase Lighting Circuit Controlled by Feeder Regulator

The swinging bracket on the left contains a synchronism indicator and an exciter voltmeter. The exciter panels each contain an ammeter, a potential receptacle, rheostat mechanism, triple-pole main switch, and, on the sub-base of the second exciter panel, an equalizing rheostat. The third panel contains an automatic voltage regulator, ammeter and automatic oil-break switch for the induction motor driving one of the exciters, and a time-limit overload relay to protect the induction motors in case of sustained overloads. The alternating current generator panels are identical, and each equipped with voltmeter, ammeter, field ammeter and indicating wattmeter, synchronizing and potential receptacles, governor control switch, rheostat mechanism, field switch, non-automatic oil-break switch and a watthour meter. The power feeder panels have each an ammeter, automatic oil-break switch and time-limit relay. The lighting panel contains an ammeter, voltmeter, feeder regulator handwheel, single-pole double-throw automatic oil-break switch, and time-limit relay. A double-pole switch is used to admit of feeding the lighting circuit from either of two phases of the three-phase system, to help keep the 3-phase generator load as nearly balanced as possible.

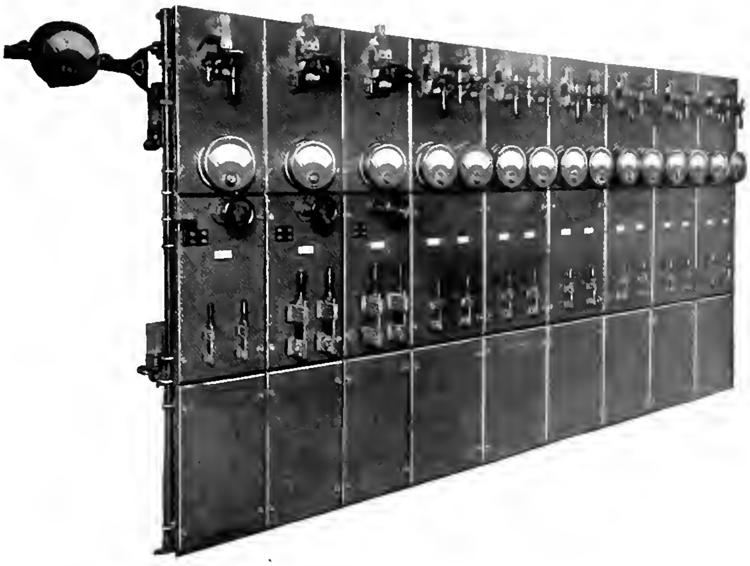


Fig. 5

Standard-Unit Switchboard for Two 250 Kw. and One 50 Kw., 250 Volt D.C. Generators, also Two 300 Amp., Two 200 Amp., and Two 100 Amp. Feeder Circuits

It would be easily possible to go on at great length along the lines indicated to show the application of the standard-unit switchboard system, to almost any variety of conditions; but it is believed that the foregoing is sufficient to indicate some of its advantages.

TRAINING SCHOOLS FOR SMALL CENTRAL STATIONS

By Sydney W. Ashe

Edison Lamp Works, Harrison, N. J.

Can a small central station support a training school? The writer has been asked this question several times lately by managers of small central stations; and in all cases the following reply has been given: A small central station can support a training school for employees, but such schools can hardly be attempted on the basis of schools carried on by large central stations. Schools, however, can be started in a small way, and maintained at little expense; and, providing the work is carried on thoroughly and continuously, can accomplish much good.

One of the best plans is to make use of either Saturday mornings or afternoons in which to hold sessions. Many central stations in the past have used this time for sales conferences, and meetings of meter departments; but the difference between the methods already used and those of a school lies in the fact that most attention has been given at these meetings to considering special problems which arise, to new business development, etc. In other words, the most attention has been given to developing men already in the organization—men already trained.

How about the young man just entering the organization? What means are used to fit him into the company—to teach him company policy, special business methods and the workings of various departments? For instance, in the commercial department, he is interested in simple electrical terms and circuits, wiring devices, fire underwriter's rules, rates, how to solicit contracts, load factor, different kinds of business, how to set up and operate various current consuming devices, how to locate trouble in these devices, various methods of sign lighting, illuminating engineering, the proper motor for the proper service, storage batteries, etc. Besides this technical information, he should thoroughly understand commercial methods—how really to get business, advertising schemes, business correspondence, value of personality, etc. For the engineering and accounting departments somewhat similar lists could be prepared.

A good plan for the small central station to follow is to lay out a scheme which can be kept in operation for ten months of the year, using about three hours either mornings or afternoons on Saturdays. Mornings are always preferable. No sessions should be run in summer time, as the men have little interest for educational work in warm weather. For the commercial department, the work can be divided into three parts: a regular course of lectures on commercial and technical topics bearing on the department work; a series of selling demonstrations assigned in advance, in which the men make actual sales; and a series of experiments in which the men will learn the meaning of technical terms, how to operate current-consuming devices, how to locate trouble, or, in other words, how to give better service to the customer. A definite plan may be formulated and printed in syllabus form, giving the complete outline for the season. Such a printed program forms good advertising material. Arrangements can also be made to invite customers to these meetings, having them speak occasionally, and criticize the scheme. This generates goodwill between the customer and the central station. Where the expense is warranted, such a school may be supplemented by an arrangement whereby every new commercial man that enters the organization will devote his time continuously to study for a period of about four weeks covering, in a general way, by means of trips, lectures, experiments, etc., about the same material as extends over the year in the previous case. This plan, however, involves having someone in complete charge who can devote a fair measure of his time to educational work. It may be possible to select someone in the organization who is now doing part of such work, and allow him to attend for a few weeks one of the schools carried on by some central station or some manufacturer.

When an educational scheme is broached there is a natural tendency to suggest carrying on the work in the evening. While this method is satisfactory for meetings of local sections of engineering and other societies, it should be avoided where systematic educational work is being carried on. Where the work is carried on during the day on the company's time, the results obtained are vastly better. No difficulty arises regarding attendance—it is part of the man's regular duty to attend. Furthermore, his attendance is compulsory, as he is receiving pay for the time spent in attendance. The man can be easily interested in study, experiments, lectures, etc. His brain is in a receptive mood; he is alert and ready to absorb. Where it is necessary to carry on this work in the evening, the plan followed by some of the local sections of the engineering societies might be introduced. Papers are read and discussed after which some social relaxation may be introduced.

This work must be carried on independent of any *welfare* work of the company, as the term often conveys the idea of charity or religious supervision which is too often misinterpreted. Educational work, as previously stated, should be carried on as part of the regular company routine. It should be the great co-operator—the thing which draws the department heads and the new employees into closer contact. It can also be used to advantage in developing speakers in the regular organization. As a beginning, a man may be asked to speak for 15 minutes as part of a regular lecture. Later, when the man has more confidence, the time can be increased. The writer has used this method most successfully. It is remarkable to see how rapidly a man will develop in this direction.

IN MEMORIAM

JAMES WHITING JOHNSON

As briefly noted in the last issue of this journal, Mr. James Whiting Johnson, District Manager in Chicago for the General Electric Company, died of pneumonia, at his home in Hyde Park, Chicago, on Tuesday, January 14, 1913, after a short illness.

JAMES WHITING JOHNSON

Mr. Johnson was born in Waverly, N. Y., December 3, 1862, and was the son of the Rev. David S. Johnson, for many years Pastor of the Hyde Park Presbyterian Church. Since his boyhood Mr. Johnson had lived in Chicago and was a student at the Hyde Park High School. In 1878 he began his business career as an office boy for the Bell Telephone Company, with which company and its successor, the Chicago Telephone Company, he remained until 1885. For two years thereafter he was managing partner of the firm of Johnson, Holland & Company, which was formed to exploit the storage battery business. In 1887 Mr. Johnson became Manager of the Northwestern Electric Accumulator Company; and a year later he entered the Chicago office of the Thomson-Houston Electric Company as a salesman. With this company and its successor, the General Electric Company, he was connected until the time of his death w h the exception of a period of about three years when he was Western Agent for the United States Fire & Police Telegraph Company of Boston.

In the early days he was Manager of the Isolated Plant Department of the Thomson-Houston Company; and later was successively Chicago Manager of the Lighting Department and of the Power and Mining Department of the General Electric Company. In 1905 he was made Assistant Manager of the Chicago office, and since May, 1908, when Mr. B. E. Sunny retired to become President of the Chicago Telephone Company, he had been District Manager.

Mr. Johnson was a dignified, quiet, retiring man of great business intelligence, a painstaking, untiring, far-seeing worker, an appreciative employer, a faithful friend and a highly respected and just executive, whose loss will be most keenly felt by his friends and associates in the business world. He was a member of the Union League, the Chicago Automobile, the Mid-Day and the Homewood Country Clubs in Chicago, and of the Mohawk Club in Schenectady, N. Y.; and a member of the American Institute of Electrical Engineers.

NEWS FROM THE CONSULTING ENGINEERING DEPARTMENT OF THE GENERAL ELECTRIC COMPANY

STUDENT ENGINEERS' COURSE

As noted in the last issue of the REVIEW a series of lectures is being given to the men in the Testing Department. The educational value of the Lecture Course is apparent, and a serious interest has been shown which promises well for the future. An attendance numbering a little less than two hundred is regularly present at all lectures. Special interest in particular lectures has been indicated by the presence of others than members of the Testing Department. There is reason to believe that an increased efficiency will be shown by the Student Engineers as a body as the result of the instruction given by the lecture plan. The following schedule has been announced by Mr. A. W. Clark of the Welfare Department, as effective until the first of July. Advance work to be accomplished from July to December is being planned and will be subject to publication later.

Jan. 27 and Feb. 5, Modern Business Economics, by C. E. Patterson; on Feb. 10 and 17, Industrial Welfare, by A. W. Clark; Feb. 24 and March 3, Work of the Production Dept., by Langdon Gibson; Feb. 10 and March 31, the Relation of the Sales Agent to the Modern Central Station, by F. C. Bates; Feb. 17 and 24, the Early History of Electric Lighting, by W. S. Andrews; April 7 and 14, Manufacturing Responsibilities, by W. C. Fish; April 21 and 28, Industrial Chemistry, by Dr. W. R. Whitney; May 5 and 12, Evolution of the Incandescent Lamp, by S. W. Ashe; May 19 and 26, Work of the Sales Dept., by C. A. S. Howlett; June 2 and 9, Problems of Transformer Design, by G. Faccioli; June 16 and 23, Cost of Manufacturing Electricity, by H. M. Hobart

CLASS IN HIGH VOLTAGE ENGINEERING

The High Voltage Engineering Class in Pittsfield, under the direction of Mr. Peek, is now well under way. Several subjects, such as magnetic and dielectric fields, insulation testing, insulator tests, transformer testing sets, high tension leads, potential stresses in transformers, and mechanical stresses in magnetic and dielectric fields, have been discussed in lectures, and also in papers by members of the class. In connection with them various problems have been assigned. Some of these problems are given below to show the nature of the work done by the class. The solution of some of these problems will appear later.

1. Given a cable with metallic sheath. The conductor diameter is x, the dielectric is homogeneous and of diameter D. If the permittivity of the dielectric is $K=1$, what is the best value of x? If the cable of same diameter is made up of equal thicknesses of insulation of permittivity $K=1$ and $K_1=2$ and equal dielectric strength, what is the best arrangement of insulation?

2. Given a 3-phase, 60-cycle line at an altitude of 5000 ft., voltage 140,000, conductors arranged in triangle with 10 ft. spacing, what is the smallest cable which can be used with no corona loss in fair weather at 25 degrees C.? What is the corona loss per mile at 150,000, 160,000 and 200,000 volts in fair weather and in stormy weather? Find the losses and visual corona voltage at 14,000 ft. elevation.

3. With a given size of conductor and spacing, why are the critical voltages different for single-phase and three-phase? What is the ratio?

4. Given a 25-mile transmission line, open at one end and separated from ground at the other by a very small spark gap. If there is a lightning discharge between two clouds above the line, how will the potential be distributed along the line? What will be the frequency of the free oscillation? What will be the potential distribution if one end of the line is grounded and the other separated from ground by a small spark gap? What, when the middle is grounded and the two ends separated from ground by small gaps?

In parallel with the lectures a large high voltage transmission system is being designed.

The Pittsfield high voltage engineering class is of particular interest to the readers of the General Electric REVIEW if only for the reason that much of the material which is now being put together primarily for discussion at the meetings of the class will later be available for publication in these columns. Mr. Tressler's valuable paper in this month's issue on methods of testing electrical insulations is already a case in point. Mr. F. F. Brand is now revising the lecture which he gave at Pittsfield on Insulator Testing, and this will we hope be ready for our April number.

ARCING GROUNDS ON TRANSMISSION LINES

An interesting experimental investigation has recently been made by the Protective Apparatus Laboratory of the Consulting Engineering Department, and the Adirondack Power Company, on the latter Company's lines, into the disturbances caused by the arcing grounds in the interior of apparatus such as transformers, and the methods of protection against them. A number of good oscillographs of arcing grounds on the transmission line have been secured, together with records of the high frequency disturbances caused by them, in the transformers, and their suppression by protective devices. Of special interest in these tests was the use, in an industrial circuit, of an apparatus which without interference with the operation of the line predicts the liability of approaching line troubles.

QUESTION AND ANSWER SECTION

The Q. and A. Section has been started with the sole object of increasing the practical usefulness of the REVIEW; and in order that it may be made of real value, we invite correspondence from any of our readers who are looking for information on any technical matter in the field covered by this magazine, and which they think we can furnish.

Where possible the answers to such inquiries will be the work of this office; where desirable we shall obtain our authority from that engineering or commercial party in the General Electric Company's organization best fitted for handling the particular subject. We hope our readers will not hesitate to avail themselves of the expert engineering opinion which should be made available through this section of the REVIEW. Information on matters of general importance and interest will be published here; questions of interest solely to the querist will be handled by mail.

Sketches should accompany questions in all cases where this is necessary to give us complete and accurate information on the point at issue. Scale drafts will be made up here from correspondent's rough pencil sketches. Questions must be accompanied with the name and address of the sender, although these will not necessarily be for publication, and should be addressed to the Editor, Q. and A. Section, GENERAL ELECTRIC REVIEW, Schenectady, N. Y.

THREE-PHASE INDUCTION MOTOR ON A TWO-PHASE CIRCUIT

(1) Having a three-phase induction motor but only a two-phase current source of supply, or the converse of these conditions, can practical use be made of the combination?

If operated under the following conditions and the output desired is not too large, good advantage may be made of the conditions offered. When an induction motor wound for a certain number of phases, as three-phase, is placed on a line of a different number of phases, for instance, two-phase, it acts as a "go-between," in fact, a phase-converter, attempting to reduce the difference between the phase angle of the incoming voltage and its own inherent angle, by pulling them into unison. This strain is severe on the motor if a full voltage is applied and the motor is allowed to come up to full speed; and although even only running light, a burn-out would follow its trial. Very serviceable use can, however, be made of the outfit if the load conditions allow that not more than about 50 per cent of the motor's polyphase capacity be required of it. This may be accomplished by using the available polyphase current to start the machine from rest, but immediately it has attained somewhat above half speed, cutting open one supply line; from which point it will rise to full speed and will then operate satisfactorily single-phase up to loads amounting to one-half its nominal polyphase capacity.

GROOVING A COMMUTATOR

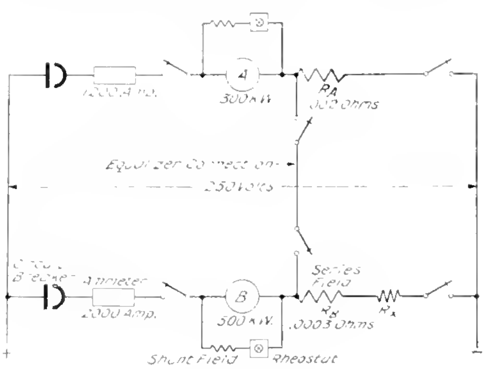
(2) What are the reasons for grooving a commutator, when doing so would seem to render a partial short circuit possible, through accumulation of dirt in the grooves?

The commutators of many machines are grooved, particularly those which receive but little attention, for this construction removes the occurrence of high mica and the necessity of turning or grinding down the commutator for that reason. Grooving also tends toward improved ventilation, for since the grooves cut up the smooth surface of the commutator, they create a slight fanning action. No accumulation of dirt or carbon dust seems to collect in the grooves, probably due to the centrifugal force tending to remove it, and further, the voltage between bars is so small that should this occur, no harm would result.

PARALLELED D.C. GENERATORS

(3) A 10-pole, 300 kw. direct current engine-driven generator, which is running in parallel with a recently installed 4-pole 500 kw. turbine generator, both of the same compound, refuses to carry its share of the load. This is apparently due to some action of the series fields, for after once balancing the load with the shunt fields, a change in the line current causes a disproportionate distribution of load in the two generators. The customary connections with equalizer are used. What is the explanation of the unbalancing?

Since one is a 10-pole and the other a 4-pole machine, it is safe to assume that the series field resistances are far different, and this is the cause of the unbalancing. Suppose, for a moment, the equalizer switch to be open. It will then be seen that the drop across the series fields of generator A (see diagram) at normal load is 2.4 volts, while the corresponding one in generator B is 0.6 volts. Now in the running condition of closed equalizer switch, generator A will send 782 amperes of its armature current through the series field of generator B, thus over-exciting the field of B and causing it to assume more than its share of the load. In order to prevent or minimize this exchange current, it is necessary to insert in series with the series field of the overload machine B, a resistance R_x equivalent in carrying capacity to the series field, and of such a resistance that, with normal load on each machine, the voltage drop in the two series field circuits (equalizer to bus) will be equal. This



will cause each series field to carry only its own armature current. Since the machines are of the same compound, each will then automatically assume its own share of the total line load, after having once been set with the shunt field.

In making measurements to determine the amount of additional resistance to be inserted, the resistance of the cables connecting each series field to the bus should be included as a part of the respective fields.

A counterpart of this case is sometimes found in other installations where machines of different speeds are required to run in parallel, such as engine driven generators with motor-generator sets, motor-generator sets with turbine generators or engine driven generators with turbine generators. The subject matter of this question is also handled by Mr. Lamar Lyndon in an article on "Parallel Operation of Dynamos having different characteristics" appearing in the American Electrician for March, 1905.

WATTMETER REVERSAL

(4) When two wattmeters are used for the measurement of 3-phase power, why will one of them reverse upon low power-factor?

Instantaneous power in a three-phase circuit is given by the equation $W = e_1 i_1 + e_2 i_2 + e_3 i_3$ illustrated in Fig. 1, which may be reduced to $W = i_1(e_1 - e_3) + i_2(e_2 - e_3)$ also given in Fig. 1. These forms show how the customary connection of two wattmeters combine to measure three-phase power.

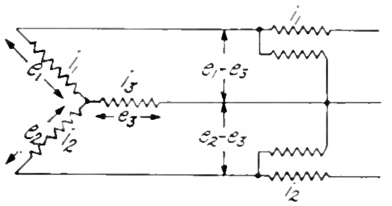


Fig. 1

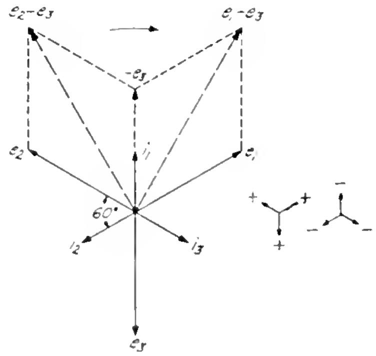


Fig. 2

The combination of voltages and currents in the wattmeters, disregarding any potential or current transformers which may be used, is illustrated vectorially in Fig. 2. In order to illustrate the value of the voltage upon the potential coil of a wattmeter, which is really the difference between e_1 and e_3 also e_2 and e_3 it is laid out in this manner: Since e_3 is negative in the equation, it is laid off in the reverse direction from what it would be if it were positive. It then combines vectorially with e_1 and also e_2, giving $e_1 - e_3$ and $e_2 - e_3$. The currents in each line are illustrated by the vectors i_1, i_2 and i_3, and in the diagram are placed 60 degrees behind their respective voltages. The power then measured by one wattmeter is equal to the voltage impressed upon its potential coil times that component of the current in its current coil, which is in phase with it, i.e., i_2 $(e_2 - e_3)$. It is seen in Fig. 2 that the component of i_2 in phase or in the direction of $e_2 - e_3$ is zero, indicating that the wattmeter reads zero for this particular lag. In a balanced circuit if the angle of lag were less than 60 degrees (power-factor greater than 0.5), the projection of i_2 upon $e_2 - e_3$ would fall in the same direction as the latter, which means the meter would read positive; while if the angle of lag were greater than 60 degrees (power-factor less than 0.5), the projection would fall in the opposite direction from $e_2 - e_3$, indicating that the meter will then read negative. The other meter under these conditions will always read positive.

CALCULATION OF TRANSFORMER REGULATION

(5) What is the usual method of calculating the regulation of a transformer?

The data which are necessary for the calculation of the regulation of a transformer consist of the results of separate measurements of its reactance and resistance drop, together with a knowledge of the power-factor of the circuit to which it is connected.

A method which is in common commercial use, and one which conforms to the latest definition of regulation, as standardized by the A.I.E.E. follows.

Expressing the above voltage drops in per cent, the per cent regulation is given by the formula,

Per cent regulation =

$$(\% IR)p + (\% IX)w + \frac{[(\% IX)p - (\% IR)w]^2}{200}$$

in which,

$\% IR$ = total resistance drop due to load current expressed in per cent of rated voltage, $\% IX$ = total reactance drop due to load current expressed in per cent of rated voltage, p = power-factor ($\cos\theta$), and w = wattless factor ($\sin\theta$).

This formula is only approximate, but is satisfactory, and widely used in all practical cases.

EFFECT OF OZONE ON RESPIRATION

(6) In a room where an ozonator is running, is the amount of oxygen reduced, and if so is this not dangerous?

The total amount of oxygen is reduced only very slightly. With normal operating conditions, which include ventilation, this action is so small as to be entirely negligible, and even though ozone were liberated in a slight excess in a closed room, the effect produced would only resemble that existent upon mountain tops, where less than the usual amount of oxygen is present on account of rarefaction of the air. This latter condition would result in a somewhat increased frequency of respiration but would be preferable to breathing impure air. A concentration of ozone sufficient to be actually harmful, would be difficult to obtain from an ordinary ozonator; and if produced, a person would be unable to remain in its presence without a knowledge of its excess.

SQUARE MILS AND CIRCULAR MILS

(7) What is the difference between "square mils" and "circular mils" and how are each figured?

Both the terms refer to units of area and are thus defined: The square mil is the area of a square whose side measures 0.001 inch, while the circular mil is the area of a circle whose diameter is 0.001 inch. To obtain an area in square mils convert all dimensions to mils or thousandths of an inch and follow the usual rules of mensuration. Circular mil area is more commonly used and is particularly adapted to the measurement of circular cross sections. It may be arrived at by dividing the area expressed in square mils by the conversion factor 0.7854, or by the far more simple method of reducing the diameter to mils and then squaring it.

GENERAL ELECTRIC REVIEW

Published Monthly by the
GENERAL ELECTRIC COMPANY'S PUBLICATION BUREAU

Manager, M. P. RICE Editor, D. S. MARTIN Associate Editor, B. M. EOFF Assistant Editor, E. C. SANDERS

Subscription Rates: United States and Mexico, $2.00 per year; Canada, $2.25 per year; Foreign, $2.50 per year, payable in advance. Remit by post-office or express money orders, bank checks or drafts, made payable to the *General Electric Review* Schenectady, N. Y.

Entered as second-class matter, March 26, 1912, at the post office at Schenectady, N. Y., under the Act of March 3, 1879.

VOL. XVI., No. 4 APRIL, 1913

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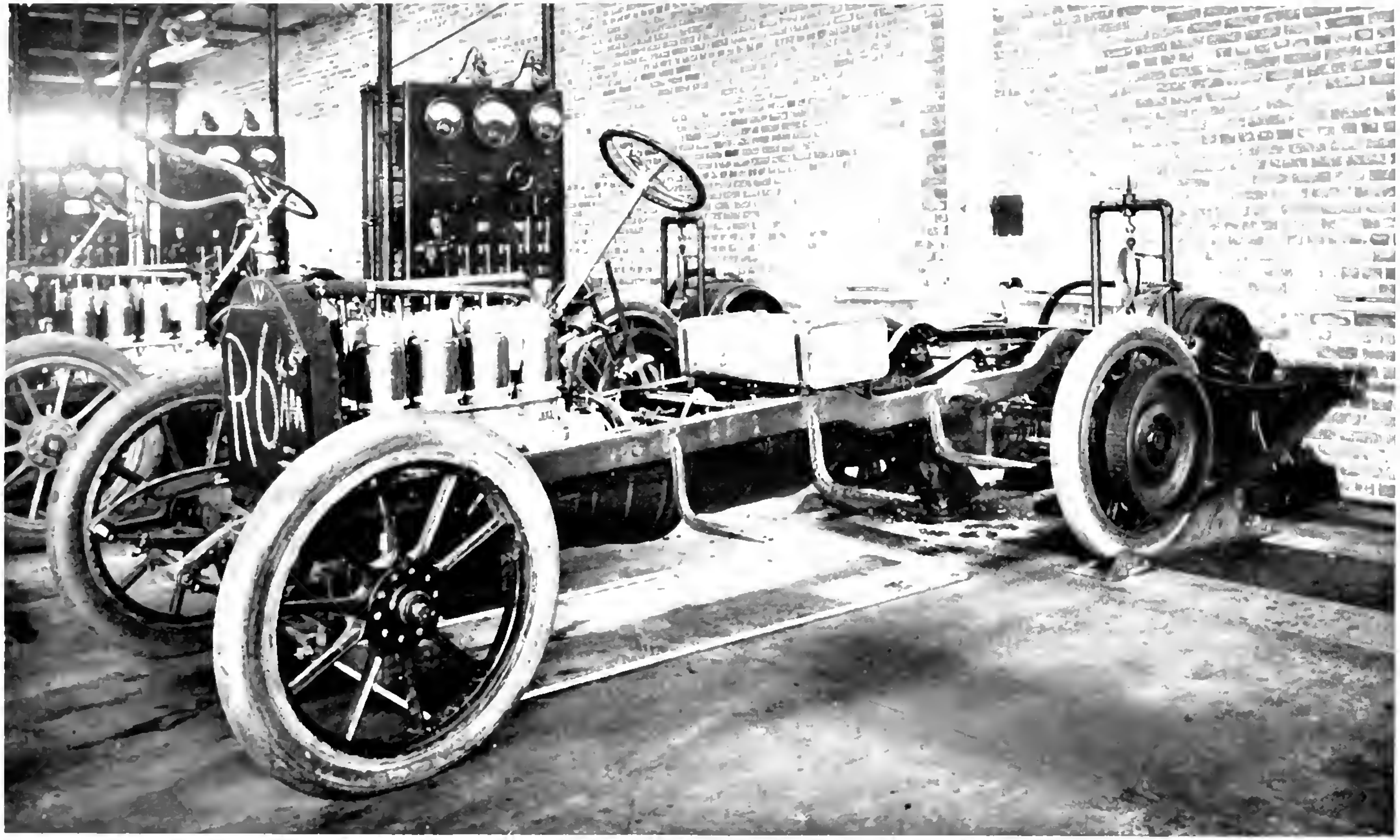

This cut illustrates the shop testing of automobiles under load by means of the electric dynamometer a subject upon which a very complete and interesting article by Mr. C. F. Scott will appear in our May number. This represents a comparatively new market for the electrical manufacturer; but as the right apparatus has become available, and its advantages realized by the automobile manufacturers, enormous business in dynamometers is now being handled. Apart from the fact that a much more thorough and complete test can be made in the factory than on the road, this method can show cost figures which beat the road-test results all to pieces. The greatest saving is of course in the tire bill, with labor a good second; while the dynamometer may be made to pump back into the shop line, and the heat from the very engine itself turned to account by using the cooling water in the factory heating system. In big auto factories the savings in testing expenses in a single year have been found to run considerably higher than the cost of the complete electrical equipment.

GENERAL ELECTRIC REVIEW

SCHEMES FOR SKINNING THE UNCAUGHT HARE

Old sayings, wise saws, hoary adages and other *dicta* of bygone generations are sometimes beautifully true, and are in other cases woefully misleading; although it may be that they were indeed models of sage counsel at the time they were written, and have, in some cases at least, become inoperative only as expediency has reacted upon our standards of ethics, and our manners upon our morals. Thus, some discrimination must be exercised before a collection of ancient proverbs is handed over to members of the rising generation, for the guidance of their feet into the pathways of peace, plenty and prosperity. "Look before you leap" was very good in the days of the dragon and the highway pitfall. It remains good, within certain limits, in these later days of the fake corporation and the speeding automobile: but it has been fairly superseded, as a general business motto, by the more genial "Nothing venture, nothing win." The homely "Everything comes to him who waits" now commands hardly any following; while even the real truth of its more recent amended edition, "Everything comes to him who works while he waits," is coming to be seriously doubted by such persons as disabled dock-laborers and dull-witted designers.

We must here disclaim explicitly any intention of reeling off an essay on the lack of Business Acumen Among the Ancients. Our original intention at the outset of the preceding paragraph was to come quickly to our main point; and to assert bluntly that the experience of later years is furnishing abundant proof of the wisdom of the man who first gave out that, before skinning one's hare, one should first catch it. (We have changed slightly the order of the words, but the reader will recognize an old friend. We might carry the re-arrangement still further, and declare boldly that the uncaught hare is seldom, if ever, really skinned.) To make a long story short, we think that many of the people who, for the last few years, have been writing articles to the press concerning electricity on the farm, may be placed in the category of the "skinners" as distinct from the "catchers." For many years now we have been looking at the same old pictures of spotless cows being electrically milked in spotless cow-sheds, farmers miles from anywhere threshing by arc light, farmers' daughters creasing handkerchiefs—and sometimes worse things than handkerchiefs—with the pressure from a guaranteed electric flatiron; and we have become a little tired of them, and have wondered how long it would be before the returns from the land showed a more gratifying indication of results actually achieved, and load actually secured to the supply system.

Skinning the hare is a very simple matter when once the animal has been caught. Applying electricity to the farm is a very simple matter when once the supply line has been run into the farm yard. That represents the crux of the whole situation, and it is only recently that the problem has been squarely tackled. There are many very excellent agricultural installations at the present time, in which the power is furnished from some independent and local generating plant. These represent excellent engineering, but do not interest the central station man, beyond possibly supplying him with data on power requirements for farm applications. He is interested only in the means for bringing this load to his supply lines—or rather for getting his lines to the isolated load; and recent N.E.L.A. publications on the matter show how deeply interested the supply companies are in the whole question of breaking loose from urban limitations, and extending their lines into the country for the benefit of the rural and farm districts. The more enterprising members have already done much in this direction, though their missionary work has frequently had to be carried out at a loss.

The pith of this editorial is after all only the statement that we hope to publish before long an article, or a series of articles, dealing fully with the matter of tapping a transmission line or a distribution feeder so as to give a supply to the isolated load, specifying and describing the substation apparatus and its arrangement for effecting a reduction from whatever primary supply is available to whatever secondary voltage is desired. It is a matter for joint working-out between central station and manufacturer, although most of the responsibility falls upon the latter, since the thing that is needed at the present time is apparatus for transformation, control and protection. The cost of whatever substation equipment is employed (using the word substation in a modified sense) must imperatively be brought down to a minimum, since the balance of profit to the supply company will be very small anyway (the solution of the whole thing is extensive farm-application, and the aggregation of small individual loads); while at the same time the equipment has to be genuinely dependable, in just as great a degree as the equipment in the power house itself, and means must be taken to secure immunity to the main transmission line or distributing feeder in the event of trouble on the farm circuit. Operating men in the past have known what they wanted, and some work has been done along this line in supplying their requirements; but the question has not really been systematically studied until comparatively recently, and a genuine attempt made to analyze the demands and standardize the "substation" equipment for meeting them. There are still many intricate matters to be decided before the manufacturer can make firm recommendations as to the equipment for every kind of duty, and to go into print on the question of costs. But this represents the first step in the catching of the hare. When that has been achieved we can confidently look to the supply companies to do the skinning; and to pick up the agricultural and other scattered loads to an extent which will really mean big business for them, and a fulfilment of the electricity-in-agriculture dream.

ICE MAKING FOR SMALL CENTRAL STATIONS

Those who direct the fortunes of electric supply systems in towns of over, say, 100,000 population are in charge of plant and methods which are becoming to a large extent standardized, and upon whose workings all the available opinion and information are in regular circulation through the various professional societies, the N.E.L.A. publications and the technical press. On the other hand the success of the small central station system depends to a far greater extent on the personal qualifications of the particular individual in charge, who is faced always by purely local conditions, who can draw comparatively little upon the opinions of others, and who, with the assistance of a comparatively small staff, must constantly be ready to find a solution to problems of widely varying nature, depending on whether they happen to relate to a burnt-out exciter, the loss of a prospect, the conciliation of an irate consumer with a faulty meter, or a selling-talk in the local paper.

Frequently, under the stress of urgent necessity, the small central station is the originator of selling schemes and publicity plans which are later eagerly taken up by its bigger brother; while the former is of course very quick at adapting for its own use any scheme which has been seen to take well in the larger towns. At the present time one of the most interesting moves for the securing of off-peak revenue, and which is being made with particular success by some of the small central stations, is the manufacture of ice by the local lighting plant. To endear itself to the central station manager such a departure should need no other claim to virtue beyond the fact that it is essentially a summer load. Many of the central-station ice-plants now in operation shut down completely for five, six and sometimes seven months in the year. Their load is therefore available at the right time, and there is never any doubt about the revenue which will be secured from this summer business. The same staff which handled the winter lighting peak can easily take care of the routine of ice manufacture, and the latter may be made to share the burden of operating, labor, office help, real estate and insurance costs. In the "Central Station Management" section of a recent issue of the *Electrical World* we noticed a wonderful collection of figures regarding the investment return which may be realized by the lighting station in towns of 1500 to 6000 population from the manufacture and sale of ice. Apparently 20 per cent on the outlay, when depreciation and all other charges have been included, represents a very low return; and the reports from several systems show that 40 and 45 per cent may easily be secured. One lighting plant in Florida, for instance, serving a community whose population does not exceed 1700, lays off $7000 for all charges and shows a net profit from the sale of mechanically-made ice of $5000 in a single season.

Some of these plants have been in operation successfully for several years; and apparently the ice-making business is going to become more and more a stable means of increasing the revenue of small lighting plants, operating in territories so thinly settled that the successful cultivation of the purely domestic electric business will continue to give the manager a somewhat anxious time. Presumably therefore the matter will become of increasing importance as a purely commercial proposition, and we have arranged to run a series of articles in the REVIEW dealing with it. Three articles, which will probably appear in our July issue of this year, will take up first the theoretical principles underlying the manufacture of artificial ice; a brief historical review of various machines which have been built and operated successfully in the past; the design of the refrigerating machines most commonly in use at the present time; a consideration of the off-peak value of the refrigeration business to the central station, where the company's supply is delivered to different users operating their own refrigerating apparatus; and a discussion of this new by-product of the central station itself to which we have already referred above, i.e., the successful operation of an ice factory in conjunction with the lighting supply plant.

SOME OF THE FUNDAMENTAL PRINCIPLES OF COMMERCIAL ENGINEERING

By W. J. Larke

Manager, Power and Mining Dept., British Thomson Houston Co., Ltd., Rugby, England

These notes on some of the elementary principles underlying the work of the commercial engineer—the representative of the manufacturer rather than the central station—were very kindly given to us by the author to serve as an introduction to a series of articles in the REVIEW dealing more specifically with the various aspects of the work. These phases, to which Mr. Larke refers in his last paragraph, receive detailed consideration in the various textbooks relating to them; and are in addition dealt with from time to time in papers before the professional societies—engineers', lawyers', patent attorneys', accountants', and so on. To follow the present paper we have already secured further articles on "The Development of New Business Outlets," "The Law of Contracts," and "The Personal Equation in Selling," the first one of which will appear in our May number.—EDITOR.

All the multifarious divisions of the science of engineering may be strictly qualified by the word "commercial," since the aim of the engineer is to direct and develop the resources of nature for the use and service of man; and, when this has been achieved as the result of the engineer's work and activity, being of value either to the community as a whole or to individual members of the community, it immediately acquires commercial value as an instrument of barter: whereby the engineer can obtain from other members of the community either those commodities which he requires, or the means of obtaining them. All engineering efforts are concentrated in the several departments into which this great science is divided, in attempting to apply commercially the discoveries which result from scientific research and practical experience.

A frequently quoted definition of an engineer, which emphasizes the commercial aspect of engineering, is: "A man who can do for one dollar what any fool can do for two"; but in this review it is proposed to consider briefly commercial engineering in a narrower sense, as the actual negotiation for the sale of the products of engineering achievement.

Assuming that the particular product which is to be exploited commercially has reached that state of development which will ensure, if properly utilized, the result claimed to be achieved, the prime factor in the success of the commercial side of engineering is the commercial engineer himself. In considering the personal qualifications necessary in connection with any position of active responsibility, the highest success is obviously only obtainable by a conscious development towards an ideal, even if the ideal itself in its complete form be impossible of attainment.

The first essential is that indefinable quality called "tact"—that intuitive sense which enables those possessing it to do and say the right thing at the right time. It is born in many, and can be acquired by others as a result of experience; and with this quality as a foundation, experience, and the cultivation of the faculties of observation, will enable the commercial engineer to acquire that knowledge of his fellow-men which is essential to success in any department of the realm of affairs. This knowledge should be a matter of conscious and deliberate acquisition: every interview with a new personality can be made to add its quota, by reviewing the interview and its result, with the knowledge of its result as a guide; and noting what different tactics or manner should have been adopted with a view to obtaining more favorable results from the person interviewed, or conveying a more favorable impression to him.

Another important and essential attribute is a sound, fundamental and practical knowledge of the subject dealt with, in order that the commercial engineer may be able to inspire confidence in the prospective purchaser, by making such recommendations or advancing such arguments as will convince the prospective purchaser of the desirability of adopting the course proposed in connection with his particular conditions. It is probable that no two sets of conditions will be found alike; and consequently the commercial engineer must be prepared to make recommendations to meet the actual conditions of each case. Only a sound, fundamental knowledge of his subject will enable him to make recommendations of an effective character. Granting the qualities of tact and knowledge of his fellow-men, the better the technical training and experience of an engineer the greater will be the measure of success of the individual in commercial engineering.

The commercial engineer should further possess a knowledge of the elements of the law of Contract and Warranty, as parts of his equipment. While, as in any other subject, the more extensive his knowledge the better, all that is really essential is sufficient to enable him to appreciate his own limitations, and to seek the aid of expert legal assistance, when necessary, before committing his employers' interests. In these days of extended and deferred terms of payment, sometimes so arranged that payment for services rendered, or plant supplied, is actually made out of the economies introduced as the result of the services rendered or plant installed, some knowledge of the law affecting the financial responsiblity of individuals connected with limited liability companies is desirable.

The function of the commercial engineer is to establish a compromise between two parties, whose interests—broadly considered—oppose one another: the purchaser, on the one hand, who wishes to obtain the benefits and advantages which the commercial engineer has to offer at the minimum expenditure to himself; and the employer of the commercial engineer, on the other, who desires to dispose of those same advantages at the maximum price obtainable. The commercial engineer has achieved real success only when *both* parties to the compromise are satisfied. Thus, credit seldom pertains to the negotiation of a contract on the basis of the lowest price quoted: the purchaser in such a case is only following his natural inclination. But the successful negotiation of a contract on the basis of a price higher than the lowest quoted to the same specification, and for apparently similar advantages, proves that the commercial engineer, by the tactful use of his more expert knowledge of the subject with which he is dealing, has been able to convince the purchaser that, even at the higher price, he is best served by adopting the scheme commended to him.

It is too often considered that the functions of a commercial engineer begin and end with the successful negotiation of a contract. This is a serious fallacy; and belief in it is the cause of the comparative rarity of the really efficient and effective commercial engineer, whose function it should be to build up such a connection that his business is established on a sure and certain foundation. It may be said, with truth, that the negotiation of a contract with a new purchaser is really only the commencement of the commercial engineer's relationship with that particular business. During the progress of the execution of a contract, he should automatically maintain and develop the relations he established with the purchaser when negotiating the contract. He should be ever ready, during the progress of the contract, to step in where necessary and exercise his influence in the interests of smooth working, where, through misunderstanding or other causes, liability to friction arises. It should always be remembered that friction is more readily prevented than cured. This does not involve constant attention on the part of the commercial engineer during the execution of a contract; but he should evince interest in the progress of the contract by giving the purchaser an opportunity occasionally of expressing any views or criticisms he may have on the progress of the work, and give no cause for the impression that he (the purchaser) was worthy of attention only so long as he had business to place. Whether the purchaser is likely to have further business to place in the future, or not, should have no bearing on the amount of attention he receives from the commercial engineer. The best foundation for the development of a business is the testimony and goodwill of a satisfied purchaser.

Further, as the representative of his employer it is not the least responsible of the functions of the commercial engineer to obtain payment for services rendered when payment becomes due. In fact, in the relationship which has been considered above, the commercial engineer is the supplier's ambassador to the purchaser; and although, at the outset of the negotiations, he must realize that "the vendor is the courtier and the purchaser the King," at the same time he must remember that his functions are not concluded until the transaction is completed to the satisfaction of both his employer and the purchaser. It is true, except for the occasional attention suggested, that after the business has been negotiated his assistance will be requested by those engaged in carrying out the contract only when it is required; but whenever such requests *are* made, he should realize that the situation necessitating such a request is serious and important, and demands his immediate and personal attention. No claims, real or fancied, of business in process of negotiation, should be allowed to endanger the good-will that should result from business secured, by lack of the attention the latter demands at such a critical stage; since a dissatisfied purchaser is a permanent menace to the development of that reputation on which all business connection must be founded to endure: better a purchaser lost than one obtained only to be dissatisfied. There is no reason, however, why the claims of both the actual and the prospective purchasers referred to cannot be met by the commercial engineer who studies the fundamental principles on which his work must be based. When in the condition stated, if the claims of either are neglected, it is the result simply of bad judgment; the reasoning being that as one purchaser is secured already and cannot be lost, the prospective purchaser should receive *first* attention until he is secured. This is wrong. Both should receive equal attention. No commercial engineer can consider himself successful if a purchaser ever has grounds for the criticism: "When we *had* an order to place you gave us every attention; now you have the order and we are having trouble we never see you."

It is a cardinal principle of diplomacy never to allow anyone who feels aggrieved to remain so; but *immediately* such feeling is known to seek an interview with a view to removing irritation or misunderstanding; thus preventing a trifle, readily adjusted at the outset, from becoming a source of irritation or rancour, impossible to adjust. Diplomacy is the soul of business. Thus, with many possibilities of misunderstanding and irritation arising from the manifold details of an engineering contract, the commercial engineer must be on the alert to see that none is left to rankle, but that all are adjusted immediately they arise. In adjusting such differences, a full, frank, but equitable recognition of the rights of both parties must be insisted upon with firmness and courtesy; as the representative who placates an unreasonable purchaser by acceding to unjust demands, not only betrays his employer's interests, but loses the respect of the purchaser for doing it. This does not preclude an honorable compromise in matters where each side has reasonable grounds on which to base its arguments for its point of view. Finally it must be remembered that "the proper study of Mankind is Man," for success depends on convincing others that success has been attained.

It is hoped that this brief survey of the elementary principles underlying the work of the commercial engineer may serve as an introduction to the more detailed consideration of various aspects of the work, which ranges so widely over the field of affairs on the one hand, and the technology of the particular branch of engineering considered, on the other.

HIGH TENSION INSULATOR TESTS: A STUDY OF DESIGN FACTORS

By F. F. Brand

Transformer Engineering Department, General Electric Company

The commercial testing of insulators resolves itself principally into a determination of the arc-over or puncture voltage under wet and dry conditions of service. The first part of this article comments on the proper manner in which to conduct such tests, attention being called to certain influencing factors and to precautions that are necessary for successful results. The design of insulators is mainly concerned with the question of the distribution of potential, or the potential gradient, over the several parts of the insulator; and data, to be of value in design should be chiefly of such a character. The greater part of the article is consequently given to a discussion of the potential gradient on two of the common forms of insulators, the pin and suspension types. Additional information on this subject will be found in an article by Mr. F. W. Peek, which appeared in our June, 1912, issue.—Editor.

The testing of insulators should be conducted with great care if reliable results are to be obtained, since the high voltages involved make it necessary to consider a great many apparently trivial points, such as, for instance, the proximity of grounded bodies. The only correct way to test insulators, or in fact almost any kind of apparatus, is under operating conditions, or conditions approximating them as nearly as possible. Almost all insulators are used between line and ground; and therefore the connections of the testing system (shown in Fig. 1), in which one high tension terminal of the testing transformer is grounded, are most suitable.

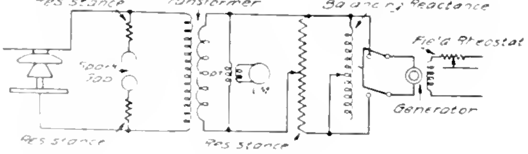

Fig. 1 Diagram of Connections for Testing Insulators

In this article it is proposed first to enumerate the usual tests and outline the best method of making them before speaking of the design of insulators and the results which can be expected from various types.

Method of Support of the Insulator During Test

The insulator should be supported as nearly as possible as in service. Normally the top of the insulator string should be grounded in suspension type and the pin in pin-type insulators. Tests should therefore be made with one terminal of the testing transformer grounded, as stated above. The insulator should be supported by apparatus of approximately the same size as the service cross arm. The voltage should be applied to a conductor of the same size as the line conductor, of a length sufficient to prevent concentration of stress on the ends from affecting the test. The line should be made fast to the insulators by the regular service clamps or tie wires. The insulator should not approach closely to any large bodies; and, in a string of suspension insulators, the line should probably not be closer than twice the length of the insulator string from the ground surface.

Standard Tests

Two standard tests, wet and dry, are usually made for reasons to be explained later. These tests should be made at the operating frequency, although for commercial tests a frequency of 60 cycles is usually chosen, as the variation between this and other operating frequencies is small.

Capacity of Testing Transformer and Generator

These should be large enough to give a fairly heavy dynamic arc and to prevent very great distortion of wave shape; also, to prevent the regulation of the testing system being changed by the insulator load, particularly in the wet test where the variation in leakage current is very great. In general, a transformer with a normal rating of 0.5 to 1 ampere high tension winding, with a generator of equal rating to the transformer, is sufficient.

Determination of Voltage

This should be arrived at by a device which indicates the maximum of the voltage wave, such as a spark gap, preferably of the sphere type. The ratio of the transformer should be checked against the spark gap when connected to the insulators, and this ratio used as a final means of determining the voltage. It is necessary to connect sufficient non-inductive resistance in series with the spark gap to limit the flow of current when the gap breaks to a value of ½ to 2 amperes. This prevents the occurrence of high frequency oscillations which would otherwise be caused by the discharge across the spark gap of the electrostatic capacity current of the system through the inductance of the circuit. The readings of the spark gap should be corrected for barometric pressure and temperature.

Method of Regulating the Voltage

The source of supply should be one which gives a smooth voltage curve or a change of voltage in very small steps, and should avoid distortion of the wave shape. The potentiometer method is undoubtedly the best, i.e. with series and shunt resistance. The shunt resistance should be large enough to carry from five to ten times the exciting current of the transformer. These resistances also tend to damp out disturbances when an arc-over occurs.

If the testing transformer takes a leading current when connected to the test load, a shunt reactance can be used to advantage to balance this leading current, the reactance being adjusted to give unity power-factor on the generator, under which condition the generator wave shape is usually less distorted. In large power outfits the potentiometer method is both bulky and wasteful of power; while a method using generator field control within small limits, and a multiple circuit generator or low tension winding on the testing transformer, is satisfactory.

Effect of Frequency

As stated before, commercial tests are usually made at one frequency, generally 60 cycles. High frequency tests are design tests and should be made only on a few sample insulators, or a small percentage of the total number. The impulse test described later is probably more definite than the sustained oscillations produced by an oscillation circuit, in which the maximum voltage is unknown, and it also more nearly represents lightning disturbances on the line. Further, a sustained high frequency is probably unfair to the insulator, by reason of the heating of the dielectric which it may produce.

Wet Tests

The wet tests are very important, as under normal line conditions the arc-over voltage of an insulator is usually much lower when wet than when dry. The amount, direction and resistance of the rain water are factors which govern the operation of the wet insulators. Two conditions of rain are required for a general wet test, depending on the climate in which the insulators are used. One is precipitation in large drops, as in a thunderstorm; the other is more nearly a mist. A precipitation of 0.5 inch per minute for the large drops, and about 0.25 to 0.3 inch per minute for the mist, gives severe enough results, as this is greater than is practically ever observed in operation. In order to wet the underside of the insulator the rain is usually directed at 45 deg. to the horizontal. In suspension insulators the underside of the insulator is wet by splashing from other units and from the line wire and clamps, and in pin type insulators by splashing from the lower parts and the cross arm. The mist can be readily produced by sprays in which compressed air is used to atomize the water, the mist in this way being blown up under a shallow petticoat. In strain insulators, which are strung nearly horizontal, the most severe condition is given by directing the rain at 45 deg. to the side of the insulator which has the greater creeping distance. The specific resistance of the water has a great effect, as it directly affects the resistance of the leakage path over the insulator, and in strings of suspension insulators has a marked effect on the distribution of potential over each unit in the string. In general, water with a fairly high specific resistance should be used to approximate rain conditions.

Corona

Insulators should certainly show no corona at normal operating voltage; and the best insulator would be one which did not show corona until the arc-over point was very nearly reached, since such insulator would be less likely to be disrupted by sudden impulses of potential which might rise to a high value before corona could form.

Puncture Test

All insulators are designed with sufficient strength of dielectric to avoid puncture at normal frequency before they arc over in air. For this reason a punctured insulator is

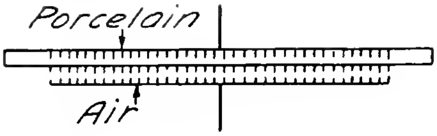

Fig. 2. Illustrating Difference in Potential Gradient

much more serious on a transmission line than one which arcs over, since the arcing can be suppressed by any device which lowers the potential of the line to ground, such as by cutting off the voltage or grounding the faulty line temporarily in the manner of the arcing ground suppressor. To puncture an insulator we must immerse it in a medium having a greater dielectric strength than air. Usually oil is used for this purpose, although this does not give exactly the same distribution of stress, since the specific capacity of the oil is higher than air. The shape of the electrodes has a great effect when in oil, and care must be used to get the same conditions as exist in practice. In this respect suspension units are ideal, as the cemented head and pin form the service connections.

Effect of Altitude

The voltage at which corona and arc-over occur on insulators varies with the altitude. Over small variations it appears to follow

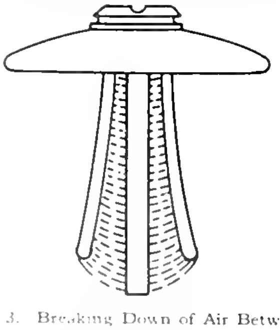

Fig. 3. Breaking Down of Air Between Insulator and Pin

the law of corona, which can be corrected according to the formula:

$$k = \frac{3.92B}{273+t}$$

where B=barometric pressure in cm. of mercury, and t=temperature in deg. C. K is the constant by which the corona voltage corresponding to $B=76$ cm. and $t=25$ deg. C. is to be multipled. In other words, the corona and arc-over voltage vary as the density of the air.

FACTORS GOVERNING THE DESIGN OF INSULATORS

The design of insulators chiefly resolves itself into a study of the potential gradient over each part of the insulator, as practically every insulator fails due to an excessive potential across one part, causing that part to fail before the rest of the insulator. The failure of the insulator as a whole is usually a kind of cascade action, the failure of the first part causing over-stressing of another part which then fails, this being continued over the whole insulator. Failure can either take place by puncture, showing overstress of the material of which the insulator is composed, or by arc-over, showing overstress of the air immediately surrounding that part.

Let us consider what happens when we apply a potential stress to a dielectric. The application of voltage produces in the dielectric a condition of electrostatic or dielectric stress, and a dielectric field which can be considered as analogous to a magnetic field, the lines of field being similar to lines of magnetic flux in the field. The stress is proportional to the voltage, and the dielectric field or flux is proportional to the area of the dielectric and to a constant of the material known as the specific capacity or permittivity.

If we connect two unequal resistances in series and apply voltage the drop of potential will be greater across the greater resistance,

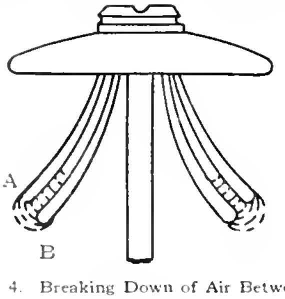

Fig. 4. Breaking Down of Air Between Sections of Insulator

or we might say the potential gradient will be steeper across the greater resistance. Similarly if we connect two unequal condensers in series and apply voltage the voltage drop will be greater across the one having less susceptance, i.e., the one with the smaller capacity. If we assume these condensers to have equal area but to contain dielectrics having different specific capacities, the voltage drop will be greater across the one having less specific capacity.

Referring to Fig. 2, it can be seen that if we have a layer of air and a layer of porcelain between two parallel plate electrodes, the dielectric field will be uniform between the electrodes; but the potential gradient will be steeper across the air than across the porcelain, as porcelain has a specific capacity about five times that of air. Now air breaks down at a potential gradient of about 30 kv. per cm., porcelain much higher; so that, by raising the voltage to a potential gradient of 30 kv. per cm. on the air, i.e. the breakdown point, the gradient across the porcelain will be about one-fifth of this, and it will be possible to break down the air long before the porcelain breaks down.

Apply this reasoning to insulators. If we have a porcelain petticoat very close to the pin (as in Fig. 3) we can break down the air, causing an arc from the petticoat to the pin; or if we have two long porcelain petticoats close together (as in Fig. 4) we can break down the air, thus cutting out the long creepage path from *A* to *B*. Referring to Fig. 5, if we apply potential between a small surface and a large surface, the density of the electrostatic field will be greatest at the small surface; and thus the potential gradient will be steeper and the dielectric will be overstressed at that point first, if we raise the potential sufficiently. Therefore the pin in an insulator should be large to avoid concentration of stress on the dielectric next to it, and the thickness of the dielectric fairly great to avoid puncture through the head.

Owing to the fact that, under the wet test, outer surfaces of the insulator are rendered partially conducting, it is necessary to have

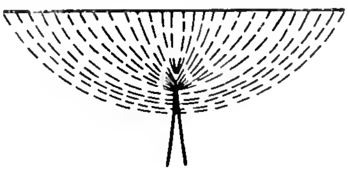

Fig. 5. Concentration of Electrostatic Field at Small Surface

a sufficient number of deep dry corrugations or petticoats in order to avoid the potential stress per cm. length of dry surface being too great, overstressing the air layer adjacent to it. Porcelain can not be properly vitrified in very thick pieces. For this reason, in order to get a sufficient thickness of dielectric in the head and to provide a sufficient number of dry surfaces that can be readily manufactured, pin type insulators for high voltage consist

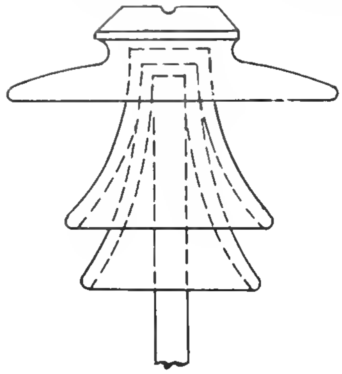

Fig. 6. Three-Part Pin Insulator

of a number of shells cemented together and to the pin, as shown in Fig. 6. In order to avoid arc-overs between the edges of the successive petticoats where the stress is more concentrated they are separated as widely as possible, and in some cases are made alternately of large and small diameter, so as to stagger the edges and increase the distance between them. The top shell, usually known as the "umbrella," is made large in order to shed the rain from the lower shell as much as possible. In some insulators designed for extremely high voltage this is done on two of the shells, as shown in Fig. 7.

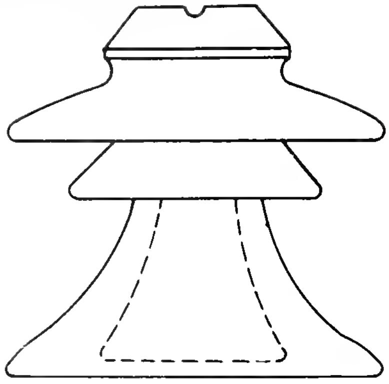

Fig. 7. Double "Umbrella" Design

The limits of potential for the pin type insulators come at about 60,000 volts. Above this the factor of safety is not great unless the insulator is made very bulky and expensive. The invention of the suspension insulator, however, allows us to carry transmission potentials up to a point where other features, such as corona or the insulation of

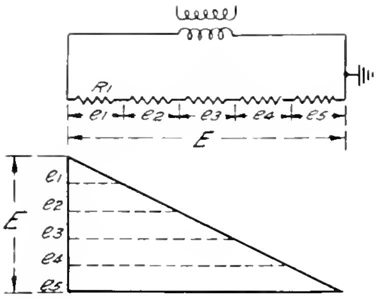

Fig. 8

other apparatus, become the dominating factors. In the suspension insulator we

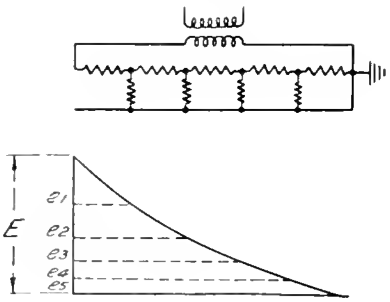

Fig. 9

break the potential up into a number of successive definite steps, and this potential is

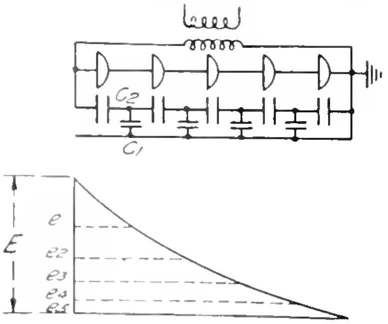

Fig 10

applied in a similar manner in each unit. It might be thought, then, that if we design a unit for, say 80,000 volts, five units in series should withstand 400,000 volts. This, however, is not the case, as the distribution of potential is not uniform over the whole string.

Referring to Fig. 8, if we have a number of equal resistances in series and apply a potential across them from one end to ground, the fall of potential is in an equal number of steps, and we can draw a curve of potential drop as shown. Now, if we connect to the junction of each resistance another resistance to ground (Fig. 9), the first resistance will not only carry the current due to the number in series, but also the currents carried by the shunt resistances. Similarly, the second series resistance will carry the "series" current and the current for the shunt resistance between it and ground, which is less than that carried by the first resistance. Thus we shall obtain a potential drop curve as shown.

In the same manner, each unit of a suspension insulator consists of a capacity which is in series with the capacity of the other units; and in addition, the surfaces of the insulators and the connecting links have each a capacity to ground. As in the case of the series and shunt resistances, therefore, the unit nearest the line will not only have to carry the capacity current, due to the insulators in series, but also the current due to all the shunt capacities to ground. We shall, therefore, have a curve of potential drop of the kind shown in Fig. 10, which will be similar to that shown in Fig. 9, in which the potential drop across the unit next the line is greater than across the others. When we raise the potential sufficiently on the whole string of insulators, we shall reach a point where the potential across the first unit is sufficient to cause it to fail—usually to arc-over. This failure then throws the potential on the next unit, which will also fail; and thus the whole string will fail, due to a cascade action. It can be readily seen that the greater the shunt capacity, and therefore the shunt current, as compared with the series capacity and current, the more concentrated will be the potential across the line unit and therefore the lower will be the voltage at which the whole string will fail; also, the greater the number of units, the more will be the concentration of potential on the line unit at arc-over.

If we call the shunt capacity of each unit C_1, and the series capacity C_2, we can see that the greater $\frac{C_2}{C_1}$ the more nearly will E, the voltage required to arc the string over, equal $n \times e$, where e = voltage to arc over one unit and n = number of units. The ratio $\frac{E}{n \times e}$ is called the string efficiency.

In this connection it can be shown that the arc-over voltage of a string of insulators, tested with one terminal grounded, is very different from the value obtained with the neutral of the testing system grounded. With the neutral grounded the number of units from line to ground is one-half that of the total string, and the potential from the line unit to ground is one-half the line voltage, so that the shunt capacity is much less, and the potential balance over the string is much better. Thus we get a higher arc-over voltage than the arc-over under operating conditions.

Fig. 11 gives a set of curves showing the arcing voltage of various numbers of units with various ratios of $\frac{C_2}{C_1}$; while Fig. 12 shows the relation of string efficiency to number of units for various ratios of $\frac{C_2}{C_1}$. It will be noticed that if $\frac{C_2}{C_1}$ is small, it is useless to use more than three or four units. Fig. 13 shows the fall of potential across the various units for the extreme ratios of $\frac{C_2}{C_1} = 2$ and $\frac{C_2}{C_1} = 50$.

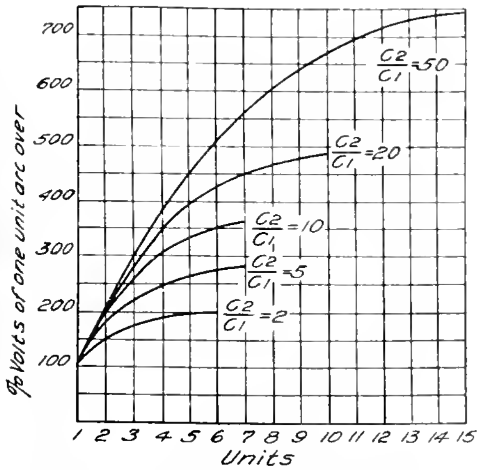

Fig. 11. Arc-over Voltage for Various Numbers of Disc Units for Various Values of $\frac{C_2}{C_1}$

This shows how very much more evenly the potential is distributed when the ratio $\frac{C_2}{C_1}$ is large.

In practice the arc-over tests are slightly higher than would appear from the calculations, owing to the fact that there is, in addition to the series capacity current, a leakage current and a displacement current due to dielectric hysteresis; these, however, being very small. A greater variation in arc-over voltage is caused by corona, which appears around the metal parts, giving an effective increase of electrode and thus a greater series capacity. This, however, usually does not appear at operating voltage. There is also a change of potential balance caused by

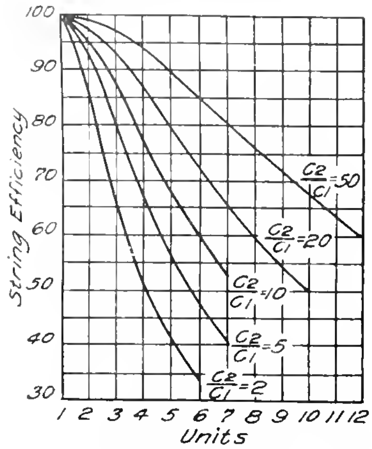

Fig. 12. String Efficiency of Various Numbers of Units for Various Values of $\frac{C_2}{C_1}$

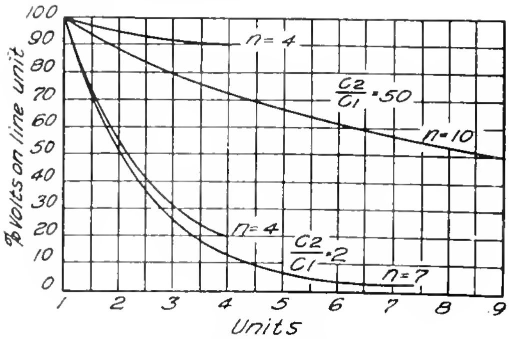

Fig. 13. Fall of Potential Across Individual Units for Values of $\frac{C_2}{C_1} = 2$ and $\frac{C_2}{C_1} = 50$

the fact that the clamp and line wire have some capacity to the next units, thus increasing the effective capacity of the line unit, and lowering the potential across this unit. This usually increases the arc-over voltage of the string.

The potential balance in a long string of insulators can usually be much improved by employing for the units nearest to the line insulators having a much greater capacity than the remainder, or in other words, by grading the capacity.

Wet Tests

The operation of suspension insulators under rain conditions shows considerable difference from operation on dry test, as the leakage current over the insulators adds itself in quadrature to the series capacity current; and, by decreasing the effect of the shunt capacity current, gives a better balance of potential over the string, so that E is more nearly equal to $n \times e$. This is illustrated in Fig. 14, which shows the difference caused by high and low resistance rain. Thus, with certain ratios of $\frac{C_2}{C_1}$, the wet arc-over may be higher than for the dry test, when a certain number of units is used.

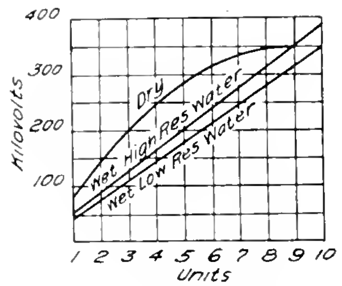

Fig. 14. Effect of Rain on Potential Balance of String

Operation of Insulators under Lightning and High Frequency Stresses

When a lightning disturbance appears on a transmission line, either by an induced charge which is suddenly released, or by a direct stroke, the disturbance usually appears as a travelling wave with a very steep front, and may die out without oscillations; or it may oscillate due to reflection from the end of the line, with a frequency depending on the constants of the line (capacity and inductance), the duration of the oscillation depending on the dissipation of energy by the line.

Very similar conditions can be produced by causing the discharge of a condenser, charged at a high voltage, to take place through an inductance across a spark gap which is in series with the insulator (as shown in Fig. 15). Consider the moment before the gap breaks: The capacity of the insulator is large compared to the capacity of the long series gap, and the fall of potential is much greater over the gap than over the insulator, the top of the insulator being practically at zero potential. At the moment the gap breaks the insulator top is thus raised suddenly to almost the potential of the line. All dielectrics appear to possess two qualities, that of capacity and that of resistance; and whether the resistance can be considered as in series or in multiple with the capacity, or both, is a point which we do not at present know. If we consider the resistance as being in series with the capacity, then at a low frequency an impressed voltage is chiefly consumed in forcing current through the capacity. As we raise the frequency the potential drop across the capacity decreases and that across the resistance increases, until, at extremely high frequency, practically the whole potential drop is across the resistance. It is thus possible that the distribution of potential is radically different at high frequencies, so that it may be possible to overstress part of the dielectric and cause failure. Moreover, the long leakage paths around the insulator have an appreciable inductance, so that the potential is not instantly propagated over the insulator surface.

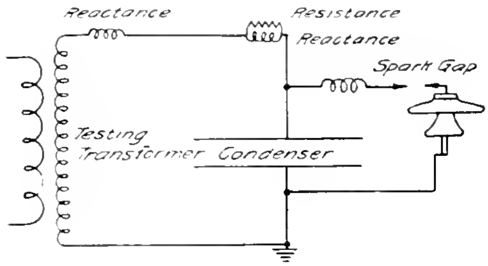

Fig. 15. Diagram of Connections of Apparatus for Reproducing Lightning Effects

Air breaks down at 30 kv. per cm. by corona, and it is known that corona takes an appreciable time to form, so that the air does not break down the instant the potential is applied. Thus, if a sudden rise of potential occurred, the dielectric might be punctured before the air around the insulator broke down, even if the dielectric normally required more energy to break it down; and, if there is a different distribution of stress at high frequency, the dielectric might break at a lower voltage than that at which it would puncture at normal frequency. As already stated, failure of a homogeneous dielectric at one point is usually followed by a total failure by cascade action; and thus, although the insulator may not be punctured completely by one impulse, successive impulses may in time cause complete failure.

Under rain conditions the water resistance may form a shunt resistance path around the insulator which may lower the potential sufficiently to prevent puncture at the arcing voltage.

A string of suspension insulators when subjected to a high frequency oscillation may act in a radically different manner from that exhibited when tested at normal frequency. If the potential balance over the string depends to any extent on leakage current, this would be obliterated at high frequency by the larger current through both the shunt and mutual capacity, and thus the voltage necessary to arc-over the string would decrease. Also, if the potential balance is dependent to any extent on corona formation, a sudden application of voltage, as by a wave with a steep front, will cause the potential to rise to a high value before corona forms, and thus the distribution of potential will not be the same. Furthermore, the links connecting the units have an inductance which is not negligible; and, as the frequency increases, the voltage drop across this inductance increases by the frequency *times* the increased capacity current through the insulators to ground. This voltage is in opposition to the voltage across the insulators; and thus the sum of the voltages across the insulators no longer equals the total voltage across the string, but is higher, thus causing the insulators to arc-over at a less total voltage across the string. With a very sudden rise of voltage it is probable that practically the whole of this voltage is concentrated across the line unit thus tending to puncture it.

Consideration of these facts makes the question of puncture voltage with reference to arc-over voltage very important, and the higher the ratio of these two voltages the better. It would appear that an insulator should withstand a voltage which would break down the surrounding air without corona, in order to withstand lightning discharges. An idea of the relative efficiency of insulators could possibly be arrived at by a comparison of the voltages at which they puncture or arc-over in oil, although the distribution of potential is possibly very different from that in air, particularly at high frequency.

NOTE—For a more complete treatment of suspension insulators, reference may be made to a paper by F. W. Peek, Jr., (*Proceedings* of the A. I. E. E. May, 1912,) to whom the author is indebted for some of the information given above.

ECONOMIES IN RAILWAY MOTOR MAINTENANCE

By J. C. Thirlwall

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The experience of railway companies shows that, for economical motor maintenance, prevention is cheaper than cure. To prevent trouble the first essential is regular inspection. The author of this article cites an instance to show the saving in dollars and cents which can be effected thereby; and touches on the various points which such inspection should cover, according considerable space to a discussion of oiling. A similar example shows the desirability of careful selection and treatment of the brushes for the particular service in hand; while the latter part of the article takes up the duties of the overhauling shop, and lays down rules which, in the opinion of the operating companies, should be followed in the periodical overhauling of the motors and their various parts. The substance of this paper was originally delivered by the author as a lecture before the Central Electric Railway Association in convention at Indianapolis, Ind.—Editor

In a discussion of this subject, it would be well, perhaps, to commence with a summary of what constitute the costs of maintenance for railway motor equipments. In the case of comparatively new installations there should be, and usually are, few repairs necessary; and the maintenance cost consists of only the labor charge for inspection and cleaning, with a small material expense for lubrication and brushes. In older equipments, particularly those put into service more than five years ago, the bulk of the charges is almost invariably for repairs and renewals of different parts. To reduce these charges to the lowest possible figure is, of course, the object of every car shop; but great differences of practice and of results exist on different systems, and some roads have been able to secure far greater efficiency and at a considerably less cost per car mile or motor mile than others. Often this is due to local differences in operating conditions of service; but in many other instances it has been effected by more scientific and efficient methods of maintenance than is the common practice. It is the economies made possible by such methods that the writer wishes to briefly discuss.

Every railway executive and every shop foreman wishes to maintain his equipment in good condition and at the least expense, but some roads attempt to reduce costs from the wrong standpoint. To cite an instance, a case occurs to me where a considerable number of new motors were recently put into service in one of our large cities. The shopmen on that road, acting upon the assumption that, since the motors were new and contained many improvements in design over the older types in service on their lines, they should require no attention at all, left them severely alone until a sudden epidemic of flashovers, grounded armatures and brush-holders broke out. When the manufacturers were called upon to explain the cause for the surprisingly large amount of trouble on motors scarcely a year old, it was discovered that the commutator covers were rusted fast to the shells, none having been opened in that period. The actual costs prior to the trouble stage had been at the very satisfactory figure of zero, omitting some slight charges for oiling the bearings; but when the repairs had been completed, and their charges totalled, the average cost for the year was found to be high—very high in fact.

This is not economy. The old adage, "An ounce of prevention is worth a pound of cure" holds very true in regard to railway equipment; and I believe that an efficient and regular inspection of motors is the prime factor of economical maintenance. This is true not only in respect to the dollars and cents that can be actually saved in operating costs, but in the increased efficiency of service resulting from the reduction of delays, "run-ins" and "hold-ins"; and in the elimination of complaints and the dissatisfaction or irritation of the travelling public produced by such conditions, which inevitably result in financial loss to the operating company, directly or indirectly.

And a first class system of inspection need not be expensive, either in total, or figured in cents per motor mile. Modern motors, equipped with auxiliary oil-wells, should run under ordinary conditions at least 1500 miles between armature bearing oilings, which in ordinary city service would bring them in to the shop only about twice a month, and on heavy interurban service possibly once a week. The regular oiling of bearings is, of course, an essential, and in most cases the cars are in the shop when this is done. At such times, it is a matter of but a few minutes work for one man to remove the commutator cover; to wipe off the inside of the shell, the commutator and the brush-holder insulators with dry cheesecloth; to examine the brushes for wear or breakage; and to make certain that the hammer spring tension is what it should be. The ordinary workman should be able to make this inspection on four-motor equipments in average condition within a half-hour. The cost per motor mile of such inspection is almost negligible, amounting to less than one dollar per motor per year under the heaviest service; and the reduction in repair bills will on an average offset this many times over each year for every motor in service.

In the case of the old non-interpole motors, without auxiliary oil-wells, the charge will be larger, both because more frequent oilings are necessary, and because more should be done to the motor itself at such periods. On account of their increased tendency toward heavy flashovers, every precaution should be taken to reduce the number of such defects and to minimize their effects and severity. To do this successfully, we must have a clear idea as to their cause. In nearly every case, a flashover is the direct result of heavy sparking or flashing between the commutator and brushes, or between the brushes and brush-holder, caused by poor contact or poor commutation. This generates a gas, which fills the air space between the commutator or the brush-holder and the nearest exposed portion of the shell or the bare commutator "V" ring. Across this gas-filled space current carries, setting up an arc which may go across to the shell or to the "V" ring, or from the positive to the negative brush-holder. In either case, it must go to some uninsulated part of lower potential before it can carry over sufficient current to do any damage.

The complete prevention of sparking under the brushes, in the case of non-interpole motors, and especially where the commutators are not slotted, is impossible. But to prevent this sparking from developing into severe "flashovers," in the commonly accepted sense of the term, is possible by the complete insulation of all exposed parts on which an arc might find a "ground." For all practical purposes such an insulation can be provided by repeated applications of insulating paint or varnish, using a small amount of gasolene for a dryer. This latter point is an essential, as the paint must be dry before the car leaves the inspection pit. The paint should be applied to the entire inner surface of the shell that can be reached through the commutator end openings, top and bottom. It may be said that at least fifty coats should be applied consecutively at each inspection on classes of motors that have bad flashover records; and it is important that, before applying each coat, the surface be carefully wiped clean with a dry cloth, an especially thorough job being done where there are any traces of oil on the shell interior. This should be supplemented by the liberal use of shellac upon the commutator string band and "V" ring, and upon the brush-holder bodies where they extend closest to the shell. Care must be taken, of course, to see that neither paint nor shellac gets upon the commutator or brushes, and in every case the inspector should finish by carefully wiping off both. The use of compressed air for blowing out the entire interior of the motor, after removing the bottom handhole plate, is also excellent practice where the shop has facilities for such cleanings; and where this is done it should in every case precede all painting or shellacking, and be the first step of the inspector's work. Particular attention should be paid to having uniform brush tension on all motors for particular service; and inspectors should be provided with small spring balances with which they can make frequent tests to see that the standard is adhered to.

All this sounds like a lot of work; but as a matter of actual fact there are shops in which these points are being daily covered and where one man averages four motors per hour, the cost for labor and material together averaging approximately $2.50 per year per motor, making approximately 40,000 miles per year.

The economy effected by this system of maintenance is easily illustrated by an actual case. The motors in question had been in service from eight to eleven years. For at least two years they averaged four flashovers per motor per year, each of these flashovers being serious enough to cause trouble reports to be turned in by motormen. Grounded and short-circuited armatures averaged two per year per motor. A fair annual cost figure for repairs was approximately $50.00 per motor. One year after the commencement of the methods I have mentioned, the flash-overs had decreased by nearly 90 per cent. The number of armatures removed and sent to the armature room for repairs had decreased 70 per cent; and the repair bills for the entire year following showed a nearly proportional decrease, averaging only about $20.00 per motor, including the cost of bearing renewals. In other words, an annual cost of $30.00 per motor was saved by an increased expenditure on inspection of about $1.00 per motor—a very good return on the investment. It is true that other factors contributed toward this result, but they were for the most part refinements of existing methods that entailed no increase in the maintenance force.

It is well known, for instance, that in all of the older types of motors a considerable part of their defects, in particular grounding of coils or of brush-holders, and short-circuited commutators, are caused by oil from the bearings working along the shaft into the motor, where it is spattered over the entire interior. Here it not only causes rapid deterioration of the coil insulation, but facilitates the accumulation of brake shoe and carbon dust on the brush-holder insulators, on the commutator string band, and between commutator segments. To keep oil from the interior of the shell has been one of the most serious problems of the designing engineer, and great improvements in this respect have been made in motors produced during the past few years. On the older types the design is such that any great surplus of oil passing through the bearings above that actually required for proper lubrication is certain to enter the motor in greater or less quantities. To restrict this to the least possible amount, it is essential that the minimum amount of oil should be carried in the wells, consistent with the protection of hot bearings. A shop foreman can make no better use of a portion of his time than in determining what this minimum shall be, and in educating his oiler to the stage where he will use the specified amount at each oiling—no more and no less.

The greatest care should be given the commutator end bearing. Experience and common sense show that the work done and the heat produced at the commutator end armature bearing are much less than at the pinion end, and therefore less oil is required for proper lubrication. In general, it is safe to say that this amount should be approximately three-fifths of that necessary for the pinion end. On motors having auxiliary wells, where the actual level can be measured, the oil level can be carried fully an inch lower. On the older types, a specified amount must be periodically added; and the oiler should be provided with measures holding the exact quantities determined by the foreman, to ensure his applying the correct amount at each end. The motor inspector should closely watch for signs of oil inside the motor, and should call attention to the fact when he finds one in this condition; any great number of motors so reported will be a fair indication that too much oil is being added to the bearings. The reduction of the amount used will not only decrease the lubrication bill, but the cost of motor repairs as well, the latter to a very striking degree.

The prevention of hot bearings, or of damage caused by worn bearings, is by no means solely dependent on the amount of oil used. The fit of bearings, the alignment of the motor, and the proper meshing of gear and pinion are all points that enter into the problem. The proper preparation of the waste, where such is used, the grade of felt used in feeders, or the adjustment of the feed on oil-cups and their cleanliness, are points that demand careful study and attention. The actual amount of oil required for proper lubrication of any bearing is almost infinitesimal, provided that the amount can be distributed over the entire surface of the bearing, and also that the bearing and shaft have no high spots. The question of lubrication is such a broad one, and local conditions vary so widely that no rules can be formulated that will cover all its details; but I firmly believe that it will well repay every Master Mechanic to make a thorough study of the subject on his own particular equipments, and to work along the lines indicated above, bearing in mind that by keeping the interior of the motors dry he will materially reduce serious motor defects.

Another point on which great economies are often possible is in the selection and care of the brushes. This again is a point on which general rules are impossible. A brush that gives excellent service in a certain type of motor on one road, or on a particular line, will be found to wear far more rapidly or to break much more freely on another line even in the same motor. The latter, perhaps, is the more frequent occurrence; and, when any considerable number of chipped or broken brushes are found, it will pay to experiment with other grades or different makes until the brush best suited to that particular service is found. In an instance that came under my notice some two years ago, the brush bill for one hundred two-motor cars operating in an eastern city was reduced from $4000.00 a year to about $400.00, a saving of 90 per cent, by changing from a brush that was giving very satisfactory results in all other motors on the system, but which, in this particular series of cars, was averaging only about six weeks life, due to breakage. This is probably an extreme case, but similar results even on a smaller scale are well worth seeking.

And now we come to the overhauling shop. No matter how efficient the inspection is made, it should be supplemented by removing the motors from the trucks, opening them up and placing all parts in the most perfect operating condition at regular intervals, if the best results both in point of service and of costs are to be obtained. The factor determining these intervals, or the time between such overhaulings, should be the condition of the bearings. If conditions are such that armature clearance can be gauged at each inspection, it should be possible to catch all motors on which bearing wear is excessive before the armatures touch the pole pieces. If, by reason of rough track conditions, frequent breakage of babbitt occurs in the shells, a definite time limit should be set, which should be somewhat less than the average time that bearings which have given trouble have been running since they were installed. In other words, bearing troubles should be anticipated, and the motors opened up with sufficient frequency to enable the shop force to maintain the bearings in the very best possible condition; and, when the motors are opened up for this purpose, a thorough job of cleaning and reinsulating all parts should be done, so that they may return to service in the most nearly perfect operating condition possible.

The chief points which the experience of different companies show that it is essential to cover are the following: The armatures should be blown out very thoroughly with compressed air; and it is preferable that this should be done inside a suction box, so that the dust and dirt displaced shall not fill the air of the shop, or be allowed to settle on freshly painted or shellacked motor parts which may be in the vicinity. If no suction box is available, the blowing should be done at a considerable distance from the place where the balance of the work on the motors is carried on. Following this blowing, the oil collars should be scraped free of all caked dirt and carefully wiped off with dry waste. The string or tape band over the mica ring should be removed, the mica ring and "V" ring heavily shellacked, and a new tape band installed. This should be wide enough to overlap the "V" ring by about one-eighth inch, thus insulating it from possible flashes. The tape band and adjacent upright section of the commutator should then be given a thick coat of shellac, or of insulating paint. If this is done, and if oil can be kept from the band thus prepared, it is certain that grounds at the end of commutators through the mica insulation can be absolutely eliminated, since a smooth, glazed surface impervious to moisture is presented, which can be wiped clean of dust with a dry cloth at each inspection, thus keeping it in perfect condition.

The commutator slots should be cleaned out with a scraper, or, preferably, a metal brush, and all beading which might tend to short-circuit adjacent segments removed. If there are any flat spots they should be turned off in a lathe. The use of sandpaper or of emery cloth on the commutator should be absolutely prohibited: this applies to the inspection shop as well as to the overhauling.

The brush-holder insulators or yokes should have special attention. On all of the older types these should be removed from the shell, and if they are not in perfect condition should be scrapped and replaced with new ones. If they are mechanically O.K., i.e. neither cracked nor broken, and the surface smooth, they should be carefully cleaned off and given a heavy coat of shellac or of insulating paint, which should be allowed to dry hard before they are replaced. It is in fact better to have some spares so prepared on hand, so as to allow the ones treated daily, twenty-four hours in which to dry, using them again the day following their removal.

The spacing of the brushes on the commutator should be measured, to make certain that the number of commutator segments between brush centers agrees with the manufacturer's diagrams. Any variation from the original design due to improper alignment of brush-holders or shifting or warping of the yoke, is certain to result in excessive sparking, with consequent rapid brush wear, overheating and tendency to flashovers. The tension of each brush-holder spring should be tested with a spring balance, and adjusted to the standard fixed upon, whatever this may be. Any excessive variation from the standard found on a considerable number of motors on overhauling would indicate that the inspection force are not maintaining the brush-holders as they should be, and the matter should be emphatically called to their attention.

Fields should be examined, and if possible tested for short-circuits, or baking. If not solidly clamped, shims should be inserted and the coils drawn solidly down upon the pole pieces. Leads and terminals should be carefully examined and placed in first-class condition, chafed insulation, loose terminals and broken stranding being the chief points to care for. The leads, fields, armature and entire interior of shell should all receive a heavy coat of insulating paint or varnish, and this should be done as early in the day as possible so that they will have dried before being returned to service. Trouble is frequently caused by the neglect of this precaution, for painted surfaces before drying hard will pick up and retain brake-shoe dust or carbon dust very readily, thus nullifying the very purpose for which it is applied, i.e. the thorough insulation of all parts.

The damage caused by hot armature bearings, the consequent stripping of coils upon the pole faces, and the damage to cores and to shafts is so great when it occurs that the most thorough precautions for their prevention are distinctly measures of economy. In this direction it will be found helpful to use nothing but new waste or feeders in the armature heads, renewing it at each overhauling, thereby lessening the bad effects of sand or dirt which is certain to be found in greater or less quantities in second-hand waste or felts; these can, however, generally be used a second time, with ordinary cleaning, in axle bearings or in the journal boxes. A press for reclaiming the surplus oil from waste or feeders no longer in fit condition for use can be made to save large sums in lubricants. Still better, by the use of a settling tank into which live steam can be introduced, all of the oil can be boiled from the waste, strained and floated off the top of the water, and the waste after being dried can be used for cleaning purposes, as it will have good absorbent qualities.

The bearings should be carefully fitted to the shafts, which should be calipered; and, if high or low spots exceeding 0.010 inch variation from the normal diameter are found, the shaft should be trued up in a lathe. The writer believes that all bearings should be babbitted to a smaller inside diameter than the standard size of the shaft on which they are to be used, and then bored out in a lathe or boring mill, this bore to be from 0.010 inch to 0.015 inch larger than the size of shaft as calipered in the overhauling shop. This will automatically compensate for the wear of shafts in service. The boring of bearings out of center will disturb the magnetic balance of the motor, and is a practice that should never be permitted. In remounting the motors on the truck, it should not be necessary to force the suspension bolt holes in the shell and the suspension bar into line by prying on the shell with a pinch bar, which I have often seen done. By so doing, axle bearing troubles are invited, by throwing the bearings out of alignment with the axle. Where difficulty in lining up these holes exists it is better to put a slot in the suspension bar to admit of mounting the motor without forcing. On all split bearings the inside contact edges should be eased off to prevent a sharp edge cutting off the flow of oil. At the end of bearings next the thrust collar, a radius should be turned in a lathe, to reduce friction and cutting at this point, and to facilitate oil working out to the collar.

It is, of course, impossible to go into all of the details constituting the most advanced practice in motor maintenance. What I have tried to do is to point out a number that are most frequently neglected, some in one place, some in another. The results obtained in service efficiency and reductions in operating costs by a close adherence to the general principles advocated in the foregoing discussion, which is based on the experience of a number of the largest and most progressive electric railways in this country, is a guarantee of their effectiveness. The keynote of this policy is that it costs less to prevent troubles developing than to pay for repairs after defects have occurred; and the adoption of this policy will show surprising economies wherever it is systematically entered into.

TESTS ON INDUCTION MOTORS DESIGNED WITH DEEP ROTOR SLOTS

By L. D. Jones

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This article gives the results of some tests that have been made on deep slot rotors in comparison with rotors having slots of normal depth. The effect of the deep slot is to increase the reactance of the lower portion of the bar at starting and at low speeds, thus causing the greater part of the current to flow in the upper section of the bar; this being equivalent to increasing the resistance and consequently the starting torque. As the speed increases, the rotor frequency decreases and with it the reactance, and the current distributes itself more nearly uniformly throughout the bar, thus reducing the effective resistance and improving the running characteristics.—Editor.

In order to obtain high starting torque in an induction motor it is necessary to have a high resistance in the secondary circuit. A high resistance secondary, however, gives the motor poor running efficiency; and these conditions have led to the design of induction motors with wound secondaries, so connected that resistance can be inserted in the circuit during starting and cut out when the motor comes up to speed. This construction is necessary under very severe starting conditions; but the simplicity and ruggedness of the squirrel cage winding offers so many advantages that it is used whenever the starting conditions will permit.

A number of attempts have been made to give the squirrel cage motor high starting torque without sacrificing running efficiency. One method which has been suggested to accomplish this is to make use of end-rings of magnetic material, of such a size that there will be considerable "skin-effect" at ordinary frequencies. When the motor is thrown on the line, the secondary frequency is equal to the line frequency, and the end-ring loss with a given starting current is several times greater than if there were no "skin-effect" present, thus giving high starting torque. As the rotor comes up to speed, however, the secondary frequency approaches the frequency of slip, and the effective resistance of the end-rings becomes equal to the ohmic resistance, thus giving a low secondary resistance with consequent good efficiency.

One objection to the use of this principle is that the current at starting is high, say three times full load current; and the magnetomotive force in the end-ring under this condition is so great that the iron is highly saturated, thus having rather low permeability and relatively low skin-effect. When the motor is running the magnetomotive force in the end-ring is lower, and the iron is nearer its maximum permeabi..y and may have considerable skin-effect even at slip frequencies. The reactance when the motor is running is also considerably higher than at standstill, due in part to the more complete distribution of current in the end-ring and in part to the lower permeability of the iron.

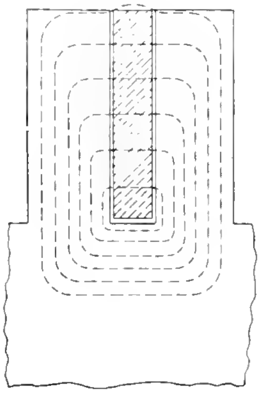

Fig. 1

Deep Slot Rotor, Showing Distribution of Flux

Another method similar in some respects to the above is that described by Mr. H. M. Hobart, in the General Electric Review for June, 1912. This method consists in making use of the increased effective resistance of a conductor placed in a deep slot when carrying alternating current of ordinary frequency. If the rotor of an induction motor is made with deep bars and low resistance end-rings, the secondary resistance at standstill may be several times the value when the motor is running. The reactance of such a motor is rather high, however, due to the deep narrow slots in the rotor.

The theoretical calculations of the values of resistance and reactance of a conductor placed in a deep slot are quite complicated, but the following considerations will serve to give a general idea of the phenomenon. If a conductor, as shown in section in Fig. 1, is placed in a slot and is connected to a source of alternating current, the lines of force around the conductor will be somewhat as shown in the figure, i.e., will all pass below the conductor, due to the low reluctance of the iron path under the slot. Thus the bottom of the conductor will be surrounded by more lines than the top and therefore will have higher reactance and, consequently, higher impedance. The effect of this will

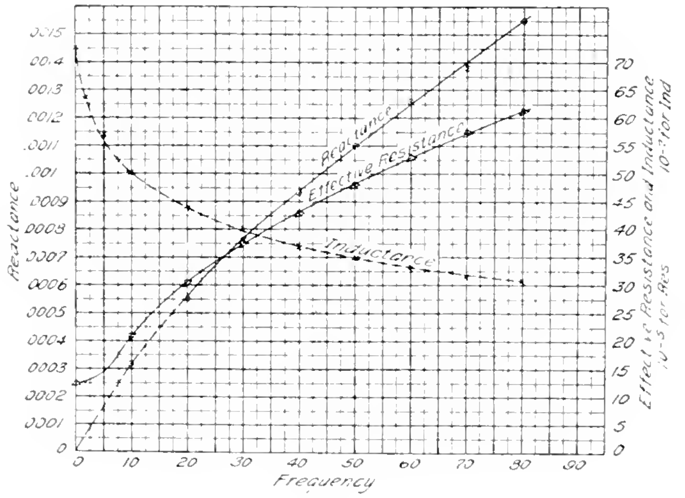

Fig. 2

Change in Resistance and Inductance with Change in Frequency

be to cause the current to flow in the top part of the conductor where the impedance is lower. The resistance of the top part of the conductor is, of course, much higher than the resistance of the total conductor, and therefore the loss with a given current will be greater. It is also evident that the total reactance will be less when the current is in the top of the conductor, as it approaches the condition of a much shallower slot. As the frequency is reduced, the current will flow in more of the bar, causing the effective resistance to decrease and the inductance to increase. This variation of resistance and inductance with the frequency is shown clearly in Fig. 2, which is plotted from the results of a test made upon a copper bar 1.4 cm. deep, by 0.32 cm. wide, placed in an open slot. From these curves it is evident that when deep rotor slots are employed in an induction motor, the secondary resistance is a minimum at the low values of frequency corresponding to the normal running conditions; while the inductance, and thus the total reactance is high. At starting the reverse is true, so that the power-factor at standstill is relatively higher, while under load it is relatively lower than in a normal motor.

In general a motor with deep slots in the rotor should possess the following characteristics: First, high starting torque with normal efficiency, or high efficiency with normal starting torque, depending upon the design of the motor. By high starting torque is not necessarily meant high torque with normal voltage on the motor; but, rather, high torque per volt-ampere input to the motor, i.e., high apparent torque efficiency. Second, rather low power-factor when running. Third, reduced overload capacity. In order to determine the advantages and limitations of this form of construction, two rotors were built, one having slots of normal proportions, while in the other the slots were made very deep and narrow. The conductor dimensions in each case were as follows:

Normal rotor, 0.762 cm. by 0.762 cm.

Deep-slot rotor, 3.2 cm. by 0.30 cm.

A careful set of tests was run on each of these two when assembled in the same stator. The more important characteristics, as determined from the results of these tests, are given in the following table:

	Normal Rotor	Deep-slot Rotor
Full load efficiency	89%	91%
Full load power-factor	91%	86%
Overload capacity	2.6	2.0
Full load slip	3.9	2.0
Apparent torque efficiency	25%	29%

The above results bear out the general statements previously made regarding the characteristics of the deep-slot motor. It must be remembered, of course, that this is only one example, and that widely different results may be obtained with different depths of slots on different motors.

One advantage possessed by this type of motor is that, owing to the high impedance, the starting current for a given voltage is considerably lower than with the usual design. This feature will allow a relatively large motor to be thrown directly on the line without the use of a compensator. When a compensator is necessary, a higher ratio tap will be used than with an ordinary motor.

While working up the test results for these motors, circle diagrams were constructed by plotting the different values of line current at their respective phase angles. In each case, the curve is the arc of a circle nearly up to the point of maximum output. Beyond this, however, the curve begins to depart from a circle, getting further away as the motor approaches standstill. The two circle diagrams are shown in Fig. 3. As is well known, the theory upon which the circle diagram is based, depends upon the reactance of the motor remaining constant. It is evident, then, that the reactance must change in order that the curve may depart from a circle. In the case of the deep-slot rotor, this is to be expected, owing to the different current distribution at the different frequencies. It would be expected, however, that the rotor with normal slot dimensions would give a correct circle diagram, as the slot depth is well within the minimum value at which the "slot-effect" is noticeable. The fact that this circle is, if anything, more distorted than the other, makes it necessary to look for other causes of changes in reactance. It is apparent from an inspection of Fig. 4, which shows the standstill, or impedance curves between volts and amperes, that the curve for the normal rotor does not follow the usual straight line throughout its length; but that, above a certain point, the amperes begin to increase at a more rapid rate with reference to the voltage than is the case below this point. This can be due only to a decrease in the reactance of the motor.

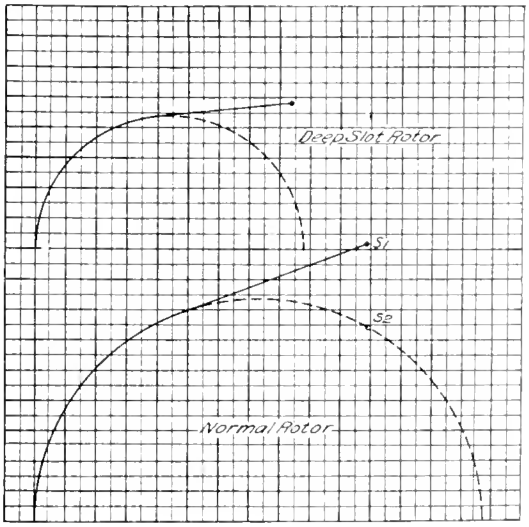

Fig. 3
Circle Diagrams for Normal and Deep Slot Rotors

The standstill point S_1 on the circle diagram is obtained by plotting the current taken from the impedance curve at normal voltage, at its correct phase angle. If the impedance curve is extended in its original direction, and the value S_2 of the current at normal voltage plotted at its phase angle, the point falls on the circle at S_2, showing that the

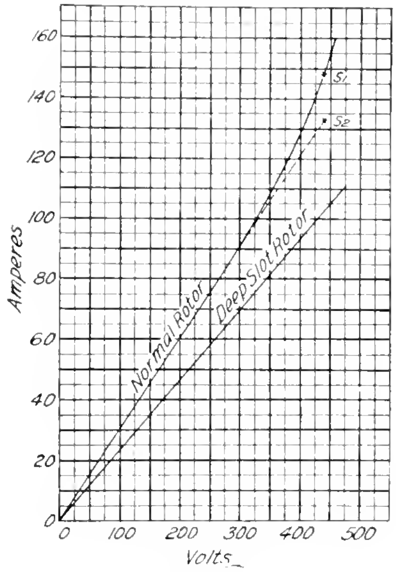

Fig. 4
Impedance Curves for Normal and Deep Slot Rotors

circle diagram would have had the usual form if the reactance of the motor had remained constant. This change in reactance is probably due to saturation of the iron parts of the leakage path, such as the tooth tips, etc. These parts do not begin to saturate until the magnetomotive force per slot reaches a certain value, which, in this case, is much higher than it is apt to reach under operating conditions.

The effect of saturation may be of advantage in motors requiring high starting torque and drawing a large current from the line; but as most motors start from compensators at from 0.4 to 0.8 normal voltage, the current will probably not be high enough to cause a reduction in the reactance, so that in general, the characteristics of such motors will be normal.

In motors in which the change in reactance is due to variations of frequency instead of current, this is not the case. As has been shown, the characteristics of motors with deep slots can be very greatly modified, thus making it possible to design motors with nearly any desired amount of starting torque which at the same time will have good running efficiency.

THE AMORTISSEUR WINDING

By M. C. Smith

Lighting Engineering Department, General Electric Company

This article first describes the construction of an actual amortisseur (or "deadening" winding built into the field of a synchronous motor; and explains its theory by a brief exposition of the principles of operation of the squirrel-cage induction motor. A short discussion (with curves) is made of the effects of the amortisseur winding on the starting characteristics of a motor; while the next section shows its advantages over the solid pole. A simple theoretical explanation is given of certain characteristics of the amortisseur winding which may be observed in the operation of motors thus equipped; while a later section indicates the advantages of this construction in preventing hunting, and in improving the operation and regulation of single-phase alternators.—Editor.

The fact that all machines or electric circuits have a natural period of vibration is a phenomenon well known to all engineers.

The amortisseur winding, as may be inferred from its name, is a "deadener," since it deadens or dampens the tendency of alternating current machines to vibrate or hunt, through irregularity in operation of the prime-mover.

An even greater field of usefulness is as a means of increasing the starting torque.

The amortisseur winding of the squirrel-cage type consists of two metal rings into which are welded or riveted bars of copper,

Fig. 1
Rotor of Synchronous Motor Showing Assembled Amortisseur Winding of the Squirrel Cage Type

bronze or other alloy. The bars are imbedded in the pole faces as near the surface as practical, and parallel to the armature slots. The composition of these rings has a marked effect upon the action of the synchronous machine, as will be considered later. At the present stage it may render the discussion clearer if we refer at once to the construction of the amortisseur winding built into an actual machine. Fig. 1 shows the rotor of a "self-starting" synchronous motor. In this rotor the bars are machined to fit tightly into the end rings and are then set up and riveted, which furnishes an excellent electrical contact. The picture also shows how the end rings are sectionalized, to permit a ready means of removing a coil if repairs should be necessary. The joints are fastened by bolts and the nuts are locked by crimped washers to render their working loose impossible.

From the foregoing, one may readily observe the close similarity between the rotor of a synchronous motor equipped with an amortisseur winding and that of the rotor of a squirrel-cage induction motor; and, since the stator windings of both machines are practically similar, the action of each may be explained in the same manner.

Action of the Motor at Starting

Referring to Fig. 2, let us consider the stator of a two-phase motor, in which, for the sake of clearness, the windings are shown concentrated. In this and in Fig. 3, the conductors marked with dots carry up-flowing, and those unmarked are carrying no currents; the currents in those with crosses are down-flowing current. When the polyphase electromotive forces are applied to the stator, currents are produced, which, by their rise and fall in value, set up a rotating magnetic field. As the sole effect of these currents is the production of this rotating state of magnetism, they may be properly termed the "magnetizing currents," and so are 90 electrical degrees behind the electromotive force producing them. (We are neglecting losses.) At the instant shown in Fig. 2, these currents are at their maximum value in phase A and zero in phase

B; whereas, as is indicated in the vector diagram, the electromotive force impressed upon phase A is 0, and that on phase B is at its maximum value.

Fig. 3 represents the machine with the rotor in position. When the rotor is running below synchronous speed, its conductors will be cut by the magnetic field, which, as has been shown, is rotating at synchronous speed. Assuming that the sequence of currents flowing in the stator conductors is such as to cause this magnetism to rotate in a clockwise direction, a consideration of Fig. 3 will make it evident that, at the instant shown, the rotor conductors lying directly beneath those of phase B, group 1 (marked B-1), will have down-flowing currents, and those marked B-2, in the opposite direction. The torque produced is due to these currents being in the field set up by the magnetizing action of the currents in phase A. The currents in the rotor conductors are productive of a magnetic flux which must be counterbalanced by additional currents in the stator, which increase with the demand for torque. To obtain a greater torque the currents in the rotor must increase, and therefore, a greater current must flow in the stator conductors. Since the currents in phase B produce the magnetism which counterbalances that produced by the currents in the rotor, they may be properly termed the "load currents" of the motor. Furthermore, the electromotive force of phase B is a maximum at the instant we are considering; and, since the currents in phase A are wattless, it is seen that the torque is proportional to the power input to the rotor.

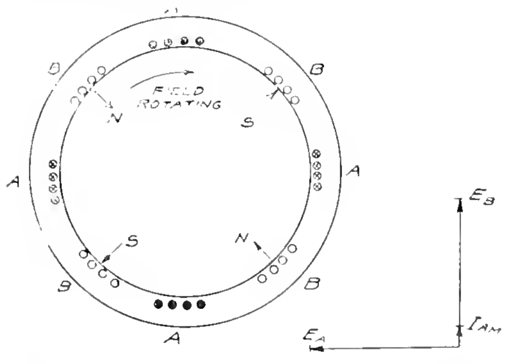

Fig. 2
Stator of a Two-Phase Four-Pole Induction Motor with Concentrated Winding. In the vector diagram E_A is the voltage across Phase A, E_B the voltage across Phase B, and I_{AM} the "Magnetizing Current" of Phase A

It is also interesting to note that the conductors of phase B lie in the flux produced by the magnetizing currents of phase A, and that the relative motion of this flux to the conductors will produce an electromotive force in phase B which will oppose the electromotive force impressed, thus preventing an excessive rush of current.

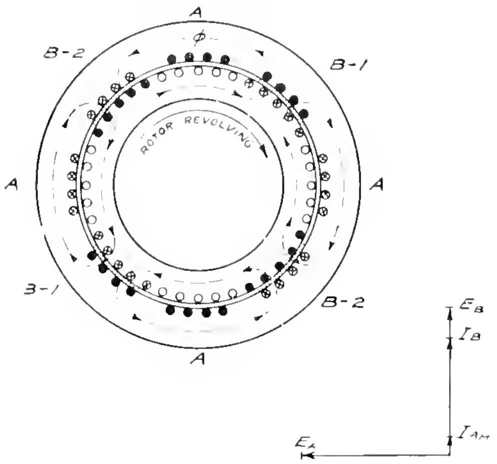

Fig. 3
Same as Fig. 2 with Rotor. In the vector diagram I_B is the "Load Current" of Phase B

As mentioned previously, the action of the synchronous motor equipped with an amortisseur winding is, at starting, practically the same as that explained above, the main difference being due to the fact that, with the synchronous motor, neither the iron of the rotor nor the short-circuiting bars are continuous, as assumed. This difference, however, in no way renders the explanation given above inapplicable to the former.

The actual starting conditions may be most readily understood by consideration of Fig. 4. These curves are given to show the relation of power-factor and kv-a. input at different percentages of synchronous speed. The main feature to be observed is the low power-factor at starting, which, in conjunction with starting torque characteristics, explains why most engineers prefer the slip ring type or variable internal resistance type of induction motor to the synchronous motor for services in which frequent starting is necessary.

The curves of Fig. 5 show the variation that may be obtained in the starting torque, both at the instant of starting and from that time until synchronous speed is reached. The full line curve indicates the torque obtained when a winding of relatively high resistance is used; whereas the dotted curve indicates the torque produced by the same machine equipped with a low resistance winding. The difference in the curves may be explained as follows: The demagnetizing action of the currents in the rotor windings (although previously neglected for the sake of clearness) has much influence upon the starting characteristics of the synchronous motor. Its effect upon the torque produced is twofold. In the first place, when the flux flowing from the stator is reduced by the demagnetizing action of the rotor currents, these currents are themselves reduced; and secondly, since the torque is a product of the current in the rotor and flux from the stator, a reduction of each must effect the torque.

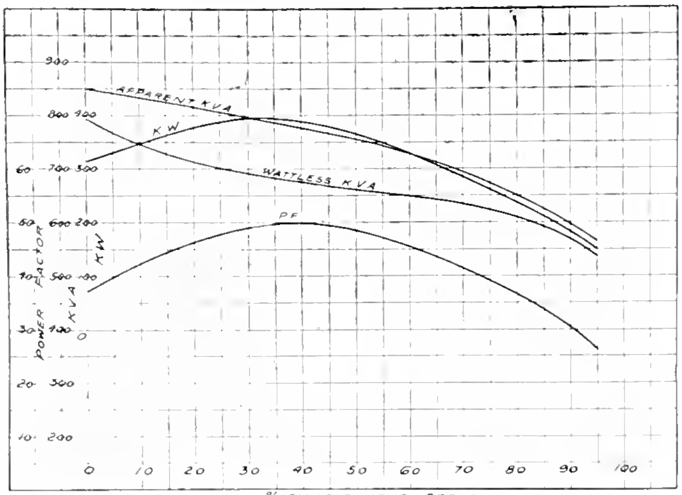

Fig. 4

Characteristic Starting Curves, Showing Variation in Power-Factor and Input to Synchronous Motor Equipped with the Squirrel Cage Amortisseur Winding

For a given flux entering the rotor from the stator, the value and frequency of the electromotive forces, and hence the currents, induced in the rotor are a maximum when the rotor is at rest and a minimum at synchronous speed. Thus as the machine approaches synchronous speed, the torque produced is less than at starting, for the relative speed of rotor conductors and the field of the stator is so diminished that the currents in the rotor, and hence the torque, are greatly diminished. When an amortisseur winding of low resistance is used, the torque is reduced at starting by the rotor currents being of such a value as to produce excessive demagnetizing action; but as the rotor approaches synchronism, the reduction of induced currents permits a greater torque than could be obtained with a high resistance winding, as shown in the figure. With the high resistance winding, the induced currents are limited at starting, however, as the machine approaches synchronism the electromotive forces induced are insufficient to cause sufficiently large currents to flow.*

* An amortisseur winding so designed as to have a high resistance at starting, which resistance would automatically decrease as the rotor approaches synchronism, is evidently quite desirable. The well known phenomenon of the variation in effective or apparent resistance of large conductors to the flow of alternating current with variation of the frequency has been suggested as a means of obtaining this result.

As has been mentioned, the frequency of the induced rotor current is a maximum when the rotor is at rest, and minimum when at synchronous speed. So if the end ring should be made of heavy cast iron or steel the relatively high frequency at starting would cause the effective resistance to be much greater than when the rotor is nearing synchronous speed.

Another, and perhaps more flexible, means of obtaining the same result, is the use of two or more end rings of different resistance, at each end of the bars embedded in the pole-faces. The bars are connected to the inner or high resistance ring. Referring again to Fig. 3, it is seen that around the periphery of the rotor illustrated any two equidistant points are of the same potential; and, midway between these, are points that are at a maximum difference of potential with respect to the first. Thus if the end rings are electrically connected only at two opposite points, no current will flow in the outer ring; but if the connection is also made at the points midway between the former, the outer ring will become a part of the rotor circuit. If the stator referred to were connected to produce eight instead of four poles, there would be four instead of two equidistant points of the same potential. So even though the rings are connected at four equidistant points no current would flow in the low resistance ring if the pole connection is used. This fact is utilized as a means of obtaining a rotor of high resistance at starting, which may be made of low resistance as the machine approaches synchronism by reducing the number of poles by one-half.

There are other methods of placing the low resistance ring in the circuit, thus obtaining the same effect as when the number of poles when running at synchronous speed is one-half the number used at starting. Such methods as having hand or centrifugally operated contacts at the points of maximum difference of potential have been attempted. From a commercial point of view the latter scheme is at present rather impractical due to its high cost; as is also the method of changing the number of poles; while with the use of the large solid end ring as first suggested, sufficiently uniform results have not yet been obtained.

The Solid Pole versus the Amortisseur Winding

When a rotor with solid pole faces is placed in the path of the rotating field produced by the stator currents of a polyphase synchronous motor, the eddy currents which flow in the pole faces are productive of torque. It is evident that practically the same results may be obtained with a rotor having solid poles as are obtained by the use of the amortisseur winding. For this reason, rotors having solid pole faces are now quite extensively used as a means of starting and preventing the hunting of synchronous machines; and the close similarity in the results obtained invites a comparison of their relative merits.

It must be admitted that the amortisseur winding has the following advantages: (1) The currents induced in the rotor windings may be predicted by mathematical calculation. (2) Their paths are so directed as to produce the maximum effect. (3) Suitable provision may be made for carrying them, thus eliminating the danger of excessive heating and consequent losses. (4) The actual starting characteristics, both as to the torque obtained and the power taken from the system, may be predicted within quite narrow limits; for, as has been previously mentioned, an amortisseur winding of high or low resistance may be used, which enables the designer to meet special starting and operating conditions.

It is claimed by the advocates of the solid pole faces that the dampening effect of the eddy currents in the solid faces is very effective in preventing high voltages being induced in the field coils. This is evidenced from the fact that the total opposition tending to prevent the rotating stator flux from entering and cutting the field coils when an amortisseur winding is used, is the counter flux produced by the current in the bars and end rings; while in the case of the solid pole, not only is the counter flux opposing, but also the reluctance of the solid poles, being greater, adds to the opposition and thus more effectively dampens the incoming flux. This theoretical advantage, however, is not of great practical importance; for since the voltage induced in the field coils of rotors equipped with an amortisseur winding rarely exceeds 4000 volts, but little difficulty is encountered in providing sufficient insulation.

The magnetic wedge, and other special features of design that are at present deemed necessary when the solid pole is used, generally introduce undesirable features. It is possible, however, that these may be improved upon and perhaps entirely eliminated, thus rendering the use of the solid pole faces more satisfactory than at present.

Sticking of a Motor at Half Speed

In starting a synchronous motor equipped with an amortisseur winding, there is occasionally a slight tendency for the motor to come up to one-half speed, and continue to run at this speed until the power supplied to the stator winding is increased. When one-half synchronous speed is reached, the rotor slip is 50 per cent, or in other words, the frequency of the induced currents in the rotor is one-half the frequency of the stator currents. Thus the field produced by these induced currents has the same periodicity as though the field were excited from a circuit of one-half the frequency applied to the stator. If the rotor were stationary, this action would be similar to that of a static transformer, i.e., this flux would induce in the stator conductors an alternating electromotive force of its own frequency. If, however, the rotor were driven at one-half the speed necessary to generate the supply frequency when the field coils were excited with direct current, the frequency of the induced electromotive force would then be equal to that of the supply.

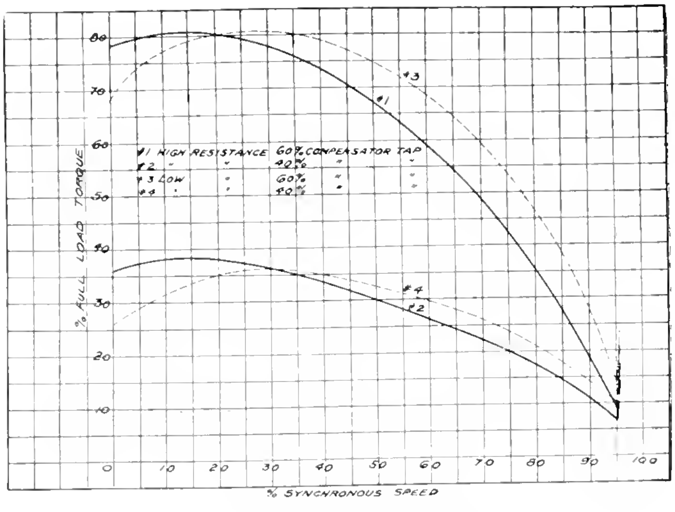

Fig. 5
Torque Curves of Synchronous Motor Equipped with Squirrel Cage Amortisseur Windings of Different Resistances

For an example, let us assume the case of a 60-cycle source of supply, and a 60-cycle motor, the rotor of which is rotating at one-half synchronous speed. Then (1) the induced rotor currents will have a frequency of thirty cycles; (2) the rotor currents, due to their own frequency, will induce in the stator an electromotive force at thirty cycles; (3) combining (2) with the effect of generator action due to mechanical rotation at half synchronous speed, the periodicity of the counter e.m.f. induced in the stator will be sixty cycles—which is that of the supply.

The flux generated by the ampere-turns of the amortisseur winding is rarely sufficient to make this tendency to stick at one-half speed noticeable. If, however, the field coils are short-circuited, the increased flux due to the current in them may be sufficient to cause the rotor to lock at half speed and continue to operate at this speed until the short-circuit is removed from the field coils.

The Unbalancing of Phases and the Variable Torque at Starting

While the effect of the non-uniformity of torque and unbalancing of phases is rarely objectionable when care is exercised in the design, the conditions causing them are interesting.

When, in the case of the squirrel-cage induction motor, the number of rotor slots is equal to, or an exact multiple of, the number of the slots in the stator, a much greater power is required for starting than when the ratio is fractional. This is due to the fact that the flux in seeking the path of least reluctance will cause the rotor to move to that position in which the teeth of each part will be opposite. The same condition exists when the pitch of the holes in the pole faces of a synchronous motor is an exact multiple of the stator pitch; for then the rotor will move to that position furnishing the least reluctance to the flow of magnetism, and in that position will not start until more power than would otherwise be necessary is supplied.

When the rotor is in a given position, the rotating flux which generates the counter-electromotive force, tends to concentrate at the parts of the stator directly opposite the pole faces. This naturally causes an unequal distribution of flux and consequent unequal counter-electromotive force generated in the different phases of the stator, which in turn allows a greater current to flow in the phase in which this electromotive force is a minimum. Thus an unbalancing of phases is caused, which affects the uniformity of the rotating magnetism. This, in connection with the action explained above, may cause the torque to vary with the different positions of the rotor.

The Tendency to Prevent Hunting

When synchronous machines, either motors or generators, are operating in parallel under normal conditions, periodic variations in motive power or load may cause the machines to oscillate in speed. These oscillations, unless opposed in some manner, may become more and more aggravated, until the machines either "fall out of step" or serious line surges occur. One of the most valuable features of the amortisseur winding is its tendency to prevent these oscillations. When the machine is retarded or accelerated, the bars of the winding are cut by the flux. The cutting of the flux produces energy currents in the bars which tend to dampen out these oscillations. The energy that would otherwise be expended in retarding or accelerating the rotor is thus absorbed and dissipated.

The Single-Phase Alternator

When a single-phase alternator is equipped with an amortisseur winding, not only is parallel operation rendered more satisfactory, but its voltage regulation is also greatly improved. As the flux produced by the magnetizing action of the armature currents does not rotate, as in the case of the polyphase alternator, but instead is stationary in space and proportional to the armature or load currents, its effect is twofold, consisting of simple transformer and generator action.

Assuming the bars of the rotor winding to be equally spaced around the periphery, the effect of the currents produced by the transformer action is to add to the pulsations or "beats" which, since they are due to the change in impedance of the armature as the relative position of the poles and armature coils varies during a revolution, are noticeable in all single-phase alternators. Unless the current thus produced in the rotor, however, is unusually large, this effect is practically negligible. On the other hand, the generator action is generally much more effective. It is caused by the bars of the amortisseur winding being driven through the stationary flux from the armature or stator currents and thus producing currents in the rotor which tend to aid the magnetomotive force of the main field magnets. As both the demagnetizing and amortisseur currents are proportional to the load the regulation of the alternator is greatly improved.

Messrs. Hawkins and Wallis in Vol. II of the *Dynamo* offer an explanation of the action of the single-phase alternator equipped with an amortisseur winding which is essentially as follows: The self-induced field from the armature ampere-turns may be replaced in the imagination by two rotary fields, each of a value of one-half the varying field. The one component field, when the speed is perfectly steady, rotates synchronously with the damper winding, and therefore, has no effect; but when free oscillations are set up, this component produces currents which tend to dampen out the oscillation and render operation stable. The other component rotates at synchronous speed, but in the opposite direction, producing currents of twice the machine frequency in the amortisseur winding. These currents exactly oppose the ampere-turns of the field which produces them; and thus, neglecting leakage, the inductance of the armature should be halved . . . By accepting this explanation one may readily account for the manner in which the dampening of the oscillations in speed is accomplished; which, without assuming a rotating component of the stator magnetism, is quite difficult to obtain.

It may be of interest to note the following conclusions that have been reached as a result of a series of tests that have been recently performed:

(1) The starting torque is roughly dependent upon, and proportional to, the square of the impressed voltage, and also to the power input to the stator.

(2) When nearing synchronous speed, a slight direct current excitation materially aids the "pull-in" torque.

(3) It often occurs, when the motor has reached synchronous speed and the direct current excitation has not been previously applied, that when it is then excited by direct current the poles will not be in the proper position relative to the stator conductors. If the direct current excitation is increased sufficiently the rotor will "slip a pole," and then, the poles being in the proper relative position, the rotor will lock into synchronism. This method of forcing the rotor to "slip a pole" may cause excessive currents to flow in the armature conductors, as it tends to lessen the flux to the stator magnetizing currents, which generate the counter electromotive forces. However, this condition may be prevented and the desired results obtained by either reversing the polarity of the applied excitation, by slightly loading the machine mechanically, or finally, by disconnecting the motor from the supply. There is, of course, an even chance that the same operation will have to be repeated; for, when again excited, a pole of the same polarity may be in the same relative position to the stator conductors.

THE PROTECTION OF HOUSE WIRING FROM HIGH VOLTAGES CAUSED BY THE OPERATION OF NEARBY WIRELESS TELEGRAPH OUTFITS

By G. F. Gray

Consulting Engineering Department, General Electric Company

This article explains the first principles of wireless telegraphy and the theory underlying the fact that long-distance electrical transmission of signals without wires may be the source of disturbances to other electrical circuits in the neighborhood of the wireless station. The ill effects are, of course, particularly noticeable in the vicinity of the big stations; but the wireless enthusiast working a comparatively small outfit in the middle of a city block may cause a good deal of wreckage to the meters, fixture wires and fuses in his own and his neighbor's house. The article briefly reports a quantitative study of such disturbances and means for their removal; and describes a system of protection, using the aluminum cell arrester and the new vacuum tube arrester, which was recently installed in a group of houses in the neighborhood of an active amateur station, and which reports practically complete protection after a period of six months.—Editor.

The art of wireless telegraphy is based on the physical fact that when a wire (called an antenna) acting as a condenser is rapidly charged to a high voltage, and discharged, a certain part of the electric l energy present is radiated into space as electromagnetic or so-called Hertzian waves. In the transmission of signals, this energy is radiated intermittently according to a prearranged code, an extremely small part of it being again converted into ordinary oscillating electrical energy at the receiving antennæ, where it is made to actuate a telephone receiver, or otherwise make its presence apparent.

Any conductor which is cut by a changing magnetic field will have an electromotive force induced in it; and the magnitude of this e.m.f. will be directly proportional to the length of the wire, and will be reduced according to the distance from the sending antennæ, since the energy sent out tends to spread itself over the surface of the earth.

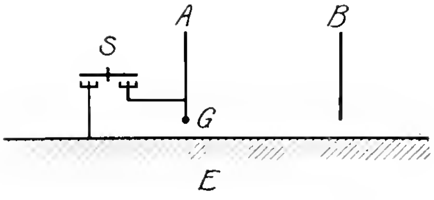

Fig. 1

Another factor also affects the magnitude of the voltage which is induced in the receiving conductor; and its particular behavior should be clearly understood, since it affects not only this but many other present-day problems. Fig. 1 is a diagram of a very simple sending circuit. *A* is the sending antenna, *S* a static machine, *E* the earth, and *G* a gap. Suppose we operate the static machine, charging *A* to a high positive potential, disconnect *S*, then slowly close *G* until a spark takes place, and consider what happens from instant to instant during the very brief time taken to discharge *A*. Using conventions rather loosely, we can say that there is a charge of positive electricity evenly distributed over *A*, which begins to rush into *E* as soon as the spark starts. In flowing down, it constitutes an electric current. Since *A* is a slightly inductive circuit, this current tends to persist after *A* and E reach the same potential. The result is that more than enough positive electricity escapes from *A* than is needed to bring it to a normal potential which leaves it below the potential of *E*. This flow gradually dies down, however, leaving *A* negative with respect to *E*, though the difference of potential is somewhat less than it was at first. It might not be great enough to again spark over *G*, but in general the hot ionized gases left by the first spark allow the second one to pass easier, and a reverse flow takes place. In fact, it generally takes a number of these oscillations to finally bring *A* and *E* to the same potential. All this happens in a very short interval, oftentimes a thousandth of a second or less. The time between sparks is determined by the size and shape of *A* and its location relative to *E*; and the number of sparks before they die out, by the resistance of *A*, and also by the amount of energy lost in other ways, for the energy initially present as the charge of *A* must be lost as heat in the resistance, eddy current, etc., or else radiated out into space from *A*.

Now let us consider what happens at the receiving antenna *B*. Actually, the energy is sent out over long distances by so-called electromagnetic waves; which are pictured as self-closed lines of electric and magnetic forces, but whose behavior is sufficiently understood by considering simply magnetic lines of force. The instant that *A* started to discharge, a current sprang into existence. As it grew, a field of force grew around it. This field in cutting across *B* induced in it an e.m.f. which caused the upper end to become positive and the lower end negative. Another way of saying the same thing is to consider that elements of negative charge on *B* are bound by the positive charges on *A* and follow them down at the discharge, thus making the lower end of *B* negative as before.

As was stated, every conductor has its natural frequency of oscillation or flow of current, which is dependent on its size, etc., and is therefore a constant for any given circuit. Suppose that *A* and *B* are identical in these respects. They will then have the same natural period. As soon as the flux from *A* ceases to increase, that is, when the potential of *A* reaches zero, the displaced charges on *B* begin to flow back again from the ends to neutralize each other. Here it is that one convention, the two fluid one, becomes unsatisfactory; and since all these analogies are admittedly only artificial frameworks on which to hang the knowledge gained experimentally, what actually happens is best explained by saying that the positive charge which was at the upper end of *B* begins to flow down to redistribute itself evenly over the surface. As in the case of *A*, however, it will do this only after a number of oscillations, because of the overshooting. Now comes the vital point. As this charge in *B* starts to flow back, due to the fact that the upper end has a higher potential than the lower, the current in *A* begins to decrease and the line of force to contract, cutting *B* in the reverse direction and adding an induced e.m.f., tending still further to displace the charge on *B* in the direction to make the lower end positive. It is this *adding together* of the impulses to build up higher and higher differences of potential and consequently heavier and heavier current surges, that makes possible the transmission of signals over such apparently enormous distances, and also which makes dangerous even small impulses if they come at the correct rate.

One thing should be noted here, however, viz., that the natural periods of the sending and receiving circuits must be very nearly the same to get this resonant rise. The sharpness of this curve may be judged by Fig. 2, which shows the effect of varying the frequency of the voltage built up in a circuit actually tested. If the natural period of the receiving circuit is much less than that of the sending, the surges in *B* will die out before another impulse from *A* is received. In this case the maximum potential is that induced on the original impulse. If *B* has a much greater period than *A*, its charge will only partially follow the impulses from *A* and much lower voltages will be generated. This last condition is known as forced oscillation, while that of two identical circuits is of course the condition of resonance, or syntony as it is known in wireless work.

Even with the magnification given by the resonance of the receiving circuit, it is necessary to radiate a considerable amount of energy in commercial telegraphy; and, as was predicted, this energy sent out in all directions is received by many conductors for which it was never intended. The fascination of this new line of experiment is so great that every little town and almost every city block has its amateur enthusiast. The result is that numerous service meters have been burned out, incandescent bulbs have been seen to glow with a pale intermittent light, fuses have been blown, and similar annoying things have happened. Naturally, the disturbances have been particularly bad in the neighborhood of the larger stations, such as those on ships. The writer has, for instance, seen a spark a quarter of an inch long playing from a guy wire to a metal pipe on one of the Hudson River steamers.

With a view to studying these disturbances quantitatively and devising means for protecting electrical circuits from damage by them, a number of investigations and experiments were undertaken. The first series of these investigations was to determine the potentials actually met with in practice, and were made on several battleships and government shore stations. On one ship air-gaps as large as ¼ in. were broken down by the potential from the end of a 30 foot length of wire strung under the aerial or antenna a little distance above the deck. In another case a rope ladder running from the top of the mast had induced in it potentials sufficient to jump one-quarter inch and produce a flaming arc. The current from these insulated parts was great enough to produce skin blisters, and considerable muscular contraction; and although not great enough to cause death, might easily

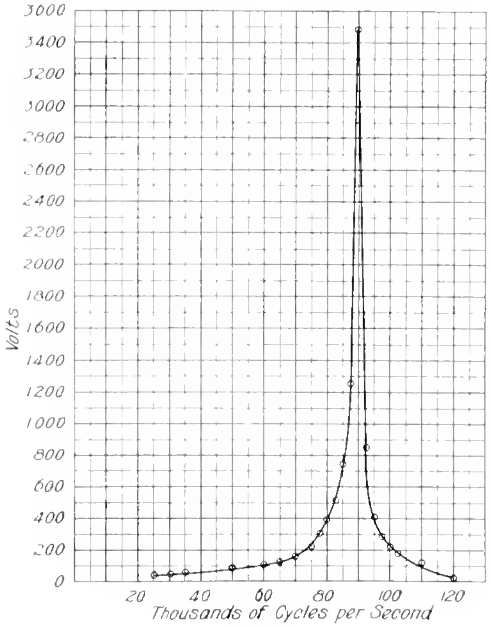

Fig. 2

cause a person to lose his hold in climbing from insulated to grounded parts. A person standing on an insulated box near the antenna had sufficient potential induced in his body to produce an appreciable shock when the grounded metal work was touched. A long wire run parallel to the sloping antennæ and grounded at one end to the deck had an induced potential (measured from the other end to ground) of less value, but nevertheless one of considerable magnitude.

The foregoing cases show the magnitude of potentials due to forced oscillations. In addition, a 30 ft. length of wire was connected to ground through an air-core coil. When the proper number of turns to produce resonance were used, the potential across this coil rose to such a value as to jump about 1 inch in air between needle points, and the current was great enough to fuse the needles and burn them back. The actual test voltage across this gap was 25,900 maximum, although the 30 foot wire without the coil produced a spark of only about $\frac{1}{32}$ inch.

The results thus obtained from commercial circuits have been checked by laboratory tests. In one case an antenna 200 feet long was set up about 25 feet from the ground, and although the high frequency current into this antenna was only 2 amperes, sparks as long as $\frac{1}{4}$ in. were obtained from a receiving antenna only 100 feet long. In this test a rather unusual result was noticed. A certain length of receiving wire, grounded at one end, being in use, sparks .08 inch long were obtained when it was 15 feet directly below the sending antenna, whereas from a receiving antenna of the same length of insulated wire lying on the ground 9 feet lower, the sparks were .19 inch long. It is also of interest to note that during this test a watt-hour meter in a nearby building was twice burned out, due to induced potentials in the service lines.

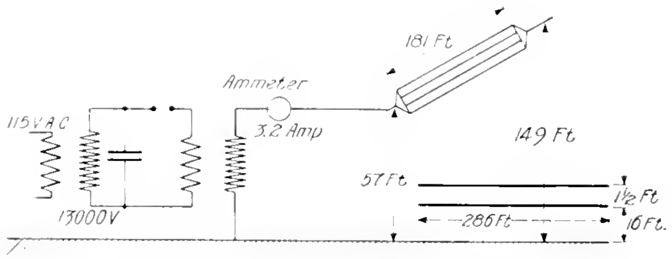

Fig. 3

Another test circuit was set up in connection with the aerial belonging to the Electrical Engineering Department of Union University, Schenectady, N. Y. Three receiving lines were used, the relative positions being as shown in Fig. 3. From the data taken with this outfit, it was found that the magnitude of the voltage to ground varies very greatly with a number of conditions. In general, this voltage is roughly inversely proportional to the distance from the antennae, and directly to the length of the receiving wire, except when the length is such as to give resonant effects. The presence of a nearby grounded wire may raise rather than lower the induced voltage, even when the grounded wire is above the one under test. The connecting of the receiving wires in parallel raises the voltage to ground. If one end is grounded, the voltage at the other end rises. In short, the conditions seem to be so complex that the only practical method of determining the result in any given case is by test. For the circuit as shown in Fig. 3, voltages high enough to spark $\frac{1}{4}$ in. to ground were obtained, and currents as great as 0.1 ampere were measured when the receiving wires were connected directly to ground.

In connection with the foregoing investigation, a study was made of the available means of protecting circuits from these high voltages. It was found that by entirely enclosing the wire in a metallic sheath (woven wire cover, or conduit) grounded at frequent intervals, they may be effectively prevented. This, however, is not possible in many cases, particularly that of service wiring and outdoor lines in general. In these cases the most satisfactory protector is an aluminum cell lightning arrester directly connected from each wire to ground. In this and all other cases it should be noted, that, to be effective, lightning arresters must be connected at the terminals of the apparatus to be protected, and that the ground connections must be short and not themselves subject to the influence from the radiating waves. On account of its inherent characteristics the direct connected aluminum cell is ideal, since it maintains a film which just prevents the flow of current due to the dynamic voltage and responds instantly to the least rise of potential. There can be nothing better than this form of protection for direct current circuits. Due to the short life of the aluminum plates when the cell is directly connected to an alternating current circuit, however, it is not in general adapted to them. Only when the apparatus to be protected is of considerable value and the arrester can be frequently inspected is its use warranted.

A high non-inductive resistance directly connected from line to ground was also tried with some success. It was found, however, that in order to obtain satisfactory protection the resistance could not be of a value high enough to render the energy loss in it negligible, and in consequence it was abandoned. In case the incoming impulses were extremely feeble it might be satisfactory, however.

The third method of protection tried was the recently developed vacuum tube lightning arrester. This device consists of a $\frac{3}{64}$ in. gap between a disk electrode and the inner wall of an exhausted metal tube. The spark potential of this arrester is 300 to 550 volts direct current (200 to 400 alternating current); and if properly connected to an alternating current line it gives entirely satisfactory protection. A low resistance is sometimes used in series with these tubes. If this is not done, the line fuses between the arrester connection and the source of energy should be of at least 25 amperes capacity, or better still, be entirely omitted as the dynamic current sometimes follows heavy static discharges for a half cycle.

To further test these results an installation was made of the two types of arresters previously mentioned (aluminum cell and vacuum tube) on the service wiring in the neighborhood of an active amateur station. Fig. 4 shows the relative location of the station and the house affected.

The sending apparatus consists of a 1/2 kw. closed core transformer, a glass plate condenser, a rotary spark-gap giving about 600 sparks per second, and an oscillation transformer of the flat coil "pancake" type. The secondary voltage is approximately 13,000 and the maximum output as measured by hot wire ammeter is 2.8 amperes. The current for operation is taken from a 60-cycle 115-volt circuit. The antennæ located as shown in Fig. 4 consist of 8 wires, each 72 feet long, spaced 2 feet 8 inches apart, the lower end being 40 feet high and the upper end 67 feet high. The wave length is estimated as being 200 to 300 meters.

When the station was first put into operation the 115-volt service wires ran to the houses *D*, *E*, and *F* from the pole *G*, the wires from *E* being parallel to and directly beneath the antennæ. As soon as the circuit was tuned for maximum output, the resulting disturbances burned off the fixture wires in a chandelier located in house *E*, and also immediately broke down and burned through the insulating joint between this light fixture and the gas pipe. The tests made at this point, using vacuum spark-gaps, showed induced potentials of 500 volts or more. The fixture was rewired and reinsulated, and two aluminum cells were installed on the incoming wires just after they entered the house, the cells being connected from the two outside wires to the grounded neutral of the three-wire system. No further trouble was experienced in house *E*.

About this time a fixture in house *D*, as well as a switch, began to crackle from discharges. In house *F* two fixtures were affected by static charges and the arc which followed burned through the canopies. One socket in this house was also short-circuited, and fuses blown from time to time due to fixtures arcing over. It was thought that the proximity to the antennæ of the service wires for houses *D*, *E*, and *F* was the cause of the trouble, and it was arranged to move these to the positions shown in the diagram. Two days after the wires were moved, the induced discharges burned out the meter in house *F*. Tests showed discharges across vacuum gaps having spark potential of about 500 volts. It is interesting to note that although the disturbances in house *F* were very severe, there was absolutely no trouble in houses *D* and *E*.

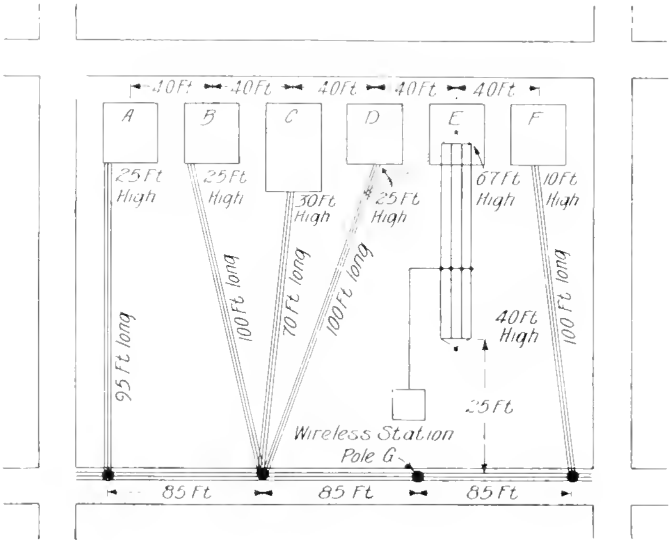

Fig. 4

Operations were suspended until vacuum tube arresters were installed on the incoming lines at house *F*, the arresters being connected outside to neutral and neutral grounded to a pipe driven in the earth directly below the incoming wires. A small resistance was used in series with the tubes as mentioned above. This absolutely corrected the trouble in this house. A few days later trouble developed in house *A*. Filaments were broken and fixtures crackled promiscuously. Tests showed the presence of a high potential as in the previous cases, and again the installation of the vacuum type arresters gave immunity from further trouble. The next affected was house *C*, where fuses were blown and fixtures arced over. Vacuum arresters corrected this trouble also. In the case of both houses *A* and *C* it was found impossible to ground the neutral at the house, but it was grounded at the pole line, and this proved sufficient.

During the tests carried on in connection with these installations it was found that high voltages were induced in house *E* even though the main switch was open, which cut the house wiring entirely clear of the incoming lines. This phenomenon was, therefore, due to the house wiring itself, the high potentials being induced in it directly from the antennæ, through the roof and floors of the building. The presence of the arresters mentioned kept the potential of the whole system below dangerous values, but it did not prevent slight rises at points distant from the arrester installation. This again points to the necessity of installing arresters wherever protection is needed, and avoiding the possibility of the induced potential being set up beyond the lightning arrester or in the ground connection.

These later installations have been in service for about six months, during which time the vacuum tube type has given no trouble whatever, and the aluminum cell has given perfect satisfaction except for the heating and deterioration of the plates, which was of course expected.

SWITCHBOARD RELAYS AND THEIR APPLICATION

By D. Basch

Switchboard Engineering Department, General Electric Company

The types, construction and application of relays will be discussed in considerable detail by Mr. Basch in this series (probably three articles in all). The first part, published below, deals with secondary a-c. relays designed to come into play on the occurrence of abnormal conditions created by disturbances in the system. A first sub-division points out the conditions which govern the general operation of the contact device (making or breaking circuit). Instantaneous, inverse time limit and definite time limit relays are all defined, and the various mechanisms for producing the time-effect described and compared. An excellent discussion is given of the conditions determining the choice of relays from the standpoint of the time characteristic, citing the most common applications of all the types; and showing how great refinement in protective and selective action may be secured in handling any disturbances which may occur in the several component parts of a system of transmission lines or distributing feeders.—Editor.

In its broadest sense a relay is an auxiliary device which, on the occurrence of some specified predetermined condition in an electrical circuit, will operate and transmit its action to another independent piece of apparatus. The condition necessary for the operation of the relay may be brought about at will by the operator, or it may be beyond his control, depending entirely on the phenomena occurring on the power circuit in which it is located. This paper will be limited to a consideration of relays of the latter class, that is, relays which operate on the occurrence of abnormal conditions created by disturbances in the system.

In its mechanical make-up, a relay consists of, first, a coil or a system of coils connected in or to the circuit which it controls; second, a movable part whose travel is regulated by the relay coils; and third, a contact device which is actuated by the movable part and which controls the operating circuit of the switch or circuit-breaker to which it is connected. In general, when operating under the conditions for which it is intended, the relay will cause a switch or circuit-breaker to open and to disconnect the circuit in which the abnormal conditions manifest themselves, either by energizing trip coils which are normally dead, or by de-energizing trip coils which are normally alive.

A. Alternating Current Relays

The big field of a-c. relays may be subdivided in accordance with three of their most characteristic features:

1. According to whether the contact device, when responding to the impulses of the system, makes or breaks contact.

2. According to the time elapsing between the occurrence of the disturbance and the operation of the contact device.

3. According to the nature of the disturbance.

Alternating current relays may be primary (series) or secondary, according to whether their coils are connected in series with the line controlled or to the secondaries of current or potential transformers. A special statement regarding primary relays will be made later on. The following remarks apply only to secondary relays.

1. A relay may be circuit-opening (normally closed) when it breaks contact at the moment of operation, or circuit-closing (normally open) when it makes contact. When used for the purpose of energizing a normally dead trip coil, the nature of the contact device to be selected in each individual case will depend on the character of the circuit which operates the disconnecting device. Where a steady, unfailing source of direct current is available the contact device should be circuit-closing, simply completing the operating circuit. Sometimes a low voltage a-c. potential circuit is used; but generally such a circuit is affected by the same short-circuits which the relay is to take care of, dropping its voltage when it is most needed. Where such an unfailing d-c. (or a-c. potential) circuit is not available, a circuit-opening contact device should be supplied. The tripping device of the switch is then in parallel with the contact device, which is in series with the secondary circuit of a current transformer. In this manner the tripping device is normally short-circuited. When the contact device is opened through the action of the relay, the tripping device is energized.

Where relays de-energize normally live trip coils no special rules can be laid down governing the selection of the type of contact device. A circuit-closing relay may short-circuit a coil, a-c. or d-c., and a circuit-opening relay may interrupt an a-c. or d-c. circuit feeding the coil. Under otherwise equal conditions, a circuit-closing contact device is preferable for relays energizing normally dead coils, as it makes positive contact with the whole force of the moving part behind it. A circuit-opening relay, especially where the break is slow, is liable to have its contacts pitted by arcing and sparking, thus creating a high resistance path in a low voltage circuit, with its concomitant effect on the efficiency of the contact bridge (short-circuiting the tripping device), and on the characteristics of the secondary circuit of the current transformer to which it is connected.

The impedance of the tripping device is generally quite high; and with the primary current close to the value for which the relay is set, a tripping device, when cut into the circuit, may break down the ratio of the current transformer and decrease the secondary current (for the same primary current) to such an extent that the relay falls back into its short-circuiting position. This restores the secondary current to its original value, so that the relay open-circuits again. The trip coil is then cut in and depresses the secondary current, and so on. This condition creates "chattering" of the contacts. In

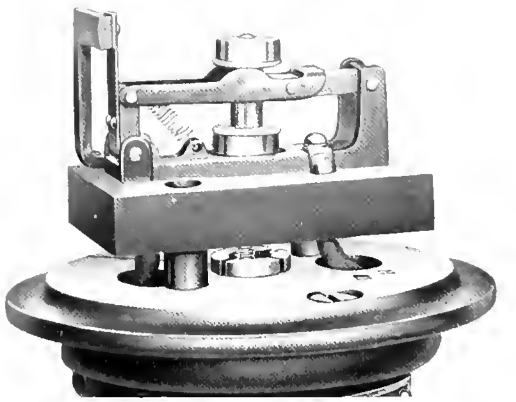

Fig. 1. Instantaneous Circuit opening Relay

order to minimize the disadvantages of open-circuiting relays, contacts are ordinarily equipped with so called quick-break devices, which open up quickly and far enough to prevent arcing, and which lock the contacts in open position against the effect of small variations of the secondary current, so as to do away with "chattering." Fig. 1 shows a typical quick-break circuit-opening contact device.

2. Relays may be instantaneous, inverse time limit, or definite time limit. With instantaneous relays the contact device will operate immediately when the abnormal conditions which the relay is to take care of make their appearance and start the moving part of the relay. With inverse time limit relays there will be a delay in the operation of the contact device, dependent inversely on the magnitude of disturbances. Many mechanical devices for causing the time lag have been developed; the more important ones consisting of a compressible leather bellows, an oil or air dashpot, or a rotating magnetic drag disk.

The compressible leather bellows is interposed between the moving part and the contact device in such a manner that, when the relay is not operating, the bellows is fully extended. The moving part of the relay presses against the bellows and tends to force the air through an aperture. The air must be driven out of the bellows and the bellows compressed completely before contact can be made. The rapidity with which the air escapes, that is, the time intervening between the start of the moving part and the completion of contact, is a function of the power behind the compressing moving part, which in turn is dependent upon the magnitude of the electrical force actuating the relay coils. The size of the hole through which the air escapes can be varied so that different time elements may be obtained for disturbing forces of the same magnitude, and different time curves for the same range of disturbances.

Fig. 2. Inverse Time Limit Circuit-closing Relay

In an air dashpot the walls of the air chamber are rigid The action of the relay propels a tight-fitting disk through the chamber, forcing the air in the dashpot through an opening. The contact device operates when the disk has reached the end of its travel. The inverse ratio of magnitude of the electrical force actuating the relay coils, and the time consumed by the disk in its travel from the initial to the final position against the resistance of the air is apparent.

In an oil dashpot the chamber is filled with thin oil, which passes from one side of a disk, through circular openings therein, to the other when the disk travels the length of the chamber. Different time curves are obtained by varying the size of the openings in the disk.

The magnetic drag device is generally used with relays in which the moving part tends to rotate, and in which the contact device consists of one contact mounted on the rotating part and the other contact on a stationary frame. The direction of rotation is such as to bring the two contacts together. The moving part carries a disk which rotates between two permanent magnets or electromagnets. Eddy currents are set up in the disk and create a drag that is directly proportional to the speed of the disk. This speed is also proportional to the torque of the moving part, which in turn is dependent on the magnitude of the electric forces actuating the relay coils. The total time consumed in bringing the two contacts together is therefore equal to the speed of the moving part (which increases with the torque) *minus* the drag in the disk (which increases in the same ratio as the torque in the moving part, but is of lower magnitude than the primary speed of the disk). Different time currents are obtained by varying the initial distance apart of the two contacts, i.e., the distance through which the rotating part must travel before contact is made.

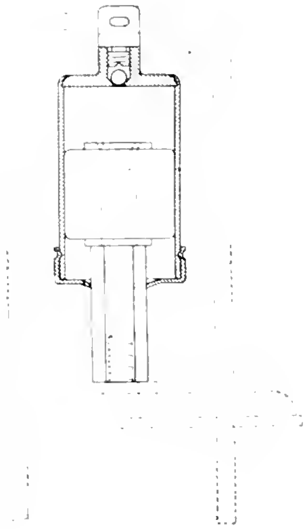

Fig. 3. Air Dashpot

Figs. 2 and 4 illustrate two commercial forms of the various types of time relay devices. As to the individual characteristics of the different devices, the following may be said:

The bellows principle lends itself easily to a very staunch, inexpensive and mechanically simple construction. The parts of such a relay are not liable to get out of order, or to necessitate repairs and re-adjustment. When given reasonable care and attention, that is, if kept oiled and free from dust and dirt, and adjusted in such a manner that the bellows is not subjected to impulses of very widely different magnitudes, this type of relay will give satisfaction.

When speaking of the time setting of any relay we refer to the time taken by a relay to make contact on the occurrence of a disturbance of just that magnitude for which it is calibrated. For disturbances of greater magnitude the time element will be smaller. Time curves for the same current setting are not straight lines, but have irregular shapes with different gradients. In general, a positive time difference should be maintained between different time curves throughout their length, for the same magnitude of disturbances. Time curves that cross each other or come too close at any point will defeat the object of giving different relays in the same system different time settings, and may cause serious trouble in the operation and maintenance of the system.

The range in time for which commercial bellows type relays may be set mechanically is from two to thirty seconds. Shorter time settings may be obtained, but are not recommended. Average operating conditions can generally be met by settings from 2 to 15 seconds.

Air dashpots have so far been adapted for small ranges in time only, as they are apt to become too big for higher time settings. It is of course mechanically difficult to keep the air from leaking out, and the time setting is affected by variations in the temperature and consistency of the air.

Oil dashpots have given very good service. Long-time ranges can be obtained in commercial types with good and constant accuracy. One objection to their use is based on the possibility of soiling the panels on which they are mounted when handling the oil for the pots, especially marble panels.

Magnetic drag devices can be made to be very accurate, but necessitate a rather delicate mechanical construction. They are in the same class as meters, and require corresponding care and supervision. The torque of disk and contact device cannot be made very great, since the passage of heavy currents through the actuating coils such as would be necessary for high torque, would affect the permanent magnets. Auxiliary devices must be supplied to handle the

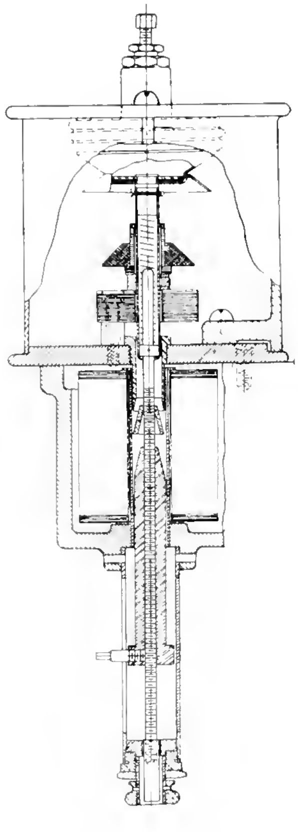

Fig. 4. Sectional View of Definite Time Limit Overload Relay

tripping current of the circuit disconnecting devices, for, with the low available torque, the contacts on the moving part and frame cannot be made strong enough for anything but very small currents.

Definite time limit relays employ generally the same integral parts as bellows type inverse time limit relays, but the moving part does not act directly on the bellows (see Fig. 4). The moving part starts immediately when the tripping value is reached, and compresses a spring. This in return actuates the diaphragm and the contact device, the time required by the spring for this operation being entirely independent of the magnitude of the disturbance, but dependent only on the stored-up energy of the spring and the setting of the air-escape hole. If the disturbance slowly and gradually reaches the tripping value for which the relay is set, the spring may not be compressed positively and may begin to react on the diaphragm before it is compressed completely. The time element would then not be definite. To take care of this it is advisable to furnish an instantaneous relay in combination with the definite time limit relay. No mechanical action would then be exerted on the spring, until the disturbance had risen (no matter how slowly) to a value sufficiently large to operate the instantaneous relay and to throw the definite time limit relay into circuit. Where direct current is available, the coil of the instantaneous relay is connected to the main a-c. circuit; the definite time limit relay having only a d-c. potential coil connected to the contact device of the instantaneous relay, and tripping in turn the circuit disconnecting device. Where no direct current is available, a circuit-opening instantaneous relay in combination with a definite time limit relay with a-c. coil is required, so that the definite time limit relay is not connected in until the disturbance has reached a value sufficiently high to operate the instantaneous relay.

When the voltage of the direct current supply is constant, i.e., where it does not vary as in the case of exciter busses with voltage regulators, a plain inverse time limit relay with direct current potential coil may be substituted for the definite time limit relay in the combination, as the current impressed on the inverse time limit relay with constant potential is constant with corresponding constant time element.

Instead of spring and bellows, a clock in combination with a fan is sometimes used. A plunger, actuated by a coil or system of coils connected in the circuit to be controlled, arrests normally a clock movement to which is geared a system of fans revolving in air. On the occurrence of abnormal conditions the clock movement and the fans are released. The angle at which the fan blades strike the air is adjustable, and their position, in conjunction with the ratio of the gearing, determines the time element. Such an arrangement gives very accurate timing, although its cost is high. The clock must be self-winding so as to relieve the operator of the responsibility of winding it. Whenever the clock gets out of order, the relay must receive expert attention to be made operative. It is doubtful whether the gain in accuracy over the method previously described justifies the greater outlay and the refinements in construction.

Regarding the operating conditions governing the selection of relays from the standpoint of time characteristics, the following should be noted:

The most frequent use of instantaneous relays results from the fact that the impedance of a relay coil is relatively small compared with that of an oil-switch trip coil. If a number of instruments and meters are connected to a current transformer, their accuracy is primarily a function of the total load imposed on the transformer secondary, decreasing as the load increases beyond a certain figure. Oil-switch trip coils have high impedance, and meter combinations requiring high accuracy are impossible with trip coils. By interposing a relay which normally cuts out the trip coil, the total load can be very materially reduced and the accuracy improved. Another field of application of the instantaneous relay may be found where the effect of disturbances in an a-c. circuit must be transmitted into another d-c. circuit, as in the case of motor or solenoid operated oil-switches or circuit-breakers. The motor or solenoid circuits of most commercial devices of this sort are d-c., and the instantaneous relay serves as a medium to actuate the d-c. motor or solenoid when the a-c. circuit develops trouble.

Inverse time limit relays may be used to reduce the strain on an oil-switch when rupturing a circuit. The sudden rush of current which occurs at short-circuit dies down very rapidly, owing to the demagnetizing effect of the armature reactance on the field excitation of the alternator. An inverse time limit relay, by holding the oil-switch in until the voltage has gone down, permits the use of an oil-switch on a circuit where the current will momentarily rise to two to three times the value at which the switch would operate without the time limit.

When using inverse time limit relays for such purposes, care should be taken that no conditions detrimental to the safe operation of the system be produced. For instance, in the case of a-c. motor d-c. generator sets or synchronous converters, a short-circuit on the d-c. side beyond the reach of the d-c. circuit breaker may cause the d-c. side of the machine to flash over if the short is allowed to hang on for some time. Inverse time limit relays may also be used where it is desirable to prevent interruption of the circuit when disturbances are only momentary, and where protection is required only against disturbances lasting long enough to cause harm to the apparatus or system.

With inverse time limit relays, by varying the time setting of the various relays, it is also possible to effect a certain sequence and interrelation of operation of oil-switches, accomplishing automatic selection of the oil-switch which is to open up according to the location and nature of the disturbance. This would apply, for instance, to the case of transmission lines in tandem or in parallel, where disturbances in any one line must not affect circuit-opening devices other than in the line where the trouble exists. Such relays are known as selective relays. They require time curves of high accuracy and reliability.

Definite time limit relays are used only where it is desirable to hold in a circuit for a certain predetermined period, no matter what the magnitude of the disturbance may be; or where it is thought that, for selective operation, the unvarying time characteristics of definite time limit relays will be safer and more reliable than selective inverse time limit relays, the time curves of which converge towards each other with increasing magnitude of disturbance.

When used for the latter purpose, the great disadvantage of having line troubles of excessive nature hang on just as long as less serious troubles must be considered, especially where a multiplicity of selective relays necessitates relative high time limits. For instance, take the case of a series of transmission lines connected with the generating station through three or four substations. For selective action, i.e., to insure that in case of trouble on any one of the lines only the relays on the particular line in trouble will operate, the relay in the line farthest from the generating station should have the shortest time element, and the relay in the line leaving the generating station the longest. The oil-switch near the generating station will hold in equally as long for trouble in the line farthest removed from the main station, where the impedance of all the intervening lines cuts down the possible magnitude of trouble, as for trouble right outside of the main station, where the magnitude of the trouble is apt to be very much greater on account of the smaller total impedance. For this reason it is advisable, especially in lines near generating stations or power transformers, to furnish, in conjunction with the definite time limit relays, other relays of short time limit, which are set high enough not to be affected by trouble in other lines farther removed from the source (the possible magnitude of such trouble being determined by the impedance of the intervening lines); but which will quickly open the line on which they are installed when trouble occurs on that line, of such magnitude as is possible only on that line.

The question may be raised, Why could not the current setting of relays without time element be used generally to act selectively by giving to the relays farthest removed from the source, where the interposed impedance is the greatest and the possible magnitude of trouble the lowest, the lowest setting and increasing the setting as the lines and relays approach the source? Reverting again to the example of transmission lines: such lines must be protected against disturbances of varying magnitude, from a high resistance leakage short-circuit to a dead no-resistance short-circuit of from, perhaps twice normal to as much as 10 or 20 times normal current. If the relays are set in accordance with the greatest possible disturbance, protection will be furnished only for such maximum disturbances, but no protection against trouble of lower order. If the relays are set in accordance with the least disturbance to be guarded against, then a dead short, even at the farthest end of the distribution system, may be large enough to operate the relays all the way to the source, and to open all the lines simultaneously instead of only the line where the trouble occurred.

In order to combine the advantages of inverse time limit and definite time limit relays for selective action and to avoid their individual disadvantages, selective time limit relays of the more modern type are arranged to give curves with inverse time limits in their first part and definite time limits for the remainder.*

*A second article in this series on relays and their applications, continuing from this point, will appear in the June issue.

THE CHARGING OF ALUMINUM LIGHTNING ARRESTERS

By E. E. F. Creighton

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This is the first of a series of three articles that Professor Creighton has in preparation for the Review. In the present contribution he reviews briefly the principal characteristics of the aluminum arrester, such as the electrostatic capacity of the cell, the safety-valve action of the film, the unusual dissolution of the film in warm electrolyte, and the necessity for periodically reforming it. These introductory paragraphs are followed by a very thorough discussion of the advantages resulting from the use of charging resistances; the maximum permissible value and the critical value of such resistances; the ratio of the stored electrostatic energy to the electrochemical energy loss; the electrochemical equivalent resistance and the ohmic resistance of the cell, etc., etc.—Editor.

Introduction

It is believed that an article embodying much new technical information on aluminum lightning arresters will prove of timely interest; and for the sake of convenience in getting the data together, the subject will be divided into several parts. This first article will deal with some of the general conditions of practice, general principles, improvements, and a number of calculations of intimate details which are related to the functioning of the arresters.

A second article will deal mainly with oscillographic tests relating to the aluminum arresters and the circuits they are designed to protect.

A third article will make a technical criticism of European practice in electrical protection and compare it in its several details to current practice in America. These articles will still leave untouched the solution of certain specific problems which are now just being worked out, and the discussion of a number of problems of protection for which there is no solution in sight.

Proper Functions of Aluminum Arresters

The factors in the operation of the aluminum arrester are very flexible and can be varied to meet any reasonable criticism. The arrester is not a universal protector against all kinds of interruptions. It meets the usual and most of the unusual needs in the protection against disruptive potentials from lightning. An arrester in a station can not protect an insulator out on the line from a lightning flash. It isn't reasonable that it should. There are certain kinds of surges of comparatively low potentials against which it is not designed to protect, for instance, it can not be used to absorb the power from a generator. It is as unreasonable to expect this as it would be to expect a hundred horse power motor to do the work of a thousand horse power motor. A case of such misuse will be cited.

The context sticks closely to general principles, treating many of the complaints as accidents of manufacture easily adjustable and jeopardizing in no way the stability and truth of the fundamental principles. Under the category of accidents of manufacture will be found occasionally such things as a leaky oil tank, defective bushing, loose horn, erroneous gap setting, defective charging resistance, etc.

Aging of Electrolyte

The electrolyte used up to some time last year had a way of deteriorating spontaneously quite independent of the natural electrochemical action resulting from the passage of the current. There was a fungus, similar to vinegar fungus, which gradually changed a part of the electrolyte into acetic acid. Acetic acid is not a good electrolyte for the aluminum cells. It has a relatively high dissolution effect on the film. It required a two years' trial of new germ proof electrolytes before it was safe to make a radical change. It was always annoying not to be able to keep the old electrolyte in store without deterioration.

The question is often asked: How often should the electrolyte be changed? There is no exact answer to this. Except where arresters are discharged for long periods, there seems to be no appreciable deterioration, excepting that from the effects of fungus.

The fungus growth is variable. It depends greatly on the exposure to the air and on the temperature. Since a germ-proof electrolyte is now available it is probable that *HG* electrolyte more than a year or two old should be changed. The germ proof electrolyte shows no appreciable deterioration after three years.

During the past few years several cases of destruction of arresters have occurred due to bad regulation of the lines. In one case the arresters were subjected to 175 per cent of normal potential with generator power back of it. This turns an arrester to functioning as a rheostat. An arrester designed to give a high current discharge at abnormal potentials evidently cannot last long if it is made to take the power from a large generator. The energy in a lightning stroke or surge is comparatively very small.

In some 13,000 volt generators, five to ten years old, corona playing to the iron of the teeth has gnawed out holes in the insulation of the coils. This condition has required extra precautions in handling the problem of protection.

Compromise of Desirable and Undesirable Conditions

Before the use of the aluminum arrester, lightning discharges to ground took place from the leads of transformers and generators either at the bushing or at the end coils. This was due to the fact that a considerable resistance and spark potential existed in the lightning arresters. The aluminum arrester, where used, has done away with these failures so completely that during the past five years there has not been reported enough cases to make them worth considering. To those who are familiar with a number of transformer failures during the past few years, it should be explained that the point of failure has been situated in internal coils, and the failures were due, not to excessive potentials that were not taken care of by the lightning arrester, but to local resonance in the coils themselves. In other words, charges of the same frequency as the natural frequency of a transformer coil but of a potential not much above normal line potential, can enter a transformer and cause a potential to rise locally on certain internal coils without in any way straining the insulation at the terminals of the transformer. Lightning arresters can aid in this protection only by preventing an excessive potential at their own terminals. For internal surges a surge protector is necessary.

The good qualities of the aluminum arrester have not been secured without introducing certain characteristics which by some engineers have been considered undesirable. For example, one of these features is the necessity of charging the aluminum cell from time to time in order to preserve the insulating film on the aluminum plates. The actual resistance of the aluminum arrester independent of its films is necessarily very small, since its discharge rate is about 600 amperes at double potential, no matter how many cells are placed in series. In order, then, to keep down the charging current it is necessary to keep the films in good order. Attempts were made in the early days of the aluminum arrester to get along without the re-formation of the films. The results were invariably disastrous. The only known method of doing this is to introduce in the circuit a resistance so high that it destroys the value of the arrester as a protective device. When such series resistance is obtained by the use of high resistance electrolyte, the detrimental effect must be determined by careful investigation, such as an oscillographic test. With the knowledge of the area of cross section of electrolyte, and the amount of electrolyte, the matter can, however, be determined with fair satisfaction by simply measuring the specific resistance of the electrolyte.

Cost of Installation versus Charging Resistances

After a vain search for an insoluble film, it became a necessity to charge the aluminum cells, and in order to simplify the apparatus and keep down the cost, which is indeed a part of the engineering problem, arrester installations were made without charging resistance. Where the conditions of installation warranted the expense without question, such, for example, as their use on cable systems, charging resistances were invariably used in the design. On overhead lines there has been a question as to the necessity of charging resistances, although from a technical standpoint their use has always been advisable. Thousands of these installations have been made and it has been rare indeed that the spark of the charging current of the arrester has given any oscillations in the circuit which could be considered dangerous, although telephone disturbances by induction have been annoying. In such cases the condition of the film became of still greater importance, and instead of depending on the appearance of the spark at the horns, convenient forms for the application of ammeters were made which would give a better knowledge of the conditions of the films. Furthermore, the horn gaps were arranged with spring contacts so that during the ten seconds of charging the aluminum cells, the spark was entirely cut off. There is absolutely no oscillating effect in charging when there is no spark.

Unusual Dissolution of Films

It has happened frequently that an aluminum arrester, put under a severe discharge for a long period, has shown no signs of failure or distress. The next day, however, when this arrester was being charged, a great tendency to damage by the dynamic current was apparent. This is due to the fact that after the arrester has been in operation for a considerable period as the result of an arcing ground, the electrolyte becomes unusually heated, and the films are dissolved with greater rapidity as the temperature of the electrolyte rises. If all users would take the precaution of charging their arresters frequently during the time that the electrolyte is cooling down the films could be maintained in good condition without the destructive currents which take place after the films have stood for several hours in the warm electrolyte. This condition called for some engineering solution. It is one of the strong factors in deciding on the general adoption of the charging resistance.

The Charging of a Condenser and the Suppression of Oscillations

It is well known that the aluminum cell is an electrostatic condenser of comparatively high capacity. Therefore, when the circuit is first closed there is naturally a rush of current into this condenser to charge it up. This is a valuable feature if the rush of current is due to a lightning stroke, where it is desirable to absorb the charge as quickly as possible. Where it is dynamic current, however, there is nothing gained. It is also well known that every spark or arc in any circuit containing inductance and capacity tends to set up oscillations, but if the resistance in series is equal or greater than the critical resistance, the tendency to oscillate is entirely counteracted. A current may take place, even through a series spark, without producing oscillations. When the conditions are such as to permit the oscillations, however, the oscillations will die away more or less rapidly according to the value of resistance placed in series.

Surges From All Switching

The starting of a charging current in an aluminum arrester is not different fundamentally from starting up any piece of apparatus or switching on a length of dead line. Before the line switch is closed, the device, no matter what, is without electric charge. Before the metal parts of the contacts meet a spark jumps out and closes the circuit, and the device suddenly takes a charge from the line locally. This causes a disturbance of potential which travels through the circuit. The arrester circuit is thoroughly damped.

Water Trough Analogy

An analogy to this condition is found in dipping a bucket of water out of a long trough. If the bucket of water is suddenly raised out, the water in the trough will rush into the hole so formed and a wave will thus be started which travels to the end of the trough. The water waves are reflected from the ends of the trough and continue to agitate the surface until all the energy given by the impulse of lifting out the bucket is frittered away in heat. The slower the movement in lifting out the bucket the less the agitation of the water level.

So it is with all forms of switching. Since every electrostatic condenser is momentarily a short circuit and since every device contains electrostatic capacity, all present day practice in switching sets up surges on the system. But these surges have no importance so long as they are harmless. Closing a switch through resistance corresponds to lifting the bucket out slowly.

High Frequency and the Electrostatic Capacity of a Single Cell

When very high frequency currents, such as lightning, are applied to an aluminum cell, the capacity of the cell being great, the potential across the cell will be comparatively small unless the current has some tremendous value. For example, at 500,000 cycles it requires a current of 1200 amperes to raise the potential to 100 volts. The normal potential of a cell is 250 volts; therefore, in order that a lightning stroke having a frequency of 500,000 cycles shall raise the potential of a cell up merely to its normal value, there would be required a discharge of 3000 amperes. This capacity effect may be a factor in explaining how the aluminum arrester has in a few cases been able to protect apparatus from direct strokes of lightning, the large electrostatic capacity of the aluminum cell acting as a shunt in parallel to the electrical apparatus. Thus, the condenser effect is one of the valuable characteristics of the aluminum cell.

Low Frequency, High Potentials and the Electric Valve Effect

To utilize this valuable characteristic of a condenser the existence of a high frequency is necessary. There are on the circuit, however, many surges of high potential of relatively greater energy which must also be discharged. If these surges have a frequency of only 1000 cycles, then the electrostatic capacity of the aluminum cell would take only six amperes to bring it up to its normal potential of 250 volts. There is no doubt that it requires more than six amperes to successfully discharge the low frequency surges. Hence under this condition the capacity of the aluminum cell has little value, and it is then that the critical voltage effect of the electric valve of the aluminum cell comes into play. At double potential the aluminum cell takes more than 1000 times as much current as it does at its critical potential. Therefore the discharge rate is independent of the frequency of the surge. If the surge is a single impulse it has no frequency and in that case the aluminum film allows the discharge to take place through it in very much the same manner that steam discharges through the safety valve on a boiler. The film does not actually break down but simply opens up and lets the charge through and closes when the potential reduces again to normal value.

In these two factors, namely, the electrostatic capacity and the critical film voltage combined with the low internal resistance, lie the valuable characteristic of the aluminum cell as a protector. These characteristics carry with them the feature of requiring charging.

Charging Resistance and Charging Potential

The best practice consists in the utilization of a resistance in series during the interval of ten seconds that is required each day to reform the films (Fig. 1). This series resist-

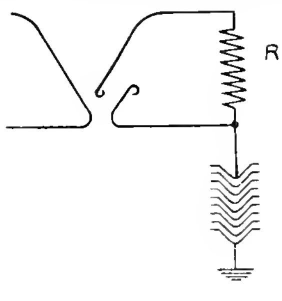

Fig. 1

ance must be high enough to prevent an excessive rush of current in case the cells are in bad condition, and at the same time it must not be so high as to prevent the cells getting their normal potential. It is now a well known fact that the working critical voltage of the aluminum cell is the voltage at which it is charged. All the thickness of film above this voltage is dissolved away. Therefore it is important that the cell shall get the full potential that it would normally get from the circuit if the resistance were not in series.

Fortunately, the natural relations in the circuit are helpful in this case. Since the aluminum cells are condensers their applied

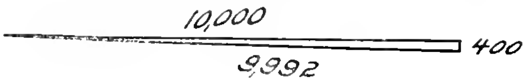

Fig. 2

potential will be at right angles to the drop in potential across the resistance, as shown in Fig. 2. Since the charging current is only about 0.4 amperes on 60 cycles a considerable value of resistance can be placed in series without reducing the potential across the cells by a very great amount. This comes from the fact that the hypothenuse of the right angled triangle is very nearly equal to the longest side, so long as the third side is comparatively short. It is possible, therefore, to place in series with the aluminum cell a resistance which would limit the maximum current to 10 amperes if the cells were completely short circuited. In other words, if the films are very much out of condition the initial current rush will be 10 amperes, and the voltage will be entirely absorbed by the resistance.

Normally, this will be the condition for only an instant. The flow of current will form the film. The film will absorb more and more voltage from instant to instant, decreasing the current and the potential will automatically shift from the resistance to the aluminum cells. Finally, when the cells are fully formed the current is about 0.4 amp. at 60 cycles and 0.2 amp. at 25 cycles. The drop of potential on the resistance has decreased in proportion to the current. When the current was 10 amp. there was full value of line potential on the resistance, but at 0.4 amp. the drop of potential across the resistance is only 4 per cent of the line potential.

A specific case always helps to clarify. If the Y potential is 10,000 volts, the final condition gives a drop of 400 volts across the 1000 ohms of charging resistance.

Since this potential of 400 volts is at right angles to the potential across the cells it makes a decrease of only 8 volts on the aluminum cells below the applied potential. The values are given in Fig. 2, which are:

10,000 volts applied, 9992 across the aluminum cells, and 400 volts across the resistance.

Maximum Permissible Charging Resistance

It is interesting to calculate how much charging resistance is permissible. With the maximum limit determined, it gives a range of possible values which are convenient when the problem is viewed from the standpoint of absorbing the energy of the surges from a line without the possibility of an oscillation. It is assumed permissible to have 1 per cent less potential across the cells than the impressed potential of the line.

A Calculation of the Maximum Permissible Value of Charging Resistance

Taking 99 per cent of the full line potential as a permissible value of potential at which to charge the aluminum cells, then the potential drop across the resistance may be 14 per cent. (From the trigonometrical tables the angle 8 deg., which gives cosine = 0.99, has a sine of 0.14.) At 10,000 volts Y potential, the potential across the resistance at the end of the charging operation may, then, be 14 per cent of 10,000, which is 1400 volts. At 0.4 amp. for charging current the resistance may be 3500 ohms (1400 volts ÷ 0.4 amp.). The maximum possible value of initial current rush would then be only 2.86 amp. (10,000 volts ÷ 3500 ohms.) On a 25 cycle circuit the charging resistance might be made as high as 7000 ohms if other conditions demanded it. The calculations of the upper limit of charging resistance may be condensed into one operation: For a 99 per cent film voltage, the resistance may be numerically 35 per cent of the Y potential. From this relation it will be seen that the actual value of the charging resistance will increase directly with the potential rating of the arrester.

How Regulation May Affect the Critical Film Potential of an Arrester

As a matter of actual practice, the variation in impressed potential from regulation is several per cent. If the arresters are charged at a time of minimum load on the system and subsequently are caused to discharge when the load is high, the impressed potential will be somewhat above the potential corresponding to the formation of the film. An extra quantity of electricity is then needed to form the films to the slightly higher potential. This is, ideally speaking, an undesirable condition. Practically, no information is at hand to attribute any harmful effects. There are many systems on which the arresters are charged at midnight when the load is light rather than in the evening when the load is at its maximum. Arresters near the power house will be the ones mostly affected by the difference in potential due to regulation.

Critical Resistance

We have now considered the charging resistance from two different viewpoints. The first viewpoint was that of a permissible maximum current in the resistance, arbitrarily chosen as 10 amp. (charging resistance in ohms is then numerically equal to 10 per cent of the Y voltage). The cells then receive 99.92 per cent of the line voltage.

The second viewpoint was that of a permissible difference of 1 per cent between the voltage on the cells and the line voltage. This gives a permissible charging resistance numerically equal to 35 per cent of the Y potential.

The problem will now be viewed from a third standpoint. The series resistance necessary to prevent an oscillation should equal what is commonly called the "surge impedance." This will be referred to as the critical resistance. The surge impedance in ohms is found by taking the square root of the inductance in henrys divided by the square root of the capacity in farads:

$$z = \sqrt{\frac{L}{C}}.$$

It is seen that the surge impedance depends, not on the actual value of inductance and capacity but on their ratio. When this equation is applied to a line the capacity and inductance per mile may be used. For overhead lines the surge impedance increases as the adopted potential for the system increases but not so rapidly as the direct proportionality of potential. Otherwise expressed, the higher the potential, the greater the spacing between the conductors, and consequently the greater the inductance and the less the capacity. The following range is given: No. 0 B.&S. wire, 18 in. apart, $L = 0.00276$ henry, $C = 0.0109$ mf., surge impedance $= 500$ ohms. No. 0 B.&S. wire, 150 in. apart, $L = 0.00394$ henry, $C = 0.00757$ mf., critical resistance $= 720$ ohms. These values are based on line to line surges of a three-phase circuit. Many of the surges of importance are between a line and ground. The surge impedance in this case is of the order of 500 ohms.

If for other reasons it is not desirable to use so much series resistance, it is permissible to use less. Dr. Steinmetz has shown that where the resistance in series is only 1/5 the value that would just prevent a reversal of potential (i.e., the critical value), it is still sufficient to damp out the surges to relatively small values within a cycle of the surge. From the viewpoint of damping in the circuit of the arrester, 500 ohms might be considered the minimum for overhead lines.

The inductance of cables is small as compared to that of overhead lines, and the electrostatic capacity larger. The critical value of resistance, calculated from the ratio

Note.—Under "Critical Resistance" and succeeding headings, some apparent inconsistencies in the rate of discharge may be noted. These are to be acco…ated for by changes that were made in the proof, in the absence of the author, as a result of having viewed the matter from a somewhat different standpoint. This confusion will be explained away in the next installment. Editor.

of damping the surges. The aluminum cells will stand 10 amperes initially and will form up easily without risk of self-damage, even if the films are very badly dissolved. Each arrester, no matter for what voltage, will have two ratings of discharge, viz., 10 amp. and 600 amp., approximately, at double delta potential. (Double delta potential is a safe test potential for electrical apparatus, and as a convenience is chosen as a standard for comparing types of lightning arresters.)

Some Characteristic Curves of an Aluminum Cell

In the aluminum cell the relations of impressed e.m.f., current, energy loss, power-factor, etc., are more elusive even than the corresponding relations in the laminated iron core of electromagnets. There is a considerable resemblance in certain respects between the two. To have any definite knowledge of the magnetic conditions it is necessary to know the history of the magnetic cycle of hysteresis and the mechanical and temperature treatment of the iron. Likewise, in the aluminum cell a complete history of the various processes must be known in order that its actions may be predicted. In place of hysteresis and eddy current losses, there are electrochemical transformation losses and I^2R losses in the cell. Except for slight effects of aging, an iron core placed in a coil has relations of current, e.m.f. and power losses which remain fixed and reproducible instantly at any time. Not so with the aluminum cell. Every instant in its life makes its change, usually small but sometimes great. In the early developmental work it was the bane of the experimenter's life to pin the cell down to any particular behavior which it was willing to repeat. Gradually, there emerged from its chaotic behavior the laws governing the dissolution of the films with time and temperature, and

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nce, an electrolyte which gives
…own internal losses and one which, from comparative observation extending over a month, would be chosen as the best, contains an element which turns treacherous after the electrochemical processes have proceeded to an indefinite stage.

The history of this development and the relations of the factors in the aluminum cell would make a chapter by themselves. It is sufficient for present aims to point out that a full knowledge of the history of a cell is necessary to properly interpret the relations published in the form of curves. By the same treatment of a cell the same general results may be obtained, but with the same materials and different treatment the characteristics are likely to be quite different. Incidentally, this condition accounts partially for the engineering attitude toward foreign-made aluminum cells, of which more will be said in a later article.

Referring to the specific relations shown in Fig. 3, it must be known that the plates of this cell were fully formed to 360 volts impressed before the readings of current, e.m.f., and power were taken. The cell represented by these curves possesses the usual initially favorable qualities, that is, low losses and low power-factor. In the early life of an active cell, the losses increase rapidly from hour to hour until about five times the initial loss is reached. (Fig. 4). The losses then remain about constant until the plates are nearly worn out. It will be seen from Fig. 3 that the current is proportional to the voltage, but the losses increase more rapidly. The interpretation of this condition is that the angle of lag between the current and e.m.f. decreases as the voltage increases. In other words, the power-factor increases rapidly at high potentials.

At 280 volts impressed, a very usual value, the current is 0.0078 amp. per sq. in., the power loss is 0.205 watt per sq. in., and the power-factor is 0.094. At 250 volts impressed the current is 0.0069 amp. per sq. in., the power loss is 0.15 watt per sq. in., and the power-factor is 0.083. As a convenient figure for calculating the losses in an aluminum electrolyte cell at the usual applied potential, a range of values from 0.2 to 0.8 watt per sq. in. may be used, according to the age of the cell, the purity of the aluminum, and other factors.

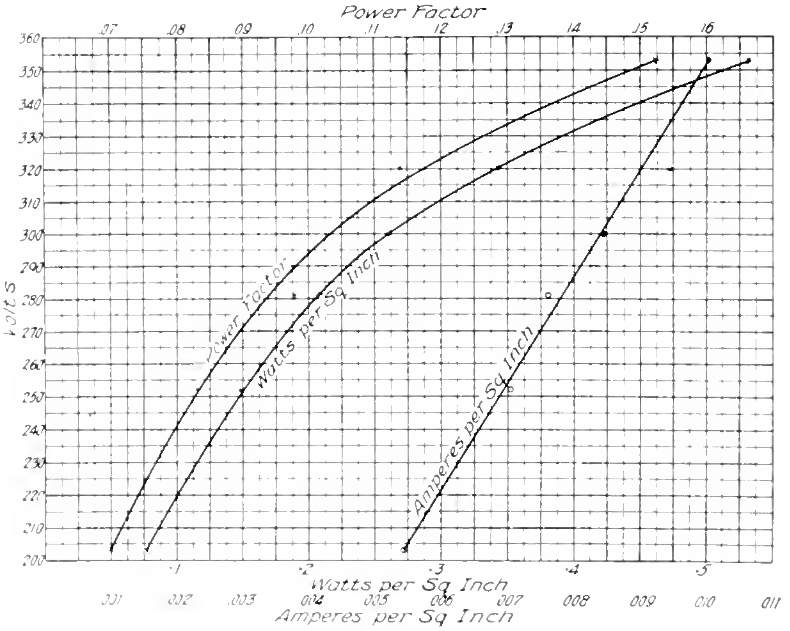

Fig. 3

Fig. 3: Tests of a good aluminum cell with the films fully formed. Frequency is 60 cycles per second. Curves of volt-amperes, volt-watts, and volt-power-factors. Current and power loss given in terms of square inches of area of the aluminum plates.

Electrostatic Capacity of an Aluminum Cell

The capacity per square inch can be calculated from the relations of the current, frequency, and e.m.f. $C = \frac{I}{E\omega} = \frac{0.0078}{280 \times 377} = 74 \times 10^{-9}$ farad $= 0.074$ m.f. per sq. in. The capacity will vary, according to the thickness of the film, over a usual range of 0.07 m.f. to 0.11 m.f. per sq. in. (200 to 300 volts).

Stored Electrostatic Energy versus the Energy Loss in Electrochemical Action

No better proof of the damping of high potential oscillation in an aluminum cell can be given than is furnished by comparing the value of stored energy to the value of the dissipated energy per half cycle. The stored energy is given by the equation:

$$\text{Energy} = 1/2\ C\ E^2.$$

At 280 volts effective (398 volts max.) the energy stored in electrostatic charge is 0.006 joules per sq. inch. At the same impressed potential the energy loss per half cycle is 0.0017 joule to 0.0068 joule per sq. inch. At this particular potential 25 per cent to 100 per cent of the stored energy is irretrievably lost in electrochemical transformations. It does not require much increase in potential in any case to be able to state that the losses in a single cell are equal to the stored energy. Later it will be shown that the losses of cells in series are additative and that it requires the use of several cells in series to prevent the oscillations of an overhead line.

At lower potentials the losses are relatively not so high, and therefore, so far as the electrochemical loss is involved, there is a little more energy left over than at high potentials. For example, in a single cell the lost energy in electrochemical action at 200 volts effective varies from 1/5 to 4/5 of the stored energy.

At potentials over 300 volts effective, sparkling at the surface of the aluminum plate uses up a great amount of energy by transforming it directly into heat.

Endurance to Discharge

It is the sparkling at the films under extremely heavy and continuous discharges, coupled with the distance between the aluminum electrodes, that puts an ultimate limit on the discharge capacity of a cell. The mechanism of failure of a cell and the conditions which can cause it will be illustrated by an oscillographic study in a succeeding article. At present it is sufficient to state, as is shown by Fig. 3, that at abnormal potentials the energy losses are extremely high and are very much greater than the energy stored in the capacity.

Equivalent Resistance of the Electrochemical Transformation of Energy in the Films

The standard text books have shown us how to express losses of energy in terms of resistance, even while there is no ohmic resistance involved. This is artificial. There is no obstruction to the flow of current; it is merely convenient at times, in making comparisons, to reduce all factors to a common basis.

The most common illustration of such a wrinkle is found in treatments of core losses in transformers. We know that the core losses do not limit the flow of current but only change the power-factor. Likewise in the aluminum cell, the electrochemical losses do not limit the discharge current when used as an arrester. The resistance of the electrolyte is real ohmic resistance and does limit the current, but the discussion is of the electrochemical changes in the film.

Although the electrochemical changes do not limit the current flow, they are nevertheless of great importance. They absorb the energy in the surges. This feature forms a vital fundamental distinction between the aluminum arrester and any of the forms of arresters using straight series resistance. Resistance also absorbs the energy of the surges but it is objectionable in that it will not allow the free discharge of a heavy surge. The ohmic drop of potential along the series resistance is sometimes great enough to cause the puncture of insulation. Resistance is always resistance and limits the current flow. Energy loss is not always occasioned by resistance, as witness hysteresis, radiation of light, corona, electrochemical change, etc. All these are non-reversible processes. So far as the return to electrical energy is concerned, the loss is irretrievable—a prime desideratum in the absorption of surges. The reversible processes, like the storage of energy in a condenser and a magnetic field, may be used in protective work as a temporary expedient, but they give no real protection in themselves.

The real object here in expressing energy in the aluminum cell in terms of resistance is in order to compare its effect to that of the charging resistance in damping oscillations. Placing the power lost per square inch of plate equal to an artificial i^2R and using the value of capacity current corresponding to 280 volts effective (Fig. 3), the following value of equivalent resistance is obtained:

$$R = \frac{0.205 \text{ to } 0.8 \text{ watt}}{(0.0078)^2} = 3,400 \text{ to } 13,000 \text{ ohms.}$$

All arresters use more than a single square inch of film surface, and therefore the equivalent resistance will be less. With 35 sq. in. of film in the electrolyte the equivalent resistance per cell will be one-thirty-fifth as much (100 to 370 ohms).

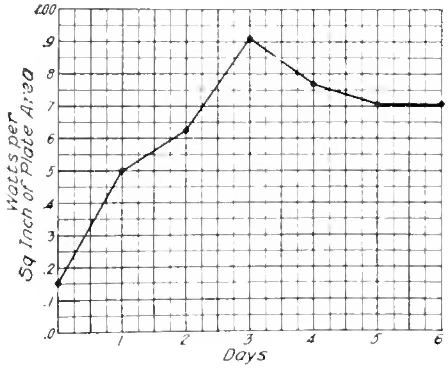

Fig. 4

Fig. 4: Curve shows the increase in energy loss in the film as it is operated continuously. This test is possible in a single cell where the radiating surface is sufficient to keep down the temperature to a reasonable value. This is the usual characteristic for aluminum cells operating at 240 volts. The energy rises to a maximum in about three days, then decreases slightly for a day or two and remains constant at four to six times its initial value until the plate is worn out. Calculations of the life of an arrester based on three weeks' continuous run corresponding to these tests on a single cell give a life so great that it seems reasonable to expect a life of ten years from an arrester which receives reasonable care.

Limiting the area of film immersion to 35 sq. inches has a very distinct importance. It gives an equivalent resistance, even in arresters for low voltage, large enough to equal approximately the critical resistance, necessary to prevent oscillation between the line and ground. It is the feature which prevents the arrester from acting as an arcing ground when being charged through a spark at the horns. This point in the design of an aluminum arrester is of great importance where neither charging resistance nor spring contact clips at the horns are used during charging.

Ohmic Resistance in an Aluminum Cell

The resistance of the electrolyte in a cell forms a real ohmic resistance which limits the flow of current and absorbs energy. A very usual value of resistance in the electrolyte is ½ ohm per cell.

At normal potentials (300 volts or a little less per cell) the current is limited, not by the resistance of the electrolyte but by the peculiar action of the film. It is only after the electric valves of the films open up that the current is sufficient to cause an appreciable drop of potential in the resistance of the electrolyte. For example, a charging current of 0.4 amp. gives a drop in potential in the electrolyte of only 0.2 volt, while the film is absorbing 280 volts effective. At 600 amp. discharge, however, the electrolyte is absorbing about 300 volts while the film is still absorbing only a little more than 280 volts. This condition of discharge is that of double normal voltage per cell. The rule for calculating discharge rate at double-potential is to divide the potential in excess of normal by the total ohmic resistance of the electrolyte. For momentary discharges this relation has been verified approximately by oscillographic tests. This factor alone is sufficient reason for not making the mistake of using high resistance electrolyte. One might just as well go back to the old water rheostat.

Collection of Information on the Resistance (Real and Equivalent) in the Lightning Arrester Circuits

If 10 amperes through the resistance rods at line potential is chosen as maximum current for all arresters, then the following relations exist:

Arrester Potential Line to Line	Charging Resistance Per Phase	Resis. in Electrolyte Per Phase	Equiv. Resis. in Film at Normal Potential Per Phase
2,300	133	2.4	500 to 2,000
6,600	382	6.4	1,500 to 6,000
10,000	580	10.	2,200 to 8,800
13,200	760	13.	3,000 to 12,000
20,000	1160	22.	4,400 to 17,600
25,000	1450	24.	5,600 to 22,400
33,000	1910	48.	7,800 to 31,200
45,000	2600	65.	10,000 to 40,000
60,000	3500	88.	14,000 to 56,000
80,000	4600	115.	17,600 to 70,400
100,000	5800	145.	22,200 to 88,800

There are two rates of discharge depending upon the path followed by the discharge. If the discharge takes place directly through the cells, shunting out the charging resistance, the rate is 600 amperes for the lower and 400 amperes for the higher voltage arresters. This rate is calculated by assuming double potential which gives a superpotential per phase equal to the phase voltage. This superpotential divided by the electrolyte resistance per phase gives the discharge rate for this path. If the discharge takes place through the charging resistance and the cells, the discharge rate is the superpotential divided by the combined resistance of the charging resistance and the electrolyte resistance, or about 10 amperes. The third column is based on a uniform spacing of 0.3 inch for the medium and lower voltages. The spacing in high tension arresters is a little greater and therefore the discharge rate is proportionately a little less.

It has already been explained how the equivalent resistance does not enter into the calculations of the discharge rate. It represents the energy loss. By comparing it with the surge impedance of the circuit (about 500 ohms for an overhead line) the conditions under which oscillations are dampened out can be determined. The 2300 volt arrester averages a resistance equal to twice the critical value. The minimum equivalent resistance will damp out the oscillations in about one cycle of the *natural* frequency. All the higher voltage arresters have equivalent resistances that are successively higher as the rating increases. For arresters from 6600 volts up, the minimum equivalent resistance is greater than the calculated critical resistance. The charging resistance increases the absorption by its own relative value. At 25,000 volts the minimum possible equivalent resistance is more than four times the average critical resistance, while at 100,000 volts the equivalent resistance is from 20 to 80 times the value of the critical resistance.

Why Use the Charging Resistance?

After noting the factor of safety in the equivalent resistance, the question might naturally arise, why is the charging resistance needed? There are several reasons. First and foremost, the equivalent resistance does not limit the initial rush of current into the arrester. It is important to limit this current when the films are very much dissolved, as this is, first of all, a matter of protection of the arrester against damage during the process of charging. An operator is seldom aware of the effects of long continued discharges on an arrester, even if he does know how severe the discharges have been. At times of trouble he is usually occupied at the switchboard and in the telephone booth. There is no outside appearance to indicate the conditions of the films. The use of the charging resistance makes it safe to charge the arrester, even if the films are badly dissolved. In the next article will be shown an oscillogram of the charging of an arrester through resistances after the arrester had stood idle for six weeks.

In the second place, the damping conditions discussed above had reference to oscillations through the arrester cells to ground. This is not the whole story there are the ripples along the line to be considered. Referring back to an analogy in the early part of this article:—after the bucket of water is raised out of the trough there are more or less ripples running over the surface of the water, according to how quickly the bucket is lifted out and also to the volume of water displaced. During charging, the gaps at the horns are sufficiently short to allow the arrester to operate in the function of a surge protector and thus absorb the ripples on the line. There is surely no virtue in these ripples, even if they can be absorbed. Since the charging resistance, chosen to protect the arrester against unforeseen conditions, eases off the initial current rush to a small value, the matter of ripples can be made negligible and may therefore be dismissed from the discussion for the present.

In the third place, there is the effect of the first impulse to be considered. This is not a matter of oscillation. The aluminum cells taking initially a sudden charge from the generator circuit draw this charge through the inductance of current transformers. The rate of change of current $L\left(\frac{di}{dt}\right)$ is sufficient in some cases to cause a spark across the closely-placed terminals of current transformers. This spark must be kept away from the insulation of the leads, as it would finally cause carbonization. The charging resistance and contact clips reduce this drop of potential at the current transformers.

In the fourth place, and often of prime importance, is the induction on parallel telephone lines during charging. Here, again, the use of the charging resistance is beneficial in reducing the initial induced shock and the resulting noise.

The detailed characteristics of aluminum arresters will be continued in the next article.

EXPERIMENTAL TESTS TO DETERMINE THE EFFECT OF A COLORED BACKGROUND UPON VISUAL PERCEPTION

By Sydney W. Ashe

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Experiments have been performed in the past to determine the variation in visual acuity with black objects against white backgrounds for lights of different colors. Among the first acuity measurements carried on in this country were those of the writer with others at Columbia University in the year of 1909. The results of this early investigation were the finding that a 16 c-p. carbon lamp unscreened in the field of vision at an angle of about 8 deg. decreased one's ability to read approximately 30 per cent; that there was a real difference in acuity for different colored lights; and that it was possible to employ a flicker photometer for a study of this nature.* The present investigation carried the study of acuity into the field of the colored background. The practical importance of such an investigation is apparent. Author's Note.

Helmholtz, the world's greatest investigator and writer on Optics, in attempting to define the functions of the eye, produced a volume of 1057 pages. From this, it may be judged to what a limited extent any subject pertaining to illuminating efficiency can be covered in a short article.

In most studies of acuity values are usually obtained in terms of the black and white series. When we enter the color series many difficulties immediately arise. Investigators, in trying to analyze the variables which present themselves, have used monochromatic light sources—changing the wave lengths. Results from such measurements are interesting from a physical viewpoint. They have less value, however, from a commercial standpoint, as our wall coverings, our scenery, and our usual light sources are of many different mixtures of colors.

In the present tests, therefore, it was realized at the start that, in order that the conclusions might have a practical value, commercial light sources and commercial colors should be used. The series of colors investigated is not as comprehensive as might be desired, but the method used is interesting and may prove suggestive to others. The results are also of value in showing that the intensity of reflected light from an object is a much more important factor than its color in affecting one's ability to perceive. The method used in conducting these tests consisted of two parts: first, the making of such measurements of a particular color that it could be designated definitely in terms which would allow of its being duplicated; second, the using of these colors as backgrounds to a test object and the determining, if possible, what effect, if any, the color of the back-

* Electrical World, Feb. 25, 1909.

ground had upon the ability to see. The third part of the investigation, which is not included in the present article, will be to vary the color of the object as well as the background and to see what effect this has. As this part of the investigation brings in the

Fig. 1. Ives Colorimeter

subject of color contrast as a large variable, it will therefore necessarily involve many measurements before conclusions can be drawn.

Conclusions of Present Investigations

Given a black object against a colored background, if the intensities of the reflected light from the differently colored backgrounds remain the same, one's acuity seems to remain the same, except in the case of especially dark colors such as dark red and dark blue. In case of the dark colors, the percentage of light reflected from the black test plate (about 8 per cent) undoubtedly affects the accuracy of the readings. The ability to perceive a given object seems to depend upon two things: the maximum intensity of either background or object, which is the plane of illumination the eye is functioning over, and in which the size of the pupil of the eye plays an important part; and the ratio of intensities of the object and its background, which is ordinarily referred to as Fechner's ratio.

TABLE 4

ACUITY READINGS TAKEN BY THREE OBSERVERS USING VARIOUS COLORED BACKGROUNDS

Color of Background	Reflected Intensity	Reading Distance, In.		
		Mullen	Ashe	Putnam
1. White	4	38.0	49.0	37.0
2. Orange	4	38.6	48.3	39.8
3. Yellow	4	39.4	48.2	36.0
4. Green	4	39.0	48.1	36.8
5. Purple	4	38.2	46.0	36.0
6. Red	4	37.0	44.0	33.2
7. Blue	4	36.0	46.0	33.0

Procedure

As Fechner's ratio has been investigated many times in the past and has been thoroughly established as the fundamental principle of photometry, it seemed unnecessary

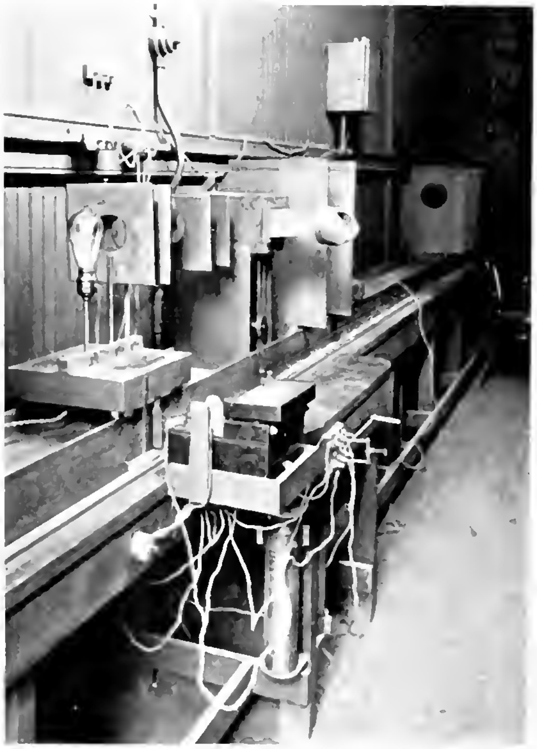

Fig. 2. Rood Flicker Photometer Installed on Laboratory Bench

to investigate this part of the subject. In the latter part of this article, however, a short description of an experimental method, which can be used to prove Fechner's constant, is given for the benefit of those unfamiliar with the theory.

Color Designation

There are several ways in which a complex color may be designated. The method which was used in the present investigation has been to determine the relative percentages of the three primaries which go to make up this color by means of an Ives colorimeter (Fig. 1). As the operation of the colorimeter has been described before in the technical press, it seems unnecessary to give a detailed description here. The color of the light which is used as a standard for the colorimeter must always be specified, as the measurements made are in terms of this color. For instance, if a tungsten lamp, operating at an efficiency of 1 watt per candle, is used in measuring the percentages of three primary colors reflected from some colored surface, a slightly different answer will be obtained than if a certain specified form of daylight is used as a standard. While the answer in the former case may not be the exact quantitative values in terms of daylight, it still serves as an excellent reference standard which any one else desiring to make measurements may duplicate and compare.

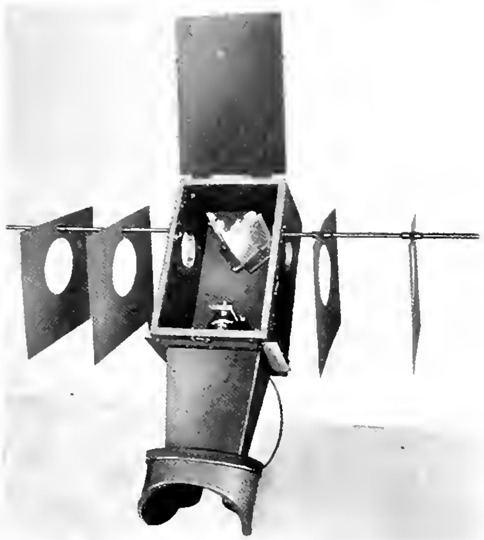

Fig. 3. Rood Flicker Photometer Head

The second feature used in these tests to designate the color is the coefficient of reflection of the colored surface. This can be most easily determined by means of a Rood flicker photometer such as shown in the illustration (Fig. 2). The principle of this photometer and of this method has also been described in technical papers, so that it is

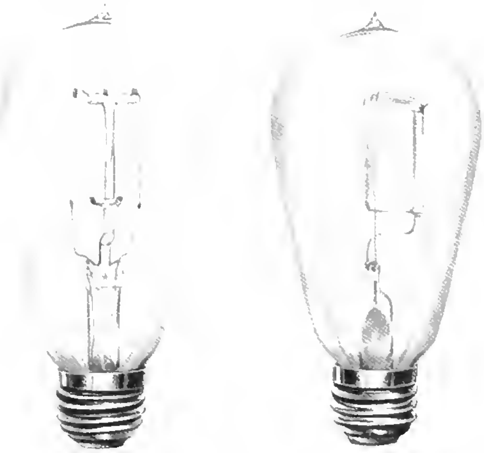

Fig. 4. 8 C-P., 45 Volt Standard Lamps Used in Tests with Rood Flicker Photometer

unnecessary to make more than a brief mention of the procedure here.

The photometer head (Fig. 3) consists of a V-shaped piece of wood, as shown in the illustration, inside of a box which is illuminated from two sides using standard lamps (Fig. 4). This arrangement is known as a "Ritchie wedge." Before the wedge, pointing toward it at its center, is a metal tube which is rotated. In the end of this tube is mounted a ten-degree prism. If an observer looks through this tube, rotating it slowly by hand, he sees first one side and then the other side of the wedge moving across the field. When this is rotated rapidly a flicker is produced. The flicker is made up of two components: one due to a difference in color and one due to a difference in intensity. As the flicker, due to a difference in color, is of a much slower period than that due to intensity difference, the former disappears first while a setting is being made, leaving the final setting to be made by intensity difference.

If we desire to obtain a coefficient of reflection of a colored card, we first use two white cards on both sides of the "V" and balance the lamps in terms of each other. We then substitute one of the colored cards for one of the clear cards on one side of the "V" and redetermine, with this arrangement, the relative candle-powers of the same two lamps. If, for instance, in the former case the candle-power of the "X" lamp was 12 and it became

4 candle-power when a red card was substituted for a white one as a reflecting surface in the photometer head, we would say that the coefficient of reflection of the red card

Fig. 6. Showing Method of Varying Intensity on Grille

was 4/12 or 33 1/3 per cent, and the coefficient of absorption was 8/12 or 66 2/3 per cent. In the tests, the various colored cards used and their coefficients of reflection as determined in this manner, were as follows:

TABLE 1

COEFFICIENTS OF REFLECTION OF THE VARIOUS COLORED CARDS USED IN ACUITY TESTS

Color	Coefficient of Reflection
Black	7.95%
Red	30.30%
Green	62.6%
Yellow	92.8%
Blue	28.8%
Orange	52.5%
Purple	37.95%

TABLE 2

PER CENT COMPOSITION, IN TERMS OF THE PRIMARY COLORS, OF THE LIGHT WHICH IS REFLECTED FROM THE COLORED CARDS

Color	Percentage of Primaries		
	Red	Green	Blue
Daylight	100%	100%	100%
Red	31%	23%	16%
Green	31%	100%	34.5%
Yellow	50%	100%	0%
Blue	16%	30%	100%
Orange	66%	63%	0%
Purple	32%	58%	99%

Acuity Measurements with Helmholtz' Grille

In a previous issue of the REVIEW,* a description was given with some descriptive measurements on direct *vs.* indirect lighting in which use was made of a test plate modeled after the early work of Von Helmholtz. The same Helmholtz grille was used in making measurements in this investigation.

For the benefit of those who may not have read the previous article, it may be stated that this grille consists of a mesh of fine wires with a white background, as shown in Fig. 5. The wires become slightly waved at

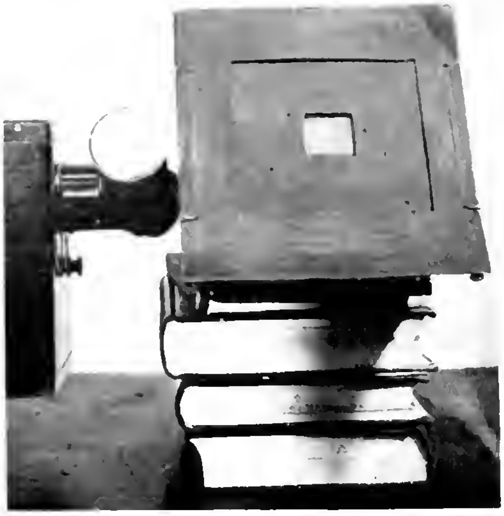

Fig. 5. Helmholtz Grille and Luminometer in Reading Position

the limit of distinct vision. A luminometer is set up with its test plate at the same height and in the same plane as the grille, so that intensity measurements may be made

*August, 1912.

simultaneously (see Fig. 6). By means of a tungsten lamp surrounded with a prismatic reflector whose height is variable, it is possible to vary the intensity of light on the working plane. In the article previously referred to, measurements were made with only a white card as the background to the wires of the grille. In this series of observations, colored cards were used whose coefficients of reflection had been previously determined. These were substituted at different times, to change the color of the background of the black wires of the grille. Knowing the coefficient of reflection of the different colored cards, it was possible to adjust the height of the lamp so that the same reflected intensity would come from the different cards used, irrespective of their colors.

A minimum intensity of four foot-candles was selected, as it was found in using the grille that, with intensities much below this, the accuracy of reading was affected somewhat by the position of the lamp illuminating the grille. Where the intensity, however, was over four foot-candles, the variation in acuity due to the position of the lamp was negligible. At the lower intensities, shadows cast by reflection of the wires affected the readings. It might have been possible to eliminate this effect, even at low intensities, by the use of indirect lighting, but the arrangement using the direct lighting was more convenient. As we did not care at this time to make measurements over the entire range of intensities, it was decided to use four foot-candles as a minimum, with direct lighting. The variation in acuity for the writer's eyes up to 12 foot-candles is shown in the curve (Fig. 7). This was with the use of a white background. The curve is the result of a large number of readings, taken over several consecutive days, under the same conditions, every possible precaution being taken to eliminate errors, the sources of which were discussed in the article previously referred to. It will be noted from the curve that there was a slight increase in acuity with the increase of intensities.

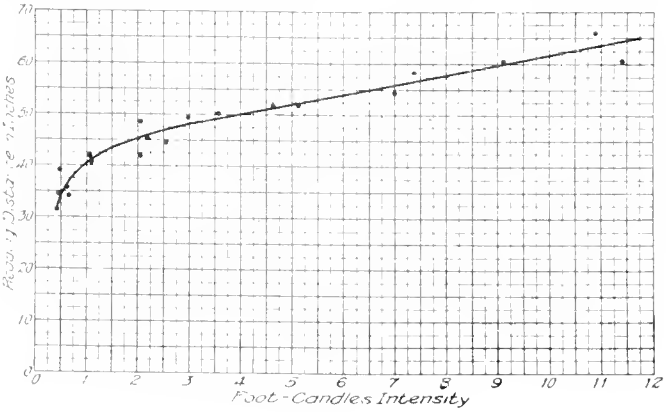

Fig. 7

When colored papers were substituted for the white background in the grille, it became necessary to apply the coefficient of reflection for that particular color, and to see what incident intensity was necessary in order to have reflected from the card the same intensity. The results of this investigation are given in Table 3.

TABLE 3

INCIDENT INTENSITIES OF LIGHT, AS DETERMINED BY COEFFICIENTS OF REFLECTION, REQUIRED TO GIVE AN EQUAL REFLECTED INTENSITY FROM VARIOUS COLORED CARDS

Colors	Coefficient of Reflection	Initial Intensity to Produce 4 Ft.-Candles of Reflected Intensity
White Cardboard	Standard of Reference	4.0
Red	0.303	13.2
Green	0.626	6.4
Yellow	0.928	4.3
Blue	0.288	13.9
Orange	.525	7.63
Purple	0.380	10.55

FECHNER'S LAW*

The smallest difference of perceptible illumination is a constant fraction (about 1 per cent) of the total illumination, known as Fechner's constant.

To determine the ratio, use the experiment of Bouguer. (Fig. 8.)

A and *B* are two light sources of the same intensity. *C* is a stick which casts the two shadows *a* and *b* on the screen *E-F*.

If *B* be moved farther and farther from the screen, the shadow *b* becomes weaker and weaker; and, when the distance of *B* from the

* Tscherning.

screen is nearly ten times that of A, it ceases to be visible.

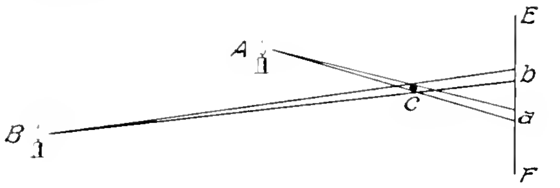

Fig. 8

Suppose at the moment when the shadow disappears, B is 500 centimeters from the screen and A, 50 centimeters.

A gives to the screen an illumination of $1/50^2$, B an illumination of $1/500^2$. While the shadow b receives an illumination of $1/50^2$ only. The difference between the illumination of the screen and that of the shadow is therefore:

$$(1/50^2+1/500^2)-1/50^2=1/500^2.$$

And the ratio between this difference and the illumination of the screen is:

$$\frac{1/500^2}{1/50^2+1/500^2}=1/10^2+1=1/101$$

The writer appreciates the co-operation of his assistant, Mr. Homer Mullen, in connection with the taking of numerous observations.

THE OPERATION AND INSTALLATION OF SWITCHBOARD SYNCHRONISM INDICATORS

By J. A. Haraden

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To properly synchronize two polyphase machines, knowledge of three factors is necessary, viz., phase rotation, voltage, and instant of exact synchronism. In the modern power station, phase rotation is determined at the time of installing the machinery and the connections to switches and busbars made correct once and for all. The voltage is shown by one of the usual switchboard types of voltmeters; while the instant of synchronism is most conveniently and accurately shown by the synchronism indicator. To facilitate the operation of synchronizing, this instrument is made to further show whether the speed of the incoming machine is above or below that of the machine with which it is to be paralleled, and to give some idea of the amount of this difference. This article explains the principles of operation of the synchronism indicator, briefly describes its construction, and shows by means of diagrams the proper connections for 220 volt circuits, and connections to potential transformers with grounded and ungrounded secondaries. Editor.

Any device used for synchronizing two or more alternating current machines should perform three distinct functions, as follows: First, it should indicate whether the incoming machine is running slower or faster than the machine with which it is to be synchronized; second, it should give an idea of the amount of the difference in speed; third, it should accurately indicate the moment of synchronism and coincidence in phase of the running and starting machines. Synchronizing lamps do not perform the first function. They perform the second function well and the third function approximately.

The synchronism indicator described and illustrated in this article performs all these functions. The pointer of this instrument moves around a dial, like the hand of a clock; and the angle of the pointer's displacement from the vertical position is a measure of the angle of phase difference between the two sources of electromotive force to which the device is attached. If, therefore, the incoming machine is running too fast, the pointer rotates in one direction, and if too slow, in the opposite direction. Coincidence

Fig. 1. Synchronism Indicator with Pivoted Bracket

in phase is shown when the pointer remains stationary in a vertical position, and indicates that the machine should be thrown in. A complete revolution of the pointer indicates a gain or loss of one cycle in the starting machine as compared with the running machine.

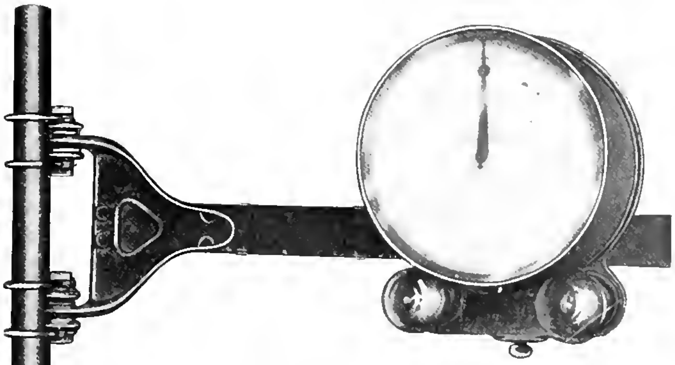


Fig. 2. Synchronism Indicator with Pivoted Bracket

Those who have actually "throw in" alternators can best appreciate the advantages of having an exact indication of phase coincidence instead of being obliged to estimate as with the ordinary synchronism devices. It should be noticed that the synchronism indicator shows whether the incoming machine is running *too fast* or *too slow*. The time-saving possibilities of this feature are evident.

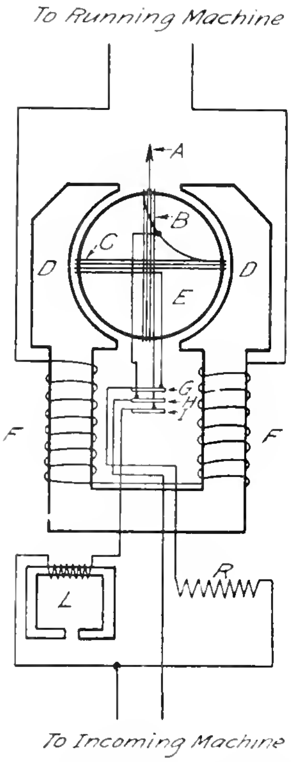
Operation

The diameter of the dial of the instrument is 8 inches, thus permitting observation by the operator of the engine or waterwheel as well as by the switchboard attendant. Indicators with large dials up to 36 in. are sometimes used, where the instrument is placed at a considerable distance from the operator.

The synchronism indicator is a motor whose field is supplied single-phase from one of the machines to be synchronized, and its armature from the other. The armature carries two coils placed at a large angle, one supplied through a resistance, the other through a reactance. This arrangement generates a rotating field in the armature, while the stationary field is alternating. The armature tends to assume a position where the two fields coincide when the alternating field passes through its maximum. Hence, the armature and pointer move forward or backward at a rate corresponding to the difference of frequency, and the position when stationary depends on the phase relation. When the machines are running at the same frequency and in phase the pointer is stationary at the marked point.

In construction, it is like a small, two-phase bipolar synchronous motor, the field or stator being supplied with alternating instead of direct current. The rotor is mounted in ball bearings in order to make it sufficiently sensitive and smooth in operating. The rotor coils are not exactly 90 degrees apart, since it is not possible to get the current in the two rotor coils exactly in quadrature without introducing condensers or other complicated construction. Fig. 3 shows the arrangement of circuits and internal connections.

Synchronism indicators are made for 110 and 220 volt circuits but will operate properly on any voltage which does not differ more than 10 per cent from these ratings. The reactance furnished



A Pointer attached to rotor shaft
B and C Coils on rotor
D Laminated field core
E Rotor
F Field windings
G, H, I Slip rings
L Reactance coil
R Non-inductive resistance

Fig. 3. Diagrammatic Arrangement of Windings and Connections for Synchronism Indicator

with 110-volt indicators is contained in a metal case on the outside of which is fastened a socket holding an incandescent lamp which serves as resistance. The 220-volt indicators have a

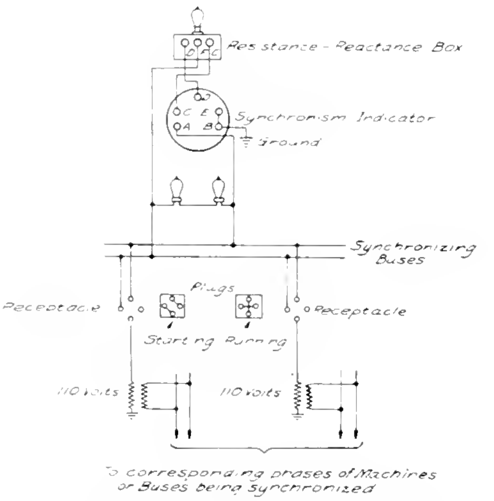


Fig. 4. Connections of Synchronism Indicator with Grounded Secondary on Potential Transformers

separate resistance and reactance box, the former taking the place of the lamp furnished with the 110-volt indicator. Both the reactance and resistance are intended to be placed behind the board. For voltages above 220-240 volts, the 110-volt indicator should be used with

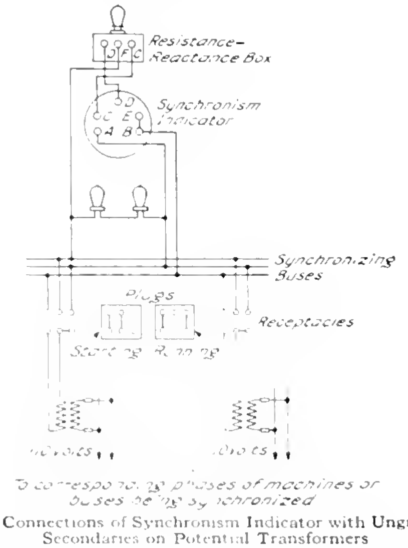


Fig. 5. Connections of Synchronism Indicator with Ungrounded Secondaries on Potential Transformers

potential transformers having 110-volt secondary. All indicators should be disconnected from the circuit when not in use, as they are not designed for continuous operation; moreover they are most often used with potential transformers of too small capacity to carry the indicator continuously.

Synchronism indicators should be used at the frequency for which they are designed,

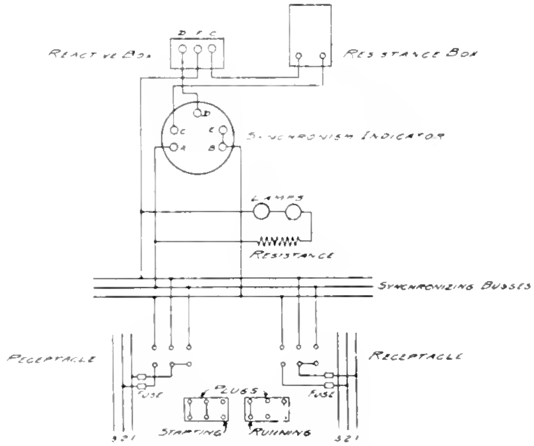


Fig. 6. Connections of Synchronism Indicator for 200-240 Volt Circuits with 6 Point Receptacles

although satisfactory operation can be obtained on circuits varying 10 per cent to 15 per cent from the normal. The words "Fast" and "Slow" on the dial indicate that the frequency of the electromotive force on binding posts E and F is respectively higher or lower than that on A and B, or, in other words, clockwise rotation of the pointer means that the incoming machine is running at too high speed, counter-clockwise rotation indicating too low speed. The synchronism indicator is equally adaptable to single-phase, two-phase or three-phase apparatus, since

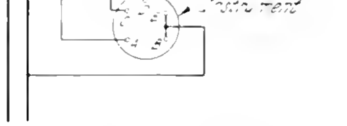


Fig. 7. Connections for Checking Location of Needle

connections are only made to one phase of a polyphase machine.

Installing Synchronism Indicators

With grounded secondaries on potential transformers the instrument should be connected as shown in Fig. 4. With ungrounded secondaries on potential transformers it should be connected as in Fig. 5. The indicators for 220-volt circuits are connected as shown in Fig. 6. The various letters indicated in Fig. 6 refer to the markings on the instrument studs and the back of the reactance coil box.

It is very important that the instrument be connected in circuit in the proper manner, so that the needle will come to the mark on the upper part of the scale when synchronism is obtained. In case the pointer becomes moved or a change in its position is necessary, it is advisable to make a check on the indication before relocating the needle. This test can be made as follows (see Fig 7): Connect together studs marked B and E, and connect stud A to terminal F on the external reactance box. When these connections are made, the instrument can be connected to a single-phase circuit of normal voltage; and if the instrument is correct, the pointer will stand vertically at the point of synchronism. If it does not, the needle can be moved and should be fastened in the correct position.

The synchronizing lamps when connected as in Figs. 3, 4 and 5 show dark when synchronism is reached. This is the only connection possible when grounded secondaries are used as in Fig. 3 and for the high voltage indicators when used as in Fig. 5; but with ungrounded secondaries, as shown in Fig. 4, the lamps may be connected as indicated by the dotted lines, when they will show bright at the moment of synchronism. The connections to the synchronism indicator remain the same as before.

A COMPARISON OF NUMERICAL AND GRAPHICAL METHODS IN THE DESIGN OF INVOLUTE SPUR GEARS

By A. Schein

Drafting Department, General Electric Company

This article has been specially prepared for the Review, and is now published here, mainly for the benefit of draftsmen and designers of electrical machines who come into contact with the lay-out of involute gearing for various motor applications, and who will probably not need to be reminded of the author's excellent article on the design of shafts which we published early in 1912. The great value of the present paper lies in the exposition which it gives of the use of charts in lessening the labor involved in gearing calculations. This, with the working-out of some actual examples, should make the article of real value in the drafting room.—Editor.

There are used commercially at present but two systems of gearing—the cycloidal and the involute. A number of years ago the cycloidal type was far the more commonly used; but on account of our changes in methods of machine design, production considerations, and also the running characteristics of the two types, the involute has become the more popular.

There are many reasons for this preference. It was at one time the custom in the design of a machine requiring gears, to locate the shaft centers with a regard only to convenience of design of the remainder of the machine; and then to lay out two special gears giving the necessary ratio, which would fit between those centers. This demanded reverting to the fundamental principles of construction each time, and the specialized services of one thoroughly familiar with that work, in addition to the grinding of a special cutter for each gear. With our advance in design, as in all else, it was found that progress is due largely to simplified methods: and, for each diametral pitch of a series, three times as many cycloidal as involute cutters are required to make a line of gears ranging from 12 teeth to a rack. It is partially on account of this reason then that, of the two systems, the involute has made the more rapid strides into favor, since it adapts itself more readily to present day methods of design. The further property of involute toothed wheels, viz., that the distance between the axes of a pair of gears may be altered to a considerable extent, without interfering with their action, is a characteristic to which this type also owes its merit; backlash is variable at will by moving the wheels further from or nearer to each other, and may be adjusted so as to be no greater than is necessary to prevent jamming of the teeth. For these considerations therefore, only the selection and layout of teeth based upon the fundamentals of the involute curve will be considered in this article.

The involute is defined as the curve generated by a point of a tangent right line rolling upon a circle, known as the base circle, or the describing point may be regarded as at the extremity of a fine wire, which is unwound from a cylinder corresponding to the base circle. It is constructed as follows:

Lay off arcs 0-1 (Fig. 1), 1-2, 2-3 and 3-4 preferably equal to each other, and from

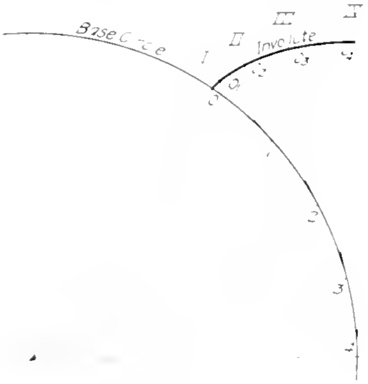


Fig. 1

points 1, 2, 3 and 4 draw tangents. With a radius equal to 1-0 draw a curve $0\text{-}0_1$, with $2\text{-}0_1$ a curve $0_1\text{-}0_2$, etc. The curve $0\text{-}0_1\text{-}0_2\text{-}0_3$ . . . . is the involute of the base circle and the one to which involute cutters are ground.

The terms used in gear design, which have become thoroughly standardized and are now universally accepted, are as follows:

The pitch circle is the right section of that solid cylinder, having no teeth and transmitting power by friction only, which the spur gear may be considered as replacing.

The pitch diameter is the diameter of the pitch circle.

The diametral pitch is the number of teeth to each inch of the pitch diameter.

The circular pitch, which is the distance from the center of one tooth to the center of the next, is measured along the pitch line.

The angle of pressure is measured between the tangent through the contact point of the pitch circles of the intermeshing gears and the resultant line of force of their interaction, the usual standard being 14½ deg.

The addendum is the distance measured radially from the pitch circle to the top of tooth.

The dedendum is the radial distance from the pitch circle to the base of the tooth, minus the clearance.

In stating the interrelations of these quantities and also the others involved in gear calculations, the following abbreviations are used:

D' = Pitch diameter
P' = Circular pitch
N = Number of teeth
T = Thickness of tooth
L = Whole depth = $M + A + f$
B = Minimum width of tooth below pitch circle
H = Radial distance from outer end of teeth to point B
P = Diametral pitch
A = Addendum
M = Dedendum
D = Outside diameter
f = Bottom clearance
F = Axial length of gear

Pitch diameter $(D') = \frac{N}{P} = \frac{D \times N}{N+2} = D - \frac{2}{P}$

Diametral pitch $(P) = \frac{3.1416}{P'} = \frac{N}{D'}$

Circular pitch $(P') = \frac{3.1416}{P} = \frac{D'}{.3183 \times N}$

Addendum $(A) = \frac{1}{P} = \frac{P'}{3.1416}$

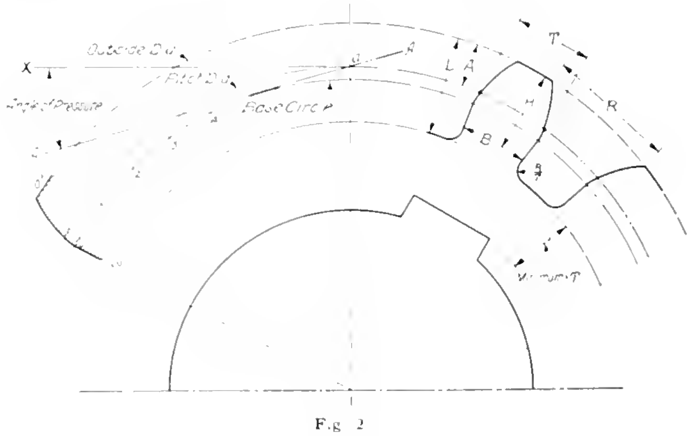


Fig. 2

Dedendum (M) usually = A

Number of teeth $(N) = D' \times P = \frac{3.1416 \times D'}{P'}$

Outside diameter $(D) = \frac{N+2}{P} = D' + \frac{2}{P}$

Thickness of tooth $(T) = \frac{1.5708}{P} = \frac{P'}{2}$

Bottom clearance $(f)=\frac{0.157}{P}=\frac{T}{10}$

Whole depth $(L)=P'\times 0.6866$

Face of tooth $(F)=$ length axially

Depth to minimum width (H)

$=(A+M+f)-\frac{R}{7}$

Tooth Layout

Using the involute curve as a base and complying with the standard relations given in the preceding, a complete tooth (see Fig. 2) would be laid out as follows:

tooth base. The thickness of tooth, also given in Table 1, is laid off on the pitch circle in the direction of the concave side of the involute curve; and through this point the other side of the tooth is constructed in the reverse manner. The next tooth will be at a distance equal to the circular pitch from it, center to center. Should the bore be particularly large as in the case of the pinion illustrated in Fig. 2, care should be taken that the keyway shall allow a thickness of metal at least equal to T to remain between itself and the clearance circle (measured radially).

TABLE 1

TOOTH PARTS FOR 14½ DEG. INVOLUTE GEARING

ALL DIMENSIONS IN INCHES

Diametral Pitch	Circular Pitch	Thickness of Tooth on Pitch Line (T)	Addendum (A)	Whole Depth of Tooth (L)
1	3.1416	1.5708	1.000	2.1571
1¼	2.5133	1.2566	0.800	1.7257
1½	2.0944	1.0472	0.666	1.4381
1¾	1.7952	0.8976	0.5714	1.2326
2	1.5708	0.7854	0.500	1.0785
2¼	1.3963	0.6971	0.444	0.9587
2½	1.2566	0.6283	0.400	0.8628
2¾	1.1424	0.5712	0.3636	0.7844
3	1.0472	0.5236	0.3333	0.7190
3½	0.8976	0.4488	0.2857	0.6163
4	0.7854	0.3927	0.2500	0.5393

Assume it is to have 14 teeth of 1½ diametral pitch and be constructed so as to give a 14½ deg. angle of pressure.

The pitch dia. $=\frac{N}{P}=\frac{14}{1.5}=9.34$ in.

Outside dia. $=\frac{N+2}{P}=\frac{16}{1.5}=10.66$ in.

Draw the pitch and outside circles. Through point a draw the pressure line AA, wherein the angle with the tangent aX is 14½ deg. The base circle is then drawn tangent to the pressure line and its involute constructed as described in Fig. 1.

From Table 1 the depth of the tooth is $L=1.4381$ in. The involute itself extends from base circle to outside diameter, while the remainder of the tooth is a radial straight line, with the exception of a reinforcing fillet of radius equal to $\frac{R}{7}$ which is placed at the

Strength of Spur Wheel Teeth

Innumerable rules have been formulated for the strength of the teeth of spur wheels, many of which give widely different results. Much of the existing confusion is due not only to the various estimates of the strength of the material and the allowable factor of safety, but also to the manner in which the load is assumed to fall on the teeth. The rule in most common use for determining the strength of gears, is the one formulated by Mr. Wilfred Lewis in a paper read in 1893 before the Engineers' Club of Philadelphia. He considered that in good machinery the load could be taken as distributed equally throughout the length of a tooth (and not concentrated at one end, as sometimes assumed); and, further, may be considered to be divided between two teeth, in which the teeth are regarded as cantilevers with the load at their end.

The Lewis formula is

$$W = S \times P' \times F \times Y \text{ or } F = \frac{W}{S \times P' \times Y}$$

Where W = Working load (torque) in pounds at pitch diameter
S = Fiber stress in lb. per sq. in.
P = Circular pitch
Y = A factor of strength dependent upon the angle of pressure and number of teeth used, see Table 3
F = The width of face in inches

A comparison of these two methods worked out numerically (one requiring a drafted layout and the other using Lewis' formula) to obtain the dimensions of a gear to fulfill certain given conditions, follows.

$$\text{Pitch dia.} = \frac{N}{P} = \frac{17}{1.75} = 9.71 \text{ in.}$$

$$\text{Speed at outside dia.} = \frac{\pi \times D \times \text{R.P.M.}}{12}$$

$$= \frac{\pi \times 10.85 \times 700}{12} = 1990 \text{ ft. per min.}$$

$$\text{Speed at pitch dia.} = \frac{\pi \times D' \times \text{R.P.M.}}{12}$$

$$= \frac{\pi \times 9.71 \times 700}{12} = 1780 \text{ ft. per min.}$$

$$\text{Torque at outside dia.} = \frac{\text{H.P.} \times 33000}{\text{Speed}}$$

$$= \frac{120 \times 33000}{1990} = 1990 \text{ lb.}$$

TABLE 2

Diametral Pitch \ No. of Teeth	14	15	16	17	18	19	20	21	22	23	24	25	26
5	2.8	3.0	3.20	3.40	3.60	3.80	4.00	4.29	4.40	4.60	4.80	5.0	5.2
4	3.5	3.75	4.0	4.25	4.50	4.75	5.00	5.25	5.50	5.75	6.00	6.25	6.50
$3\frac{1}{2}$	4.0	4.28	4.58	4.86	5.14	5.42	5.71	6.00	6.28	6.57	6.86	7.15	7.43
3	4.67	5.00	5.33	5.66	6.00	6.33	6.66	7.00	7.33	7.66	8.00	8.33	8.66
$2\frac{3}{4}$	5.09	5.46	5.82	6.18	6.54	6.90	7.26	7.64	8.00	8.36	8.72	9.09	9.45
$2\frac{1}{2}$	5.6	6.0	6.4	6.8	7.2	7.6	8.0	8.4	8.8	9.2	9.6	10.0	10.4
$2\frac{1}{4}$	6.23	6.67	7.12	7.55	8.0	8.44	8.88	9.33	9.78	10.22	10.65	11.10	11.53
2	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0
$1\frac{3}{4}$	8.0	8.57	9.14	9.71	10.28	10.85	11.42	12.0	12.57	13.14	13.72	14.28	14.85
$1\frac{1}{2}$	9.333	10.0	10.66	11.33	12.0	12.66	13.33	14.0	14.66	15.33	16.0	16.66	17.33
$1\frac{1}{4}$	11.2	12.0	12.8	13.6	14.4	15.2	16.0	16.8	17.6	18.4	19.2	20.0	20.8
1	14.0	15.0	16.0	17.0	18.0	19.0	20.0	21.0	22.0	23.0	24.0	25.0	26.0

*Pitch Diameter

*Pitch diameter expressed in inches.

Example

What will be the dimensions of a $14\frac{1}{2}$ deg. involute steel pinion, having an approximate pitch diameter of $9\frac{3}{4}$ in., and which will transmit 120 h.p. at 700 r.p.m.?

Referring to Table 2, it is noticed that there are several combinations of diametral pitch and number of teeth, which make up a pinion having a pitch diameter of about $9\frac{3}{4}$ in. All other factors being equal, the gear with the fewest number of teeth will be the strongest. Therefore the 17-tooth pinion having $1\frac{3}{4}$ diametral pitch and 9.71 in. circular pitch is selected.

Method I

Proceed as in Fig. 2 (this requires a scale layout to get values of B and H).

$$\text{Outside dia.} = D = \frac{N+2}{P} = \frac{17+2}{1.75} = 10.85 \text{ in.}$$

The maximum allowable tooth stress for steel at 1780 ft. per min., as given by Table 4, is approximately 5000 lb. per sq. in. And therefore that pinion whose fiber stress is 5000 lb. per sq. in. will be the smallest and cheapest one that will give satisfaction. Of course lower values of stress may be assumed at the discretion of the designer. Having assumed a fiber stress, which in the following example will be 5000 lb. per sq. in., it is now only necessary to find the length of pinion which will cause that stress.

$$\text{Section modulus} = \frac{\text{Bending moment}}{\text{Bending stress}}$$

$$\frac{F \times B^2}{6} = \frac{\text{Tooth load at outside end} \times H}{\text{Bending stress}}$$

By scaling layout, $B = 0.87$ and $H = 1.0$.

$$\text{Face of pinion} = F = \frac{6}{.87^2} \times \frac{1990 \times 1.0}{5000}$$

$= 3.15$ in. approx. $3\frac{1}{4}$ in.

Method II

According to Lewis' formula (no layout required).

Pitch dia. $= D' = \frac{N}{P} = 9.71$ in.

TABLE 3
FACTOR OF STRENGTH Y
LEWIS FORMULA

Number of Teeth	20° Involute	$14\frac{1}{2}$° Involute
14	0.088	0.072
15	0.092	0.075
16	0.094	0.077
17	0.096	0.080
18	0.098	0.083
19	0.01	0.087
20	0.0102	0.090
21	0.0104	0.092
23	0.0106	0.094
25	0.0108	0.097
27	0.0111	0.0100
30	0.0114	0.0102
34	0.0118	0.0104

Speed at pitch dia. $= \frac{\pi \times D' \times \text{R.P.M.}}{12}$

$= \frac{\pi \times 9.71 \times 700}{12} = 1780$ ft. per min.

Torque at pitch dia. $= \frac{\text{H.P.} \times 33000}{\text{Speed}}$

$= \frac{120 \times 33000}{1780} = 2200$ lb.

Value of Y for $14\frac{1}{2}$ deg. involute and 17 teeth from Table 3 = 0.08 in.

$$F = \frac{W}{S \times P' \times Y} = \frac{2200}{5000 \times 1.795 \times 0.08} = 3.10 \text{ in.}$$

approx. $3\frac{1}{4}$in.

Charts I and II which are based on the following equations respectively:

Speed at pitch dia. in ft. per minute

$= \frac{\text{pitch dia.} \times \pi \times \text{R.P.M.}}{12}$

Torque at pitch circle

$= \frac{\text{H.P.} \times 33000}{\text{Speed at pitch circle in ft. per min.}}$

Torque at outside dia.

$= \frac{\text{H.P.} \times 33000}{\text{Speed at outside dia. in ft. per min.}}$

A calculation of the same example by this latter method would employ:

(*a*) Table 2, to obtain exact pitch dia. and diametral pitch.

(*b*) Scale layout of gear, to get values of B and H.

(*c*) Speed at outside dia.

(*d*) Speed at pitch dia., whereby to choose maximum allowable stress (Table 1).

(*e*) Chart II, torque at outside dia. to use in (*f*).

(*f*) $F = \frac{6}{B^2} \times \frac{\text{Torque at outside dia.} \times H}{\text{Max. allowable stress}}$

Use of Charts in Lewis Method

The second numerical method, that applying Lewis' formula, is particularly adapted to simplification by chart, which in fact obviates all computation. The sequence in which the intermediate steps are made, is given below:

(*a*) Table 2, to obtain exact pitch dia. and diametral pitch.

(*b*) Chart I, to find speed at pitch diameter thereby determining the maximum allowable fiber stress (given in Table 4).

(*c*) Chart II, to ascertain torque at pitch dia.

(*d*) Chart III. Explanation—

From that point in the torque scale representing the value of torque at pitch dia. (2220 lb.), trace horizontally to the left, to vertical line representing number of teeth to be used (17). From this point I continue

TABLE 4
MAXIMUM ALLOWABLE WORKING STRESS (S) CAST IRON AND STEEL

Speed at pitch dia. in ft. per min.	100 or less	200	300	600	900	1200	1800	2400
CAST IRON:								
Lb. per sq. in.	8000	6000	4800	4000	3000	2400	2000	1700
STEEL:								
Lb. per sq. in.	20000	15000	12000	10000	7500	6000	5000	4300

Use of Charts in Layout Method

The calculation made necessary in Method I can be very much lessened by the use of radially toward point O, to meet the horizontal whose number is the same as the diametral pitch being used ($1\frac{3}{4}$). The location of the point of intersection of a vertical line, from this last point H, with a horizontal from the

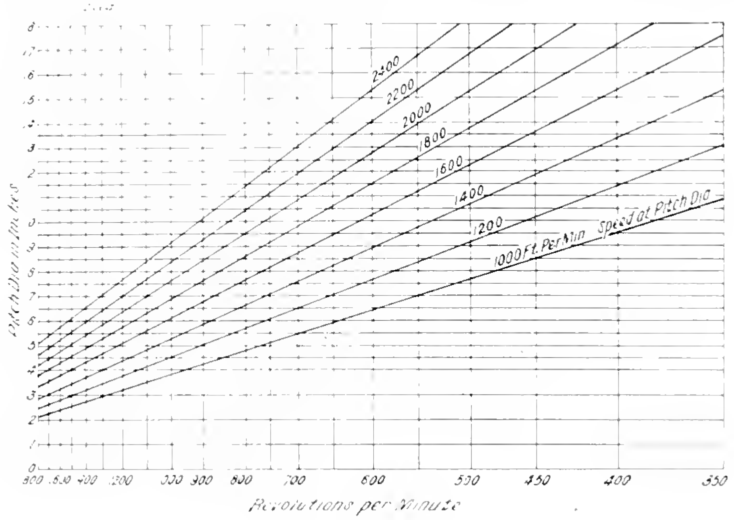


Chart 1

point of maximum fiber stress allowed, in reference to the slant lines (labeled "width of pinion"), determines the width of the pinion which will fulfill the stated conditions.

Either one of these chart methods (the latter to be preferred) will be found to give identically the same result as was obtained previously in a numerical manner.

Versatility of the Charts

Further, the charts are very flexible and by their applications in different orders of succession any standard gear problem may be solved, if sufficient data are given to determine the remaining factors. For instance, if in the above example the width of the face was assumed to be 7 in. (other factors, excepting unit stress, remaining unchanged), then by dropping a vertical from the point H (Chart III) till it intersects the sloped line representing a 7 in. face, a fiber stress of 2200 lb. per sq. in. would be indicated by a horizontal through this latter point

Limit of Pinion Face as Determined by Shaft Deflection

From experience it has been found that the shaft of a gear drive should be sufficiently strong to prevent its attached pinion from deflecting more than 0.01 in., as shown by D in Fig. 3. Larger deflections than this prevent the meshing teeth from bearing throughout their length, and consequently render them very liable to breakage. After the length of the pinion face has been determined by the preceding tables, an additional check should be made to determine if the deflection comes within the safe limits of 0.01 in. If not, it may be brought within the limits by shortening the pinion length, provided the maximum allowable fiber stress permits this change, or by stiffening the shaft.* Two convenient test relations, which it is also advisable to bear in mind, are the following approximate ones:

$F_{max.} = 0.6$ to $0.8 \times$ pitch dia. for overhung pinions,

$F_{max.} = 0.8$ to $1.1 \times$ pitch dia. for pinions supported on both sides.

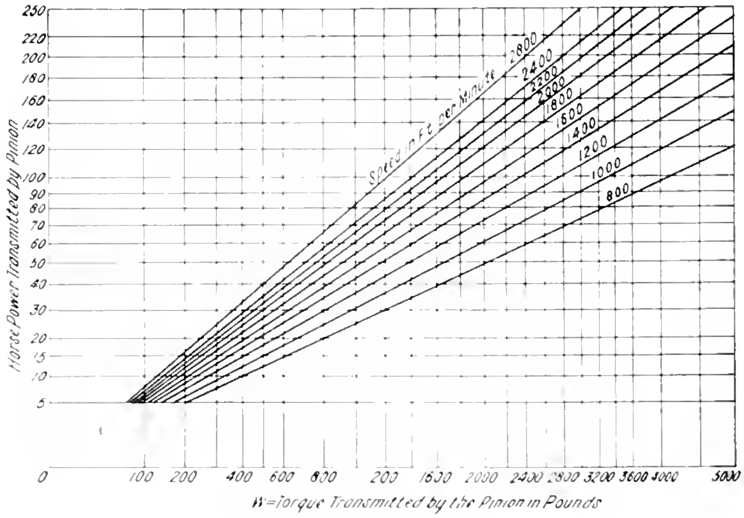


Chart II

*A very simple method of obtaining shaft deflections appeared in the GENERAL ELECTRIC REVIEW of March and April, 1912, in an article "Graphical Methods in the Design of Shafts" by the Author.

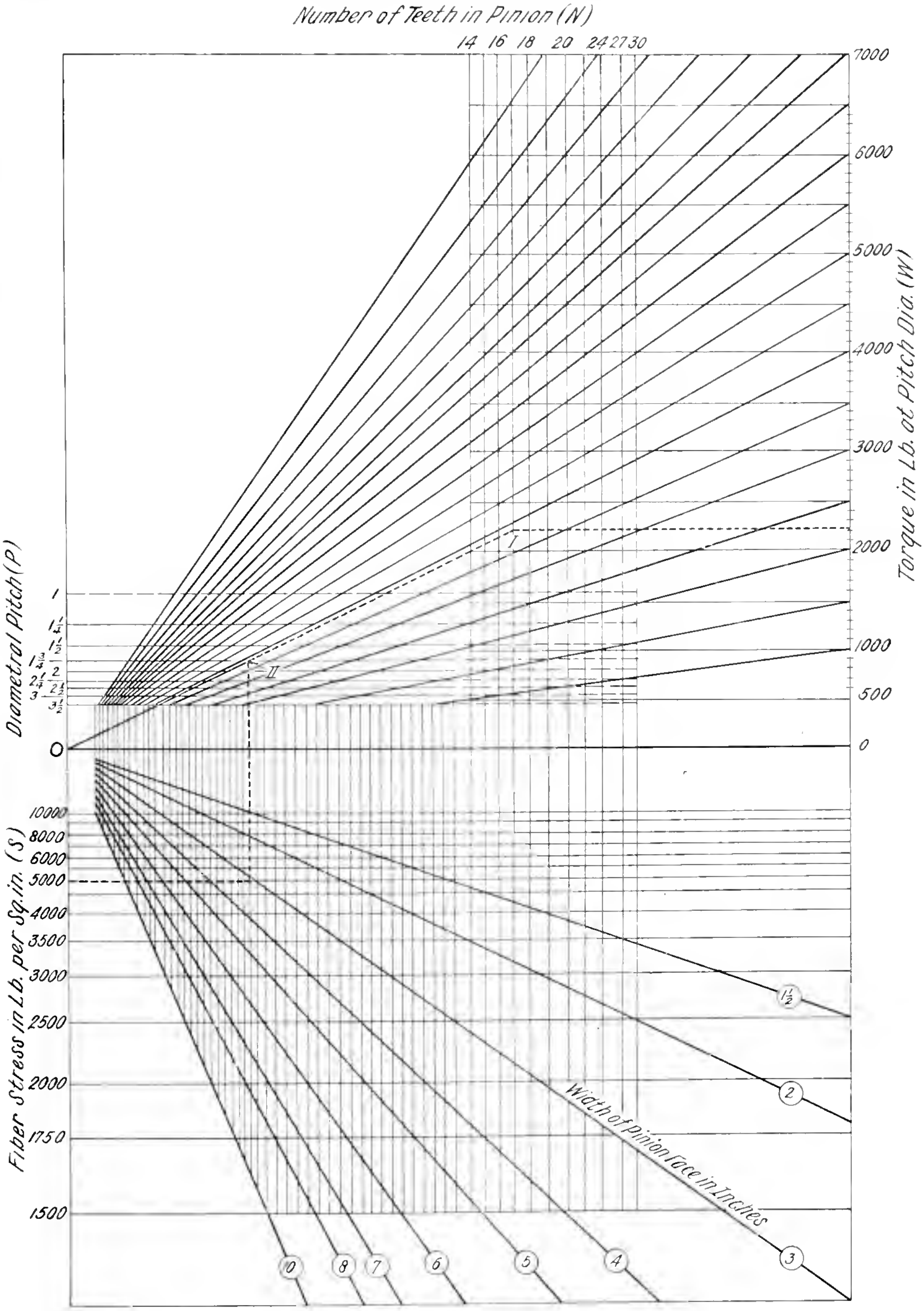

Number of Teeth in Pinion (N)
14 16 18 20 24 27 30
7000
6000
5000
4000
3000
2000
1000
500
0
Torque in Lb. at Pitch Dia. (W)
Diametral Pitch (P)
1
1¼
1½
1¾
2
2¼
2½
3
3½
O
I
II
Fiber Stress in Lb. per Sq. in. (S)
10000
8000
6000
5000
4000
3500
3000
2500
2000
1750
1500
Width of Pinion Face in Inches
1½
2
3
4
5
6
7
8
10

Chart III

Short Tooth Construction

In certain special lines of gear design, namely, railway and mill drive, there has recently seemed to be a tendency toward shorter teeth than given in Table 1, for usually, under such conditions of sudden shock, excessive strength is most important; efficiency and good wearing qualities are secondary. The Hunt and the Logue teeth are of this shorter type. The former possesses an addendum and dedendum each equal to 0.25 of the circular pitch, with a clearance equal to 0.05 of it, making the total depth $0.55 \times P'$ and employs a $14\frac{1}{2}$ deg. angle of pressure. The latter uses the same dimensions for tooth depth, but a shape constructed with a 20 deg. involute.

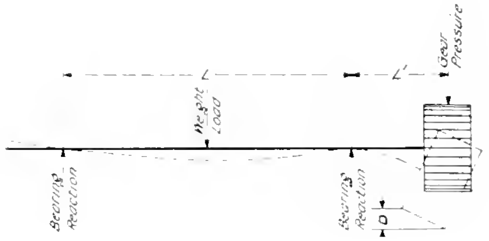


Fig. 3

While these latter shapes of teeth are well adapted to special cases of heavy duty, and while for them tables and charts similar to those given may be worked up, they are not well suited for general use. The factors and constants given in the tables and charts of this article are based upon the Brown and Sharp standard, which has been found universally to be the most satisfactory.

High Speed Pinions

Cotton and rawhide pinions are often used in installations where pinions are to operate at high speed, but must run quietly. The length of pinions of this type must be at least sufficiently great to permit them meshing with their companion gears without the shrouds coming into contact.

The size of a cotton pinion to be used may be determined by the foregoing charts, assuming safely the same fiber stresses as given for cast iron. The limit of the strength of rawhide pinions may be arrived at in the same way; with the exception that for them the fiber stresses given in Table 5 are to be used, and also the dimensions must pass a further test, on account of their characteristics due to heating (see Table 6).

TABLE 5

MAXIMUM ALLOWABLE WORKING STRESS S, RAWHIDE

Speed at pitch dia. in ft. per min.	200	400	600	800	1000	1200	1400	1600	1800	2000
Stresses in lb. per sq. in.	3600	3300	3100	2800	2600	2400	2200	2000	1900	1800

TABLE 6

MAXIMUM ALLOWABLE VALUES OF C FOR HEATING, RAWHIDE PINIONS

Diametral Pitch	1	$1\frac{1}{2}$	2	$2\frac{1}{2}$	3	$3\frac{1}{2}$	4
C	1600	1400	1200	1000	900	800	600

Heating Test Rawhide

W = Total load on the tooth at pitch dia

V = Velocity in ft. per min. at pitch dia.

N = Number of teeth.

F = Width of face.

C = Heating coefficient, which must not exceed values given in Table 6

$$C = \frac{W \times V}{F \times N}$$

IN MEMORIAM

Mr. R. E. Steele, Comptroller of the General Electric Company, died at his home in Schenectady about nine o'clock on Tuesday morning, March 4th, after a lingering illness.

Robert Etheridge Steele was born at Frankfort, N. Y., June 19, 1869, but most of his boyhood was spent at Herkimer, N. Y., where he was graduated from the High School in 1887. After studying medicine for one and one-half years he changed his plans and purposes, and took up the study of law with his father, the late Josiah A. Steele. He was admitted to the bar in Albany in 1890 and practiced his profession in Herkimer until 1902, holding various town offices until his removal to Albany on January 1, 1902, when he was appointed Deputy Attorney General of the State of New York. From January 1, 1905, until May 1, 1907, he practiced law in the offices of Rosendale & Hessberg. On May 1, 1907, Mr. Steele formed a partnership with Mr. Danforth E. Ainsworth, which continued for one year. During this partnership he was retained as the special counsel of the Superintendent of Banking, Clark Williams, in connection with the Knickerbocker Trust Company failure. Mr. Steele took care of the State's interests in this momentous episode with great success. His advice as counsel was followed in every particular, his brilliant work being an important aid in the prompt and successful re-organization of the trust company's affairs. His great ability and high character having attracted the attention of prominent officials in the General Electric Company, he accepted the comptrollership of that Company and entered upon his duties on May 11, 1908.

ROBERT ETHERIDGE STEELE

Mr. Steele was a man who combined rare qualities of mind with a most attractive personality. He was a strong, clear, courageous thinker, whose opinions inspired respect and whose conclusions carried conviction. Personally he was a man of exceptional charm, always approachable and kindly, and possessing a marked faculty for winning and holding friendships; and although he had only lived in Schenectady a short time, he leaves a remai ably large circle of devoted friends. Throughout his long illness his quiet courage, poise, and unfailing sweetness of spirit were an inspiration to his family and friends.

Mr. Steele was married on June 27, 1895, to Miss Mabel Munger, of Herkimer, N. Y., who, with two children, Bruce and Eleanor, survives him. He also leaves a mother, one brother and two sisters.

Mr. Edward Clark, General Auditor of the General Electric Company, died at his home in Schenectady on February 15, 1913, within a few days of his 65th birthday.

Edward Clark was born in Edinburgh, Scotland, on the 19th of February, 1849. In this city he began his business career as an accountant, for which profession he had been carefully trained in the office of the North British Railway Company. In 1883 he moved to London in search of a wider field of endeavor; and there became acquainted with Edward H. Johnson, one of Edison's early associates in his pioneer electrical work. Clark accompanied Johnson to America in 1884 and became auditor of the Edison General Electric Company of Schenectady in 1891, and had full charge of the arduous accounting work involved in the foundation of the General Electric Company. Two years later Mr. Clark was made assistant to the Comptroller, the late Joseph P. Ord, and soon thereafter was made General Auditor of the Company, and continued in that capacity until his death. His latter days were passed in leisure and comfort under the devoted care of his wife and family.

EDWARD CLARK

Of a mild disposition, Mr. Clark's gentle courtesy gained him a host of friends. To an orderly and systematic method of work, he added a capacity for organization and administering the affairs of a large and complex department. He brought to the discharge of his official duties a precise and exact knowledge of the technique of his profession, and his skill as a corporation accountant was probably unrivalled. He was well known amongst the more prominent of his contemporaries in the electrical business, and possessed a large personal acquaintance among those who have been foremost in the development of the industry.

Mr. Clark is survived by a widow and two sons, Thomas S. Clark, of Schenectady, and Edward Clark, Jr., of Charlotte, N C.

QUESTION AND ANSWER SECTION

The Q. and A. Section has been started with the sole object of increasing the practical usefulness of the Review; and in order that it may be made of real value, we invite correspondence from any of our readers who are looking for information on any technical matter in the field covered by this magazine, and which they think we can furnish.

Where possible the answers to such inquiries will be the work of this office; where desirable we shall obtain our authority from that engineering or commercial party in the General Electric Company's organization best fitted for handling the particular subject. We hope our readers will not hesitate to avail themselves of the expert engineering opinion which should be made available through this section of the Review. Information on matters of general importance and interest will be published here; questions of interest solely to the querist will be handled by mail.

Sketches should accompany questions in all cases where this is necessary to give us complete and accurate information on the point at issue. Scale drafts will be made up here from correspondent's rough pencil sketches Questions must be accompanied with the name and address of the sender, although these will not necessarily be for publication, and should be addressed to the Editor, Q. and A. Section, General Electric Review, Schenectady, N. Y

COMBINED POWER-FACTORS

(8) Three circuits leading from a set of busbars have power-factors of 75, 85 and 95 per cent respectively. What is the power-factor on the feeder that supplies these busbars, the system being three-phase?

Problems of this nature are easiest solved in a graphical manner. As to whether the system is single or polyphase makes no difference, since the problem is handled in the same manner in either case. Since no values for the kv-a. loads are given in the question, they will be assumed to be equal. Referring to Fig. 1: from the point B in the base

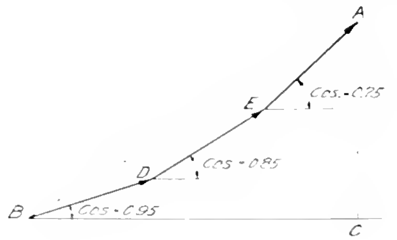


Fig 1

line BC, lay off a vector BD, of length indicative of the kv-a. it represents and at that angle with BC whose cos. is 0.95; then DE of equal length making that angle with the base line whose cos. is 0.85; then EA again of the same length, but making that angle with the base line whose cos. is 0.75. Join BA and draw AC at right angles to base line. $\frac{BC}{BA}$ then measures the combined power-factor of the feeder circuits. The numerical value of this ratio may be obtained by scaling the diagram or through the use of trigonometric functions.

E.C.S.

INTERRUPTING ACTION OF AN OIL SWITCH

(9) What is the action in an oil switch while the arc is being ruptured?

When the contacts separate in opening the circuit, a film of oil flows between them introducing a high resistance to the flow of current. As the potential wave passes through zero the arc is interrupted, re-establishing itself at the high points of the wave, until the quantity of oil between the contacts is sufficient to resist puncture at the highest peak of the wave. Due to this action, the circuit is opened with the least disturbance and surges are reduced to a minimum.

E.B.M.

HOT WIRE METER CONSTRUCTION

(10) What construction is used in the design of a hot wire meter to magnify reliably the very small lengthening of the hot wire?

What are the special conditions for which this meter is superior to the magnetic type?

The hot wire, which carries the current or a shunted portion of it, is fastened immovably at both ends, but is not drawn tight. This slack is taken up by the side-pull of a small wire, one end of which is fastened at the center of the hot wire and the other end at a point within the meter, such that the two wires form a T. At the middle point of this second wire another is attached which, leaving it at right angles, later passes several times around a small pulley and then to the end of a spring, which maintains the whole in tension. Any lengthening of the current-carrying wire results in a greatly magnified side deflection, which is transmitted by the other wires to the pulley and is there converted into a rotational motion. The indicating needle is usually attached to this pulley.

Since the deflection of the meter depends upon the heating value of the current, it is independent of frequency and wave shape. This fact makes it particularly suitable for making current measurements in wireless telegraphy or in cases where a sudden change is made from alternating to direct current or vice versa, provided shunted or divided circuits are not used in making the measurements.

E.C.S.

CALCULATING REACTANCE COIL COMBINATIONS

(11) Having a number of reactance coils, how can a number of them be figured to give approximately a desired reactance?

Problems of this nature may be treated in a manner exactly similar to those involving resistance only. Reactance coils usually have a resistance so low in comparison to their reactance that it can be neglected; but which if considered necessary, may be taken account of by the usual vector method. The impedance ohms of each coil is the quotient obtained from a test of the volts impressed upon that coil, divided by the amperes flowing through it, when alternating current is used. Assuming that this is equal to the reactance ohms, the coils may be conveniently grouped and the reactance of the whole combination arrived at by using the following rule: those in series add directly and those grouped in pairs combine giving a reactance equal to the product divided by the sum of its two individual parts.

C.M.D.

RAILWAY MOTOR ARMATURE TROUBLE

(12) A railway motor which has been in service for over a year, recently attracted attention by reason of its having two burned mica commutator segments and yet possessing no open or short circuited coils, as shown by test. The mica segment between two certain adjacent bars is burned away for some depth as are also the edges of the bars bordering on it. The next mica strip is unharmed, while the third displays the same condition as the first one mentioned. What is the cause of this?

A careful test of the volts-drop from bar to bar over the commutator would have been the proper test to make in this case, as it would have definitely located the trouble. Burned

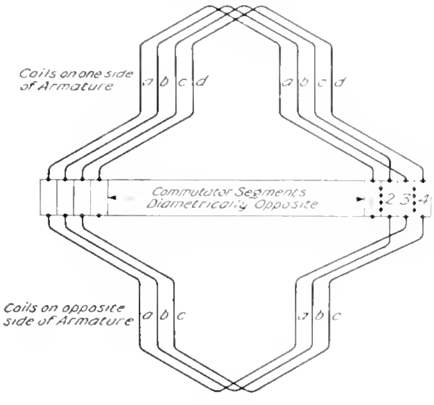


Fig. 1

commutator segments ordinarily indicate open circuits, but since these are stated as not being present, there seems to be but one other solution. Although this involves a condition of very rare occurrence, its possibility is strengthened by the peculiar succession in which the segments were burned. Judging from the fact that only two mica strips were burned and that these two were separated by a good strip, there is perhaps a condition of misconnections existing in the armature. If when the armature conductor leads were connected to the commutator, two of them became exchanged, a short circuited coil would be produced, or if one lead became omitted, an open circuit would result. In the case in question, however, the conditions seemed to indicate that the two leads of each pair of conductors coming into adjacent bars were interchanged. This gives a condition which is not an open or short circuit, but which results in a double potential between the segments of two pairs of bars; and the brush failing to commutate this abnormal voltage burned the mica separating the high voltage bars. In Fig. 1, the conditions described are illustrated, i.e., the two leads of each pair of conductors entering segments *2* and *3* are interchanged. It will be seen by tracing out the winding that, between the bars *1* and *2*, coils *a* and *b* are in series; between *2* and *3* coils *b* only; and between *3* and *4* coils *b* and *c* in series. This condition imposes a double potential on those mica segments which are shown dotted.

E.D.P.

ELECTRIC FLASHING SIGN OPERATION

(13) What is the reason for the lamps in many intermittent electric signs burning at a dull red glow during the "off" period, instead of completely going out?

The lamps act as described by reason of the type of control switch or flasher used. The main switch of the sign is automatically opened and closed by an electrical auxiliary; but, by reason of a comparatively high resistance shunt, which is permanently connected across the gaps that are made when the switch is opened, the circuit still remains unopened, the new condition, however, being that now the lamps are in series with a resistance. The resistance of this shunt is so proportioned, in order to effect automatic operation of the flasher, that it assumes the major share of the voltage drop, leaving only such an amount for the lamps as will cause them to glow at a dull red. When the main switch closes, it short circuits this shunt resistance and the lamps burn again at normal voltage.

Those flashing signs whose lamps completely go out are controlled by a type of automatic flasher in the operation of which the main switch is opened and the lamps isolated during the "off" period.

O.P.A.

ELECTROLYTIC CONDUCTION

(14) In an electrolytic cell, having lead anode and copper cathode for precipitating copper on the cathode from a solution of copper sulphate in sulphuric acid, what function do the hydrogen ions and the SO_4 ions of the sulphuric acid perform in the conduction of the current? What becomes of the SO_4 ions of the copper sulphate after its corresponding ion of copper has been precipitated on the cathode?

The character of the solution will be that of a mixture of hydrogen, copper, and SO_4 ions, the SO_4 ions from the $CuSO_4$ behaving no differently from those of the H_2SO_4 present. The phenomena of conduction through the intervening solution and those at the electrodes must be kept distinct. In the conduction in the solution, all the ions present take part in proportion to their individual concentrations and their characteristic velocities.

If the voltage be less than 1.7 volts no hydrogen ions will separate whatever the current density may be, but an increase in concentration of hydrogen ions will occur about the cathode. With a voltage above 1.7 volts the transference of charges to the cathode may be partly performed by the hydrogen ions, and this will certainly happen if the current density is much above 2.0 amp. per 100 sq. cm. of the cathode surface, for a 15 per cent $CuSO_4$ solution. The more concentrated the solution is in copper ions, the greater the current which can be passed through it without any separation of hydrogen ions.

Accordingly, in the above case with the voltage customarily used for precipitating copper at the beginning of the electrolysis, the hydrogen ions will transfer no electricity to the electrode, unless the solution be very dilute. The current will be carried by all the ions, but delivered at the electrodes by equal quantities of (positive) copper and SO_4 or oxygen (negative) ions; and the latter, if SO_4, after giving up their charges to the anode, react with water according to the equation:

$$2\ SO_4 + 2\ H_2O = 2\ H_2SO_4 + O_2$$

The oxygen is evolved as gas. The action of the oxygen at the lead anode is to produce lead peroxide.

W.R.W.

SECONDARY OF SERIES TRANSFORMER OPEN CIRCUITED

(15) What is the cause of the excessive voltage rise, which occurs across the secondary terminals of a series transformer, if they become open circuited?

First keep in mind those properties peculiar to a series transformer, viz., that it is designed to work at a very low magnetic density and that also a change in its secondary current can only be effected by first a change in its secondary induced voltage. Since the magnetic density is so low, the magnetizing current required is very small, being only sufficient to magnetize the core to such a density that it will induce, in the secondary, that small e.m.f. necessary to force the stable value of secondary current through its low resistance meter load. Furthermore, if under any existing conditions the value of this magnetizing current were deducted from the primary current, the primary and secondary ampere-turns would exactly balance. Holding a constant primary current, and increasing the resistance of the secondary circuit, decreases the current, which causes a diminishing of the secondary ampere-turns. Therefore less primary ampere-turns are required to equal it in opposition; but, the primary ampere-turns remaining the same, an excess is left over. This excess becomes then additional magnetizing current, tending to raise the secondary e.m.f., and causing a greater secondary current to flow. This action being in opposition to the original decrease of current causes a stable condition to be arrived at, in which a smaller amount of secondary current flows but under a greater e.m.f. As the resistance which may be inserted in the secondary increases, this same action is continued; and at the limit (an infinite resistance or open circuit), the secondary ampere-turns fall to zero and all the primary ampere-turns become magnetizing. These, working on a nominally low density core, produce an excessively high density flux, which in turn, being unopposed by the secondary, generates in it an abnormally high voltage.

E.C.S.

METHODS OF DRIVING EXCITERS

(16) What is the best method for driving the exciters of a generating station? What are the disadvantages of those driven by motors directly from the main line?

The best method is that which ensures the maximum continuity of main line service, and in view of this it is not worth while to depend upon only one source of power for driving the exciters. There are two means which are very suitable in accomplishing this end: first, supplying the power from a separate steam or waterwheel driven low voltage alternating current generator, in parallel with additional transformers drawing power from the main line at this same potential; or, second, by using direct current motors driven also by a separate unit with a storage battery floating on the line.

Should the motors be driven directly from the main alternating current line, the whole system would be liable to a complete shut-down in case of a heavy, sudden load or short circuit on the line, for this might perhaps cause the motors driving the exciters to fall out of step.

Ref.—"Some Problems in Central Station and Substation Operation," by C. W. Stone, G. E. Review, June, 1912. E.C.S.

CHARACTERISTICS OF ELECTRICAL PORCELAIN

(17) What is the primary difference in the manufacture of wet and dry process porcelain, and for what insulating purpose is each of these products especially adapted?

As the question implies, the fundamental point of difference is in the amount of moisture which is present in the material, as handled in the two processes. As a matter of fact, there is only one stage in the process of manufacture, viz., the moulding, where such a variation occurs, and it is at this point that the two processes diverge. The moist cake, resulting from the wet grinding of a mixture of clays, is partly dried and then disintegrated into the form of a damp powder for use in the dry process, while that which is to enter the wet process is allowed to remain in its putty-like consistency. The dry process material is moulded under pressure in steel dies to the exact final shape desired: the plastic mass for the wet process is moulded under slight pressure into a blank, from which, after partial air drying, the final form is obtained by turning on a lathe or its equivalent. It is at this point that the processes again coincide, the moulded shapes being sprayed with a glaze and baked, which concludes the manufacture.

It is fortunately a property of the clay when at the "dry process" consistency that it will flow in even a very intricate die, and yet be dry enough to withstand later handling, for this permits a rapid production of those numerous complicated porcelain parts which are necessary in low voltage wiring.

Chemically the product resulting from both processes is the same; physically that of the wet process is the least porous, therefore, electrically the wet process insulator is the one best suited for high voltage work, dry process insulators being used up to about 2500 volts.

Ref.—"Porcelain for Electrical Purposes," by L. E. Barringer, G. E. Review, March, 1908.

L.E.B.

USE OF METER TRANSFORMERS

(18) Enumerate concisely the advantages to be gained by the use of current and potential transformers, in modern switchboard practice.

(a) The combination of a transformer and ordinary meter, trip coil, or relay, is cheap. Equivalent single apparatus of a special design, to carry the total current or voltage direct would be of prohibitive cost, and in fact, would be in some cases well nigh impossible to construct.

(b) The transformers eliminate high potentials at the meters or coils, thereby lessening their liability to injury, and personal danger at accidental contact.

(c) Several transformers may be permanently inserted in the alternating current lines and all wired to read (one at a time) on a single meter, thus saving the expense of several meters and eliminating interruption in the alternating current lines, which would be necessitated by opening them to insert the direct reading meters.

(d) In case of injury to a meter or instrument transformer, only that which is damaged need be replaced, and not the whole measuring appliance, as in the case of a special combination meter. Further, a meter replacement will cause no interruption in the main lines.

(e) One transformer may supply both ammeter (or voltmeter) and wattmeter at the same time, or various types of relay coils if desired. The limit to the number of devices operated is set only by the maximum allowable value of volt-amperes, which may be drawn from the secondary of that transformer. J.R.C.

GENERAL ELECTRIC REVIEW

Published Monthly by the
GENERAL ELECTRIC COMPANY'S PUBLICATION BUREAU

Manager, M. P. RICE   Editor, D. S. MARTIN   Associate Editor, B. M. EOFF   Assistant Editor, E. C. SANDERS

Subscription Rates: **United States and Mexico, $2.00 per year; Canada, $2.25 per year; Foreign, $2.50 a year, payable in advance. Remit by post-office or express money orders, bank checks or drafts, made payable to the *General Electric Review*, Schenectady, N. Y.**
Entered as second-class matter, March 26, 1912, at the post office at Schenectady, N. Y., under the Act of March 3, 1879.

VOL. XVI., No. 5   MAY, 1913

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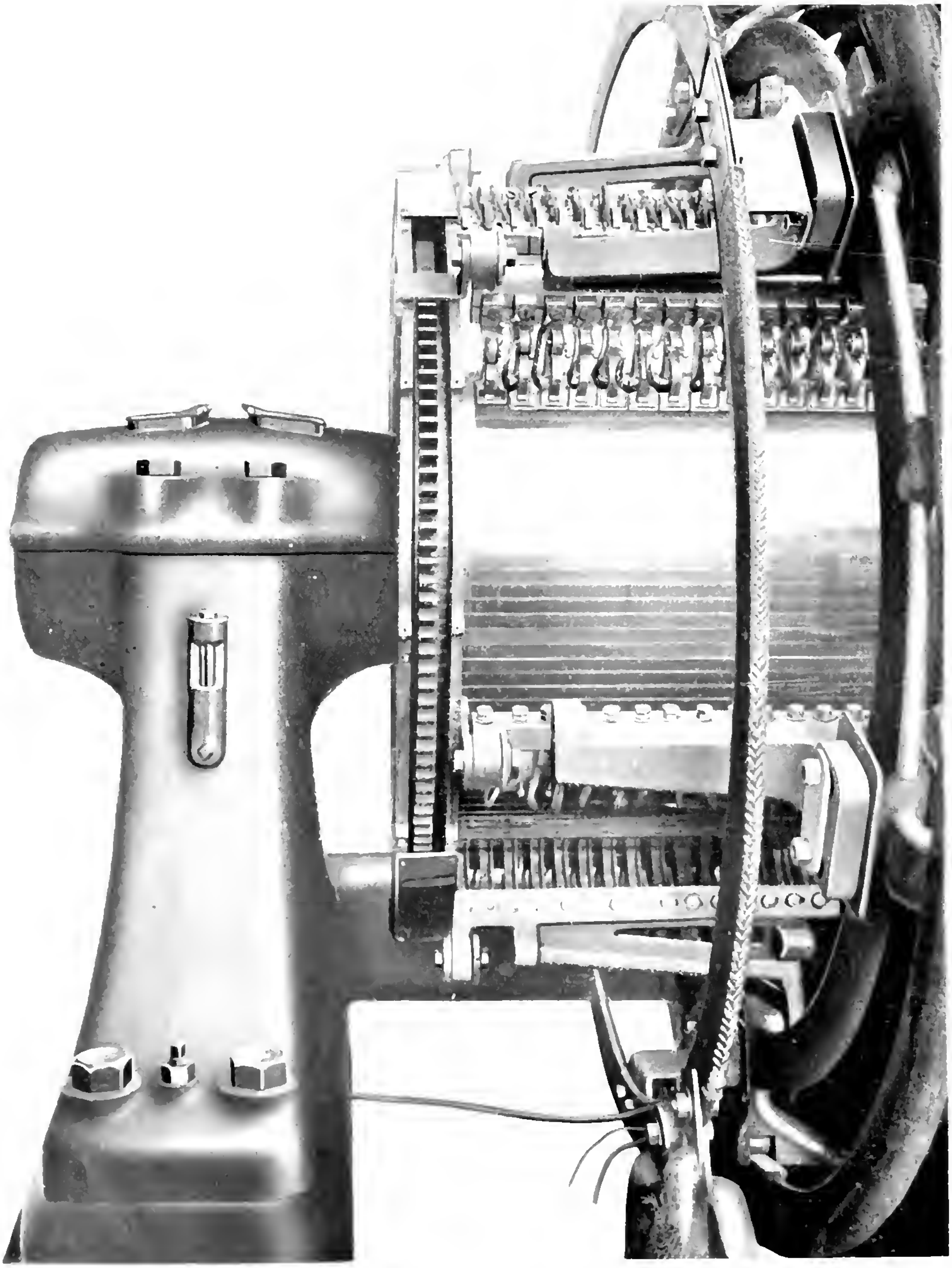


The successful use of commutating poles on the synchronous converter has so improved the commutation that this factor has become less of a limiting feature, and has resulted in the ability to realize more nearly the full capacity of the material in the machine as determined by heating. The increased output per pole, however, has compelled attention to be directed to methods of improved ventilation to take care of the heating factor, and much ingenuity is being evinced in the design with this end in view. This cut is a good illustration of a successful ventilating method. Note the cooling vanes on the commutator, one of which is attached to each bar. In operation the vanes are covered by an inverted trough which protects the operator, and, at the same time, effectively guides the air past the vanes. (See "Recent Designs of Synchronous Converters," by J. L. Burnham, page 299).

GENERAL ELECTRIC REVIEW

REAL CO-OPERATION IN THE ELECTRICAL BUSINESS

Of nearly every great invention it may be said that, while, at the time of its consummation, it has excited bewilderment and admiration and has been hailed as the greatest wonder since Time began, nevertheless its appeal to the popular imagination has become gradually subdued and ultimately hushed as it has taken every-day commercial form and its results have become as daily bread; until finally people have said, not "What master mind brought this thing into being?" but "Why did not some fool think of it before?" Hence the pithy apophthegm, "Familiarity breeds contempt."

We will not say that, in a few years time, there will be anything approaching contempt in the feelings of the electrical man when he contemplates the first-fruits of the Society for Electrical Development (Inc.); but, when he does begin to realize what a mighty instrument for good is now at the disposal of the whole electrical industry, and has seen something of the results which it can achieve, and will very quickly achieve, it is pretty safe to say that he will wonder why we have gone along for so many years without it. Because, after all, relatively few men in the electrical trades in America are in business for their health. They are there to make money. This Society will help them to do it much more quickly and in a much safer manner than any other which they could think of.

The business of electrical engineering is making money quite rapidly now. It is one of the safest investments in the market, and it represents a capitalization of about 10 billion dollars. But even though this sum, compared with the figures for, say, 1883, represents a rate of growth which has only been beaten once in history, and then only by a beanstalk, it nevertheless seems that we have only just begun to scratch the surface of the lighting, heating, power and traction loads. The new movement for co-operation in the electrical industry, culminating in the inception of this Society, simply indicates one thing: that all the various electrical interests have now realized that the quicker these additional loads are snapped up the more money there will be in the individual electrical pocket. An increase in the sale of toast-racks, for instance, does not simply represent so much money in the pocket of the man who sold the toasters. It means load for the central station and full time in the workshop, and may be at the same time the dawn of an electrical-cooking era. The effects of any obstacles in the way of making such sales are felt as much in the station accounting room as in the store, and as much in the store as in the factory. The mere existence of the Society is practically a guarantee of its success, since it implies a universal recognition, on the part of the electrical interests, of a fundamental truth. It will aim to clear away the obstacles which stand in the way of further expansion of the whole electrical business, whether these obstacles are set up by the ignorance of the public as to the good things they are missing, or internal dissensions between central station and jobber. "All power to its strong right hand" is the wish of the manufacturer, who stands to gain as much as anyone from the efforts which are going to be made. A central station man at the recent Conference said that "the central station industry is largely the residuary legatee of all the good that comes out of this expansive effort to increase electrical service to the public, and find new outlets for current and apparatus." This promises well for the support which the central stations will want to render; but as a manufacturer's paper we must give it as our opinion that the producer of the apparatus is back of the central station, and stands to gain even more. It may be electrical apparatus for a sign outside a city drug store, or a loom in a Southern mill; the ward of a hospital, or the turret of a battleship; but if the sale is made some factory gets the order, whoever makes the sale and whoever supplies the energy. The manufacturer therefore wants to boost.

A great deal has already been written about the scope, aims, functions, purposes and other things pertaining to the new society. We can recommend the article by Mr. Judson on page 308 in this issue, as going a little deeper into the subject than many, and throwing some very illuminating spotlights on definite points which will require attention.

FURTHER EVIDENCE OF THE CRIMINALITY OF THE BIG ELECTRICAL CORPORATION

Very recently, say in the last twelve months, we have been able to detect, in the public speeches of leading electrical men, a note of anxiety and sometimes apprehension as to what is going to be the future attitude of the public and the Public Service Commissions towards the big electrical corporation. Several recent occurrences prove beyond all doubt that the public are utterly ignorant of the nature of electrical service; cannot appreciate the reasons why electrical supply, to be successful, must be a monopoly; and are willing to place a monopoly of this kind in the same category as a monopoly of bread or of dry goods. An electrical engineer who is also a taxpayer may take some pleasure in contemplating a clever cartoon in a weekly paper, in which, say, a hardworking citizen is depicted in a death agony, fighting for his life in the grip of a dozen hideous giants one representing a money-trust, another an oil-trust, a third a beef-trust, and so on. When he catches sight of the *n*th figure labelled "Electrical Trust," his reason manfully asserts itself, his joy disappears, and he turns quickly to the next page, wishing devoutly that the artist was as well versed in economics, and especially in electrical economics, as he was in humor and in the craft of the pencil.

That false view still represents the view of the average citizen; and it is to be devoutly hoped that future operations of the Public Service Commissions will be based upon a sane and enlightened view of the nature of electricity, its generation and supply. The central stations for their part have little difficulty in establishing their case for sympathetic treatment and a comprehending system of regulation; and their viewpoint has been placed on record many times of late in eloquent speeches by such men as Samuel Insull, H. M. Byllesby and other leaders.

As a symbol of the economic value, or even of the economic necessity, of the big manufacturing corporation, we have for some time seen nothing more eloquent than the recent *Abstract-Bulletin* of the Physical Laboratory of the National Electric Lamp Association.* The Laboratory was organized in the autumn of 1908 for the development of those branches of science with which the art of lighting is closely associated. The results of the investigations have been presented before the various scientific and technical societies and in the technical press of this country and Europe; and, while a complete reprint of these various papers would result in a volume of most unwieldy size, it has nevertheless been considered that the complete work of the laboratory should be collated in such a way as to render it available to all interested parties. The *Abstract-Bulletin* is the outcome. It contains an abstract of every research carried out in the laboratory from its inception to the summer of 1912, and reads more like a contribution from a university than from a manufacturer's establishment. The original work, of the results of which this *Bulletin* is a very condensed digest, represents by far the most extensive and most valuable which has been carried out in the last few years, in this country or elsewhere, in the endeavor to ascertain more exactly the physical properties and physiological effects of light. The ordinary man will never see the *Bulletin*, and could not be expected to attach any significance to it should he chance to come across a copy. For our part, we consider the publication valuable enough in itself; but, far more than that, are duly impressed with its significance as a further proof of what the big manufacturer has been doing, and is still doing, in forwarding the cause of the electrical industry. Sometimes in a national campaign of advertising his methods catch the popular eye and due note is made of them. In other cases he does good largely by stealth and his movements are likely to go unnoticed. Their beneficial effects are not for that reason any less genuine and far-reaching.

For the benefit of our technical readers we wanted to review this review in the Review. Realizing our limitations, however, we called in the aid of Mr. G. H. Stickney, who is very well-known in the field of illuminating engineering; and a somewhat detailed notice by him of the technical contents of the *Bulletin* appears on page 339 of this issue.

*Since its incorporation the name of the association has been changed to "National Quality Lamp Division of the General Electric Company." The former name is the one which appears on the publication under notice.

HUNTING

By Charles P. Steinmetz

Chief Consulting Engineer, General Electric Company

Dr Steinmetz employs only the simplest language in defining and explaining the nature of synchronizing power and synchronizing force, and in showing that the hunting of a synchronous machine—a cumulative oscillation—is not a function of the synchronizing force, but is a true hysteresis effect, the result of a lag of the synchronizing force behind the position displacement which produces it. He draws an interesting analogy between such electro-mechanical hunting and the purely mechanical hunting of a belt on its pulley; and also states that a further analogy is provided by electro-magnetic hunting in transformers and arcing grounds. Dr. Steinmetz will be represented in the June power transmission number by an article on grounding the neutral.—Editor.

If two synchronous machines, such as converters, are connected together slightly out of step, or are thrown somewhat out of step by some other means, the machine in which the rotor is ahead of the position of mean rotation (i.e., the "leading machine") gives more power and so slows down, while the "lagging machine" gives less power and so speeds up, and the machines thus come nearer together.

However, when they are in step, the machine which was formerly leading, being slower in speed, still loses, and thereby drops behind; while the machine which was formerly lagging gains due to its higher speed, and thus runs ahead, and the machines again pull apart, this time in the opposite direction. This goes on until the increased load on the leading machine retards it and once more causes it to drop back; while the decrease of load on the lagging machine causes it to speed up and gain. In this manner by a number of successive oscillations the machines settle down into step. If there were no losses, at every swing the machines would pull apart again as much as they were apart in the preceding swing; but, owing to the energy losses caused by the oscillations, the swings decrease the more as more energy is dissipated by them, and the oscillation thus is damped out. This is not hunting, but the natural and inherent adjustment into step by a decaying oscillation.

The pulling together of synchronous machines is the result of the increase of load on the leading machine, which retards it, and the decrease of load on the lagging machine, which accelerates it; and the change of load with the change of the relative position of the machines thus is called their "synchronizing power." That is, we may consider—and if the machines are running at no load, this is actually the case—that the leading machine transmits power to the lagging machine, and that hence an interchange of power occurs. If there were no interchange of power with the relative position—that is to say, if the running ahead of a machine would not put any load on it, and inversely—there would be nothing to stop the machines from drifting out of step with each other. If the running ahead of a machine would decrease the load on it—as is the case in series connections of two alternators—it would continue to run ahead with increasing force, i.e., the conditions of "in-stepness" would be unstable, and equilibrium and synchronous operation impracticable.

The synchronizing power, i.e., the power exerted by one machine upon the other, is the result of a position displacement of the machines, and is thus the cause of the possibility of parallel operation. The synchronizing power is, approximately, proportional to the displacement in position; if the two machines are thrown out of step by twice the angle (i.e., the one pushed ahead, and the other back, from its mean position by twice the position angle) obviously the exchange of current, and thus of power, is approximately twice as before.

Synchronizing force, i.e., the force with which the leading machine is pushed back and the lagging machine forward, thus is (approximately) proportional to the amount of lead or lag of the respective machines; and, as a result, the force with which a machine runs ahead, is held back and finally stopped, is the same as the force with which it moves back into step again and then out of step in the opposite direction. This, however, is the case only if there are no losses and no lag of the synchronizing force behind the position displacement.

The result of losses is that the machines are held back from going apart with greater force than they are pushed together again, and thus on the next swing go apart less, i.e., gradually settle into step.

The result of a lag of the synchronizing force behind the position displacement is that, when the displacement increases (i.e., the machines pull apart), the opposing synchronizing force is less than it is when the machines come together again; and the machines thus are pushed together at an increased energy, and on the next swing go apart further. In other words, the result of a lag of the synchronizing force behind the position displacement is an increase of the successive swings: a cumulative oscillation, or *hunting*. Thus hunting is not an incident of synchronizing force or insufficiency of it; but is the result of a lag of the synchronizing force behind the displacement in position which produces the synchronizing force, and is thus a true *hysteresis effect*, i.e., a "lagging." If there is no lag of the synchronizing force, there can be no cumulative oscillation, i.e., no hunting; but, since energy losses must always be present, the machines must steady down to rest.

The relation between mechanical momentum and magnetic forces, the frequency and intensity of energy impulse, etc., have no direct bearing on the phenomenon of hunting, however important they may be; but merely determine the frequency of the synchronizing oscillation, and thus of the hunting, if it can occur, and to some extent the rapidity of its increase.

If a lag of the synchronizing force is present—and some lag almost always exists—hunting would occur if the cumulative energy resulting from this lag is greater than the energy losses due to the oscillation. If the energy losses are greater, hunting does not occur; but the energy losses decrease the oscillation more rapidly than the lag of the synchronizing force increases it.

Practically all anti-hunting devices—i.e., devices which dampen oscillation by energy dissipation, such as short-circuit conductors around the poles, between the poles, a complete squirrel cage winding, etc.—also cause more or less lag of the synchronizing force, and thereby increase the hunting energy. This explains why an anti-hunting device may in one case stop hunting; and the same, or similar device, in another case make hunting worse. If the increase of energy losses due to the device is greater than the increase of lag of the synchronizing force, it improves the operation; otherwise it makes hunting worse.

The foremost problem in the design of anti-hunting devices thus is to reduce to a minimum the lag of the synchronizing force caused by them. They usually operate by currents produced in them by *c.m.f's.* induced by the position oscillation. Since, owing to inductance, the currents lag behind the induced *c.m.f's.*, this gives an unavoidable lag of the synchronizing force; and the more non-inductive the anti-hunting winding is made, the more effective it thus becomes. Therefore, while a conducting collar around the face of the pole close to the armature may stop hunting, the same short-circuit around the field pole at a distance from the armature may make hunting worse, owing to the greater self-inductive lag of the currents induced in it.

Hunting then is the phenomenon resulting from the lag of the synchronizing force behind its cause, the position displacement; and is a general phenomenon, which can be observed in all oscillatory phenomena where a lag of the effect occurs behind its cause.

Thus the vibration of a belt may become a mechanical hunting, increasing an amplitude until the belt is thrown off. The pulley is double cone shaped; so that the belt, when running towards one side, grips on one side of the cone and therefore rolls up on the cone towards the middle of the pulley. There it runs over on the other side, grips there, and rolls back to the first side; and so see-saws between the two sides of the pulley. If now the conditions are such that the belt runs beyond the middle of the pulley, before it grips on the other side, it comes back with increased force, i.e., the vibration increases in amplitude, in true mechanical hunting. Here also the observation can often be made that the operation is steady at heavy load, where the energy losses (slippage and stretching of the belt in this case) dampen the hunting; while at light load the oscillations begin, just as is often observed in the case of synchronous machines.

One of the most important oscillations with which electrical engineering has to deal, is the electromagnetic oscillations of distributed capacity and inductance—electric waves, impulses and other transients. When dealing with such waves in overhead transmission lines below the corona voltage, i.e., in magnetic and dielectric fields which are proportional to the current and the voltage respectively, no hunting can occur. As soon, however, as this proportionality ceases, and a lag makes its appearance, such as the lag of the magnetic field behind the current in magnetic materials, the lag of the arc voltage behind the arc current, etc., true hunting may occur, if the energy dissipation (i.e., the ohmic resistance) is sufficiently low; and in such case, then, as oscillations in the high potential windings of alternating current transformers, in the phenomena of arcing grounds, etc., electromagnetic hunting—analogous to the electromechanical hunting of the synchronous machine—can occur and has been observed and studied. This, however, must be reserved for a future article.

THE DISCOVERY AND DEVELOPMENT OF NEW BUSINESS

By Fred. M. Kimball

Manager Small Motor Department, Lynn Works, General Electric Company

Following the paper by Mr. Larke in the April Review on "Some of the Fundamental Principles of Commercial Engineering" we publish here a very interesting essay by Mr. Kimball on the opening up of new-business outlets, and the qualifications which the salesman must possess for such work beyond those of the agreeable and gentlemanly order-taker, who can tell the latest story and entertain gracefully. Mr. Kimball has made a close and sympathetic study of salesmanship and the education of salesmen; and the present article will shortly be followed by another from him in this same series on "The Personal Equation in Selling."—Editor.

The remarkable ingenuity and resourcefulness displayed by American inventors and manufacturers has resulted in a constantly increasing number of new products, new processes and new machinery, all of which have created for themselves a demand and market of large dimensions as soon as they were properly advertised and exploited. The normal and constantly expanding wants of our people, stimulated by reading, by travel and observation at home and abroad, and by the intimate contact with all classes of their fellows,—a closeness and character of contact which is perhaps existent in no other country,—automatically insure an ever-enlarging market for the product of the farmer, the mechanic, the artisan, and the producer of every other necessity and luxury, more diverse and of greater magnitude than has ever existed since the beginning of the world.

Our luxuries of yesterday have truly become the necessities of today. Our public school systems have educated our people to a nice discrimination between existing and living; and they all seek to share in the conveniences and luxuries as well as in the necessities and comforts of life, and exert every effort to that end. The desire of the wage earner to emulate the capitalist, the stimulation to purchase afforded by the extraordinary quantity of seductive advertising which appears in our daily papers and in all our current literature, as well as the general tendency to expand the scale of living and conduct of business, all add to the absorptive power of our people, and contribute to enhance the diversity and growth of commercial activity.

Under existing conditions of business in America today, purchasers place their orders with a large degree of spontaneity; and, to a considerable extent, the growth of our business depends more upon the attractiveness of the merchandise offered, and prompt and satisfactory service to existing customers, than on the systematic and aggressive development of new ones.

There still remain, however, many outlets for our various products which are not utilized or imperfectly developed by reason of the fact that business-getting has not, as yet, in adequate degree, been reduced to an exact and systematic science. The systematizing of business and business-getting, however, has been attracting more and more attention during recent years, and in the aggregate many progressive manufacturing and merchandising organizations have made remarkable progress toward achieving high efficiency in developing new outlets and customers, as well as in the conduct of all other branches of their business.

Notwithstanding this progress, however, we continue to accept to a large extent the obvious opportunities for securing business; and fail to realize and develop the latent opportunities, which, while individually yielding comparatively small results perhaps, cumulatively and in the aggregate will yield enormous returns.

In a comparatively new country, possessing the tremendous natural resources found in the United States, primary development is still the principal object, and our efforts are naturally very largely concentrated on and directed towards securing the spontaneous business, the big business, the business which will apparently yield the greatest profit with the least expenditure of time and effort. I think this is particularly true in regard to those lines of activity which are of more recent origin; and the electrical industry is, in considerable degree, typical of such a line.

When a salesman is assigned to a territory, it is perfectly natural that he should lay out his route, if left to his own devices, so as to insure the most comfort in passing from place to place; to complete his journey in the least time; that he should devote his principal attention to the larger cities and towns; and that in such cities and towns he should give preference to the larger customers, to those with whom he has established pleasant personal relations, and to others from whom he is pretty sure to secure large orders without great effort.

This is all well in itself; but in so doing, he frequently neglects a large amount of latent business, which, in the aggregate, if pursued and secured, would very materially swell the volume of his sales during the initial period of development, and almost certainly lead to largely increased sales as time elapses.

To secure this latter business, however, requires a very conscientious, energetic, industrious and well-informed salesman. He must possess other qualifications than those of an agreeable and gentlemanly order-taker, who can tell the latest story or entertain gracefully and tactfully. To develop new business opportunities, a salesman must have imagination and a highly cultivated "mental eye." He must be able to look beneath the surface and beyond the obvious. He must be able to see an opportunity for creating a demand or supplying a need that the more superficial observer does not discover. Needless to say, he must not only have a most thorough knowledge of the product which he handles, but, in general, of similar product sold by competitors. He must know every valuable feature of his merchandise, and similarly, every valuable or vulnerable feature in the merchandise sold by his competitors. In addition, he must acquire the greatest possible knowledge in respect to the known or possible uses of his wares, and their application or desirability in every line of business activity with which he may come in contact, or in connection with which his imagination may lead him to think them applicable. He must overcome the natural antipathy which every salesman has to a greater or less extent for locating, approaching and introducing himself to new, prospective customers, and to expending the time and effort necessary for securing their acquaintance and full confidence.

He must become thoroughly acquainted with the general condition and development of the business of all his customers, analyze the opportunities afforded for introducing his product to them, and demonstrate that the purchase and utilization of his wares in connection with their business will be profitable.

To prospective customers whose orders are not spontaneous, that is, to those who have no knowledge or appreciation of the value of the product or service offered by a salesman, he should first of all demonstrate the general advantages which will follow from purchasing wares or service of the general class in which he is interested. His own particular product or service may well be kept somewhat in the background during the initial stages of negotiation. The main object should be to interest the prospect by such presentation of fact or argument that he will become in greater or less degree a spontaneous buyer; and, when perfect or partial spontaneity of interest or desire has been aroused in respect to the wares or service offered, as a class, then every effort should be exercised to demonstrate the superior value and fitness of the particular wares or service which the salesman offers to meet the disclosed needs of his prospect.

If a salesman is approaching a new prospect for the purpose of introducing the electric drive, it is not desirable to endeavor to sell him a power plant and motors first off. The first and most important thing is to demonstrate to the prospect that the electric drive is a necessity to him; that its adoption will insure greater production, and greater reliability in maintaining continuous operation of his establishment; lesser cost of operation and maintenance; more hygienic surroundings for his employees; minimum insurance, and the opportunity to so rearrange his machinery as to secure more direct and time-saving sequences in manufacturing operations;

and better light and thus a better utilization of his floor space and other facilities. When the prospect has become thoroughly convinced that the electric drive will prove a real advantage to him in many or all of these respects, the time has come to emphasize the special value of the product manufactured by the company in whose interest the salesman is working. To do all this successfully requires imagination, ingenuity and close application as well as knowledge.

The small town, remote from the main line of travel, must not be ignored: large factories and other business enterprises are frequently located in comparatively small towns. In the aggregate they may yield a great deal of business; and having established friendly and close relations with even a small manufacturing concern in its formative period, if due care be exercised that the advice and service given the customer are reliable and prompt, that whatever is sold to him is thoroughly adapted to his requirements, that he is never "oversold," that his complaints, if any, are promptly and carefully investigated and adjusted in accordance with the facts disclosed, the future business of such customer, as his business expands and his purchasing power grows greater and greater, will usually be conserved to the salesman who originally found him out and first established cordial and helpful relations with him.

The reader asks, How shall all this be done? Where shall we find such men as you describe? How shall we secure and assure systematic exploitation of the territory? What will induce the acquirement and exercise of the rather unusual qualities you declare to be necessary?

The supply of order-takers is large, but the supply of salesmen is short. The same painstaking and definite attention and interest must be concentrated on training salesmen that is devoted to improving one's product or service and reducing its cost. This involves the expenditure of money, but such expenditures are fully warranted. How incongruous to entrust the demonstration and sale of an article, the perfection of which has entailed a cost of thousands of dollars, to a man who neither knows, appreciates, nor can point out and emphasize its particular construction or fine points of merit; whose "ammunition" consists of glittering generalities and the idea that entertaining secures permanent business! Such a man's "overhead charges"— traveling, hotel bills and entertaining—are usually more than those of the trained salesman, and the latter's orders far surpass the orders of the former in value and total amount.

The training of salesmen for one's own business may well be classed as one of the most important activities of the employer. An encouraging sign of the times is that many of our most progressive and successful corporations and firms have established regular courses of salesmanship within their own organizations, from the graduates of which their salesmen are recruited. While all business houses cannot carry out this method of training on the broad scale adopted by the larger companies, in degree it can be undertaken by all.

Systematic exploitation of territory is only to be obtained by systematic direction, and friendly and helpful supervision; a route carefully laid out after the most thorough study of the territorial possibilities; an assignment of no more territory than can be fully covered; and finally, by frequent meetings of the salesman with his superiors, at which time his work should be carefully reviewed in detail, and an accounting for all the customers or prospects in his territory required. In such interviews, cordial appreciation of achievement should be volunteered, when merited; the vicissitudes encountered by the man on the "firing line" should never be lost sight of; and thoughtless, harsh criticism should give place to kindly, helpful and constructive suggestions.

The incentive of the salesman to acquire and exercise the needed qualities of salesmanship should be his sure knowledge that he will share, by reason of a definite arrangement to that end and without the necessity of periodical solicitation on his part, in the increasing fruits of his labors. He should be assured that neither volume of business nor profit, alone, determine his compensation; but that these, together with his success in gaining new and holding old customers, his success in maintaining reasonable prices, the clearness, completeness and accuracy of all his correspondence, orders and records determine his value to his employer.

The time, the labor, and the money bestowed upon increasing the efficiency of the human element in business will produce results far surpassing those that can be obtained by any increase in the quality or efficiency of inanimate articles of merchandise; and the surest way to discover and develop new business is to provide well-trained, eager, efficient salesmen, working under capable, systematic, friendly supervisors.

THE SPHERE GAP AS A MEANS OF MEASURING HIGH VOLTAGE

By F. W. Peek, Jr.

Consulting Engineer, General Electric Company

This article shows that by using spheres for the electrodes of spark gaps much more consistent results are obtained than with the present extensively used needle gap. Correctly proportioned sphere gaps are not nearly so sensitive to the modifying effects of varying degrees of humidity; there is no corona formation preceding spark-over, and consequently no heating of the air by the streamers; the space factor is smaller; while several thousand measurements can be made before repolishing becomes necessary. The results of some calculations and tests on gaps formed between spheres of different size are shown in the shape of curves. A few simple formulæ are given to assist in calculating special cases.—Editor.

General

The needle gap has long been a useful means of approximating high voltages, but with the present extra high voltages we have about outgrown it. Although it is possible to measure high voltages with a fair degree of accuracy with needle gap, too much skill is required, and too many variables must be considered, especially at extra high voltages. The voltmeter coil offers a reliable means of high-voltage measurement, but a gap method is desirable because the gap measures the maximum point of the wave and this is what determines the breakdown of insulation.

With a gap method it is thus not necessary to take oscillograms, except to know that the wave fairly approximates the sine; i.e., is a good commercial wave. The sphere gap used within the limits described below seems the best solution of the practical problem. It is free from the eccentricities of the needle gap, requires less skill in manipulation, the space factor is small and, furthermore, the curve can be readily calculated within a small percentage error.

There is one variable that must affect all gap measurements—air density. Over the ordinary small range of temperature and variation of barometer *at or near sea level* correction may be made by multiplying by δ, where

$$\delta = \frac{3.92\ b}{273+t}$$

For high altitudes, where the range of δ is large, the correction is slightly different and will be given later. The curves given in this article are for 25 deg. cent. and 76 cm. barometer.

The Needle Gap

The needle gap is generally unreliable, due to the broken-down air which surrounds the gap long before the spark passes, and to the large space factor which makes it necessary to remove surrounding objects to a great distance for consistent results. The broken-down air causes discrepancies by heating the gap, and there is also a very great variation with varying humidity. The effect of humidity is shown in Fig. 1, where it can be seen that a higher voltage is required to spark over a given gap when the humidity is high than when it is low. The

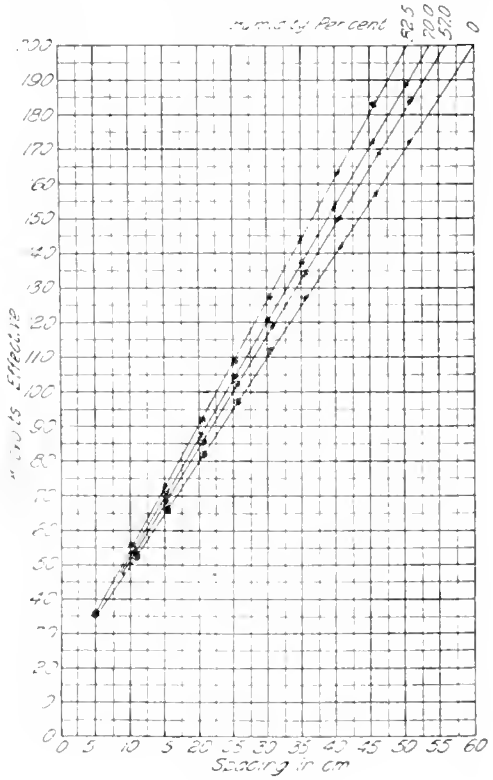


Fig. 1. Needle-Gap Curves for Different Relative Humidity

curve thus varies from day to day as much as 20 per cent. It is probable that the corona streamers in humid air cause a fog, as it were, agglomerating the water particles, and these, in effect, increasing the size of the electrode. There is also considerable variation with the sharpness of the needle, and probable variation due to local resonance set up by the streamers. Needles must be changed after each spark-over.

The Sphere Gap

The voltage required to spark over a given gap between spheres increases with the diameter of the sphere. If a sphere is chosen so that the spacing for the required voltage is never greater than four times the sphere radius (practically 3R), the first evidence of stress is complete spark-over; corona can never form, and all of the undesirable effects and variables due to the broken-down air are eliminated.

Humidity has no measurable effect. The space factor is small—for instance, at 200 kilo-volts, the gap between needle points is from 50 to 60 cm.; for 25-cm. diameter spheres it is only 13 cm. It is not necessary to polish the spheres after each spark-over. Several thousand measurements may be made without repolishing. Care should be taken that the spheres are at least twice the gap distance from surrounding objects. A greater distance is desirable, especially when one sphere is grounded. The curves may be accurately calculated. With 12.5, 25, 50 and

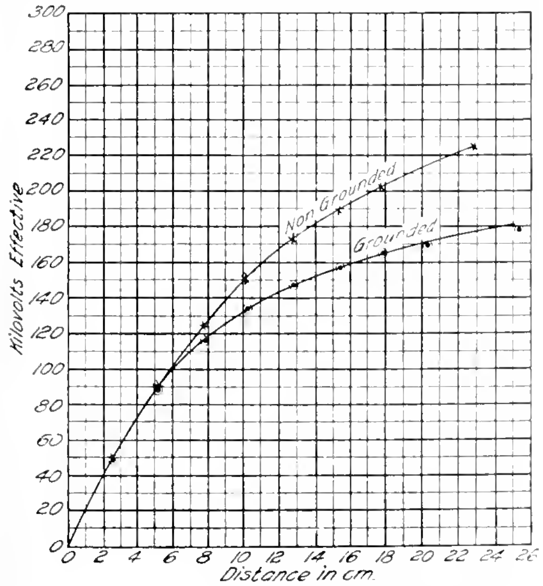


Fig. 2. Spark-Over Curves, Using Spheres of 12.5-cm. Diameter. The drawn curves are calculated, while the points represent measured values

100-cm. spheres, a range of voltage from 20,000 to 1,500,000 may be covered. It must be noted that the curves are different when one sphere is grounded and when both spheres are insulated.

Fig. 2 gives grounded and non-grounded curves for the 12.5-cm. sphere; Fig. 3 gives

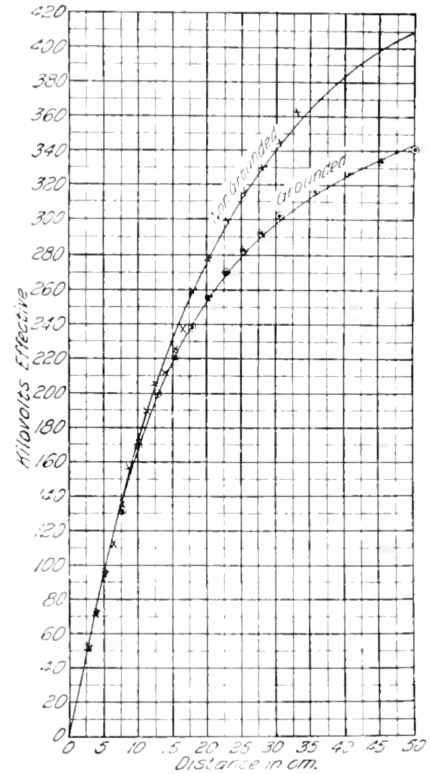


Fig. 3. Spark-Over Curves Using Spheres of 25-cm. Diameter. The drawn curves are calculated, while the points represent measured values

curves for the 25-cm. sphere; Fig. 4 gives curves for the 50-cm. sphere; and Fig. 5 gives curves for the 100-cm. sphere. Values for practical measurements are given in tables I, II and III. Where investigations overlap, these values check well with others recently published.* In all of these the drawn curve is calculated, while the crosses mark the measured values. The calculated curves were drawn long before measurements were made on the larger spheres, from laws derived from a series of tests on spheres ranging from 0.32 to 5.0 cm. in diameter. No measurements have been made on the 100-cm. sphere, but the calculated curve, Fig. 5, should be correct within a small per cent.

High Frequency

A curve on the 12.5-cm. sphere was made up to 25,000 volts at 1000 cycles and coincided

* Calibration of the Sphere Gap Voltmeter, A.I.E.E., Feb., 1913.

with the 60-cycle curve. At 50,000 cycles similar curves were made on spheres and needles. The sphere gap curve for this frequency was somewhat lower than the

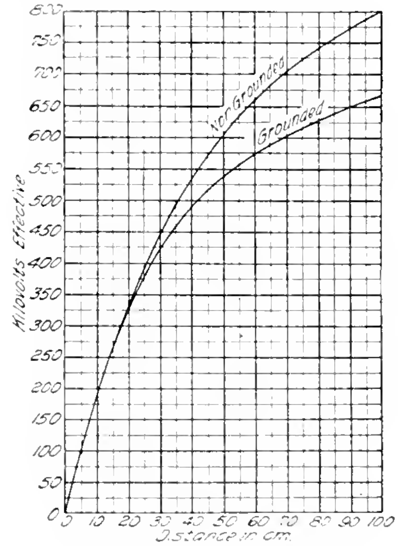


Fig 4 Spark-Over Curves Using Spheres of 50-cm Diameter. Curves Calculated

60-cycle curve, while the needle gap curve was very much lower. The curves given are for commercial frequencies 25 to 100 cycles.

If a needle gap is set so as to just spark-over when a steep wave-front or high-frequency voltage of constant value is applied, and a sphere gap is similarly set, and these two gaps are then placed in parallel, and the same impulse voltage applied, apparent discrepancy results. Spark-over will take place across one gap, and not the other, even when the spacing on the non-sparking gap is decreased. This will be noticed in all cases where electrodes of different shape are employed. The reason, apparently, is that energy is necessary to start rupture in the dielectric, the amount of energy varying with the shape of the electrode. This introduces a time element which differs for different gaps. The effect, however, is rarely noticed in commercial testing.

Method of Measurement

Up to 200,000 volts, measurement was made by a voltmeter coil giving a great degree of accuracy. Check was made on this by step-down transformer, by ratio and by corona starting point, results from which were all in agreement. Above 200,000 volts, step-down transformer and ratio were used. The voltage ratio was very close to turn ratio. A good wave, very nearly sinusoidal, was used, and oscillograms were taken for correction in low side of step-up transformer, in voltmeter coil and in step-down transformer. The waves on high and low side were practically the same. Care was taken to place spheres not closer than twice the gap distance from surrounding metallic objects; greater distance is always desirable.

Glass water tube resistances were used in series with the gap, limiting the arc current to from 0.25 to 1.00 ampere. The object of this resistance is to limit the current in the arc, and also to eliminate the effect of any high frequency disturbances which may result from the test piece, as it is not desirable to include any such effects in a 60-cycle test. The potentiometer method† of voltage control was used. This regulator consists of a resistance shunting the low voltage side of the transformer and by-passing five or more times the exciting current. The voltage is controlled by varying a resistance in series with the supply. It is often convenient to combine this method of control with generator

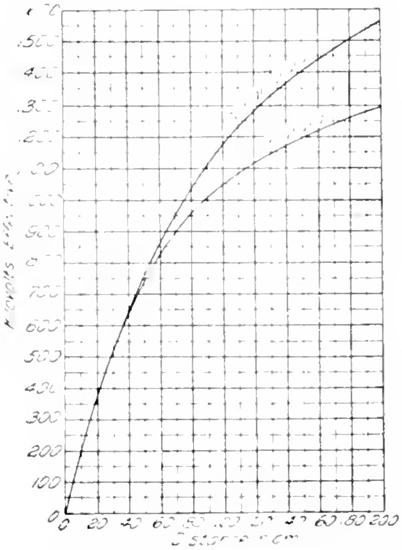


Fig. 5. Spark-Over Curve Using Spheres of 100-cm Diameter. Curves Calculated

field control, but never operating generator below half voltage.

† See *The Law of Corona and the Dielectric Strength of Air*, by F. W. Peek, Jr., TRANSACTIONS A.I.E.E., 1911, XXX, III, p. 1889.

Calculation of Curves

The voltage gradient on the air is greatest at the sphere surface. This stress or gradient derived mathematically is expressed*

$$g = \frac{e}{x} f \qquad \text{(kv cm.)}$$

where e is the applied voltage, and x is the distance between sphere surfaces. e/x is the average gradient, and f is a function of $\frac{x}{R}$, where R is the radius of the sphere in cm. The f is different in the two cases when one sphere is grounded, and when both spheres are insulated. The values of f for the two cases are given in Fig. 6. We have found experimentally that g_s, the surface gradient at spark-over, as in the case of g_v for corona on wires (see Fig. 7), increases with decreasing radius. It may be expressed approximately†

$$g_s = g_0 \left(1 + \frac{a}{\sqrt{R}}\right)$$

where g_0 for a given size of sphere is constant for the practical range of spacing used in measuring, that is, when x is not less than about $0.5\sqrt{R}$, nor greater than $3R$. When x is less than $0.5\sqrt{R}$, g_s increases very rapidly because the spacing is then less than the "rupturing energy distance."‡

The increased value of g_s when x is large seems to be only apparent and due to the shank, surrounding objects, etc., better distributing the flux or lessening the flux density. When both spheres are insulated this effect is small, and is inappreciable for large spheres where the mathematical f may be used. When one sphere is grounded, however, this apparent increase of gradient is very great if the mathematical f_1, which does not take account of surrounding objects, is used. The f values given in Fig. 6 are for the *non-grounded case*. They are the *mathematical values* and, within the limits prescribed, *give a practically constant gradient* g_s. The dotted line, Fig. 6, is the mathematical curve for the grounded case. This does not hold, due to

TABLE I

SPHERE GAP SPARK-OVER VOLTAGES**

12.5 CM. SPHERES

Spacing Cm.	Spacing In.	Kilovolts Effective Non-Grounded	Kilovolts Effective Grounded
0.25	0.098	6.5	6.5
0.50	0.197	12	12
1	0.394	22	22
1.5	0.591	31.5	31.5
2	0.787	41	41
3	1.181	59	59
4	1.575	76	75
5	1.969	91	89
6	2.362	105	102
7	2.756	118	112
8	3.150	130	120
9	3.543	141	128
10	3.937	151	135
12	4.72	167	147
15	5.91	188	160
17.5	6.88	201	168
20	7.87	213	174

TABLE II

SPHERE GAP SPARK-OVER VOLTAGES**

25 CM SPHERE

Spacing Cm.	Spacing In.	Kilovolts Effective Non-Grounded	Kilovolts Effective Grounded
0.5	0.197	11	11
1	0.394	22	22
1.5	0.591	32	32
2	0.787	42	42
2.5	0.983	52	52
3	1.181	61	61
4	1.575	78	78
5	1.969	96	94
6	2.362	112	110
7.5	2.953	135	132
10	3.937	171	166
12.5	4.92	203	196
15	5.91	230	220
17.5	6.88	255	238
20	7.87	278	254
22.5	8.85	297	268
25	9.83	314	280
30	11.81	339	300
40	15.75	385	325

TABLE III

SPHERE GAP SPARK-OVER VOLTAGES**

50 CM SPHERES

Spacing Cm.	Spacing In.	Kilovolts Effective Grounded Values
2	0.787	40
4	1.575	76
6	2.362	112
8	3.150	145
10	3.937	185
12	4.72	220
14	5.50	250
16	6.28	275
18	7.07	300
20	7.87	320
22	8.65	345

* Mathematical values of f have been derived by Russell, *Philosophical Magazine*, vol. XI, 1906. G R Dean, G.E. REVIEW, Mar., 1913.

† The constants are not the same as for wires. Values will be given later.

‡ See *The Law of Corona and Dielectric Strength of Air-II* PROCEEDINGS A.I.E.E., June, 1912.

** At 25 deg. C. and 76 cm. barometer.

the effect of shanks, etc., which it does not consider, and the actual curve is f_0. This was derived experimentally, assuming g_s constant. For a given value of $\frac{x}{R}$, f_0 is constant, inde-

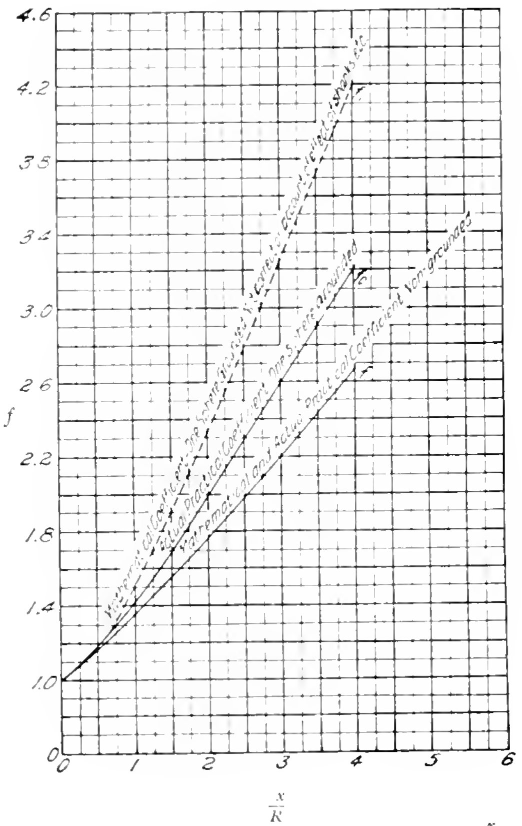


Fig. 6 Relation Between Different Values of $\frac{x}{R}$ and Function "f"

pendent of the size of the sphere (from tests on spheres from 0.32 to 25 cm.). Where x is greater than $4R$ the expressions do not hold, because corona then forms before spark-over.

We have then

$$g = \frac{e}{x} f \text{ (mathematical)} \quad \text{(kw. cm.)}$$

$$g_s = g_0\left(1+\frac{a}{\sqrt{R}}\right) \text{(experimental)(kv. cm.)}$$

Therefore

$$g_s = g_0\left(1+\frac{a}{\sqrt{R}}\right)\frac{X}{f} \quad \text{(kilovolts max.)}$$

or

$$e_s = g_s \frac{X}{f}$$

As an example of its use: What is the spark-over voltage for 25-cm. spheres (one grounded) 20 cm. apart?

$$R = \frac{25}{2} = 12.5$$

$$x = 20$$

$$\frac{x}{R} = \frac{20}{12.5} = 1.60$$

$$g_s = g_0\left(1+\frac{a}{\sqrt{R}}\right) = 31.2 \text{ kv. cm. max.}$$

This may be taken directly from the curve shown in Fig. 7

$f_0 = 1.74$ (from Fig. 6).

$$e = g_s \frac{x}{f_0} = 362 \text{ kv. (max.)}$$

$$e = \frac{362}{1.41} = 256 \text{ kv. (effective)}$$

For small spheres the range of the constant part of the g_s curve is very small, as the effect of shanks extends over a greater range. Hence, in practice, the above expression is especially applicable to spheres 10 cm. in diameter and above.

In order that the sphere gap may be used at various altitudes, and corrections made, curves must be taken at various air densities.

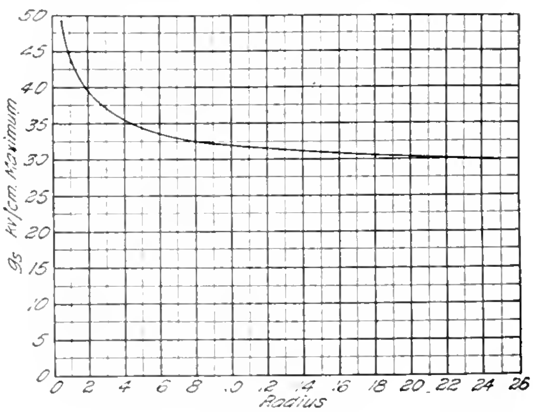


Fig. 7. Surface Gradient for Spheres of Different Size

It is probable that the full correction will be made as in the case of parallel wires:

$$g_s = \delta g_0\left(1+\frac{a}{\phi(\delta)\sqrt{R}}\right)$$

This is being investigated and the constants of the equations will be given when the data have been more thoroughly analyzed.

THE ELECTRIC DYNAMOMETER IN THE AUTOMOBILE INDUSTRY

By Carl F. Scott

Commercial Engineer, Sprague Electric Works, New York City

This article explains the principle of the electric dynamometer, and enumerates its marked advantages in the testing of all types of gasolene engines; describes its construction; shows how the readings of torque and speed are obtained; explains the control system and the method of absorbing the load; and describes the procedure for conducting the tests on the engine. The latter part of the article deals with the chassis-testing electric dynamometer; and is in the main a very striking summary of the reasons why the automobile factories are finding that this method of testing chassis pays—a method in which the tire bill is eliminated, labor costs reduced, whole-time operation of men and plant made possible, and, in brief, economies effected which quickly outrun the entire costs of the complete electrical equipment.—Editor.

The enormous growth of the automobile industry, represented by an increase in the production of pleasure cars and trucks to a number undreamed of half a decade ago, has been accompanied by marked improvements in the engine itself, which is the heart of the gasolene vehicle, and is now well along towards perfection.

All of those parts of the engine which exercise so vital an influence over its performance and efficiency must be studied, modified, and subjected to experiment until the most suitable designs are developed. The carbureter, the intake and exhaust passages, the valves, the compression ratio, the bore and stroke, the ignition system, the lubrication, the cooling system, and the fuel are all variable factors whose proportions or properties have the greatest influence on the characteristics of the engine. The design of these various parts is still the object of much theory and considerable discussion, and their true relationship to engine output and efficiency can only be determined by accurate

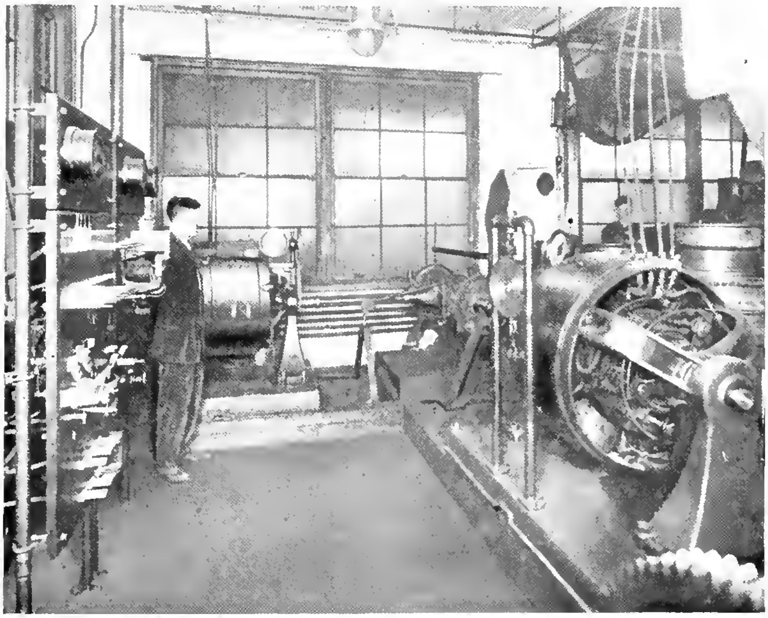


Fig. 1. Electric Dynamometer Applied to Testing Automobile Transmission and Rear Axles. One machine drives the transmission and measures the input; the other machine absorbs the power and measures the output. Timken-Detroit Axle Company, Detroit

and scientific tests. The supreme importance of an adequate testing device for gasolene engines is therefore manifest.

Of all methods of testing gasolene engines the electric dynamometer method has proved to be the most suitable. An article by Mr. H.S. Baldwin, descriptive of the earlier developments of such a device was published in the issue of the REVIEW for October, 1909, in which were pointed out the many advantages of the electric dynamometer as compared with dynamometers of other types, such as the prony brake, the hydraulic dynamometer, etc. During the past three years great advances have been made by the adoption of the electric dynamometer, and it is to-day used by most of the leading automobile, gas engine and carbureter manufacturers throughout the country.

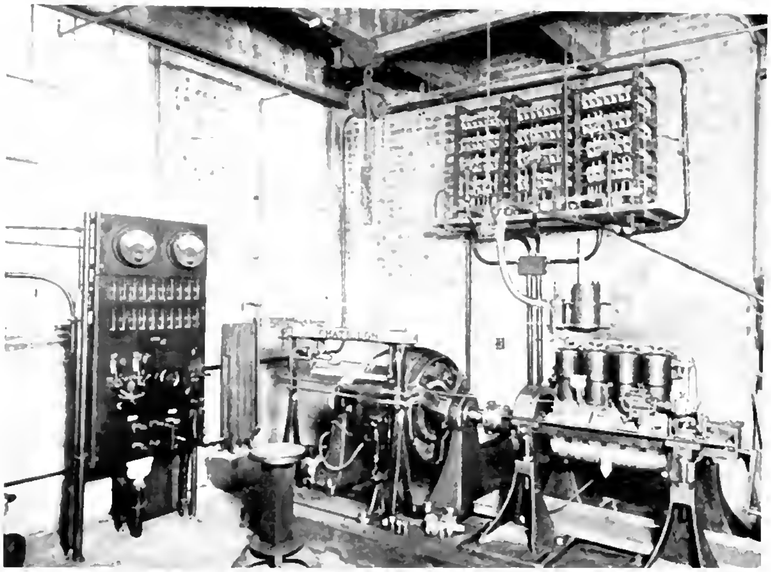


Fig. 2. Testing Laboratory of Carbureter Manufacturing Company Equipped with Electric Dynamometer. Findeisen & Kropf, Chicago

The electric dynamometer was first used in the automobile industry only for the testing of gasolene engines, the dynamometer shaft and engine shaft being coupled directly together. A later application, and one of very far-reaching importance, is for the testing of the complete automobile chassis. This application is discussed in detail below. Still another field for the electric dynamometer is that of testing transmissions, as by its use very accurate measurements of gear efficiencies under load can be obtained.

The electric dynamometer is essentially a device for absorbing or transmitting power, and is so constructed that the torque delivered to its shaft, or by it to some driven machine, can be directly measured on a standard scale or balance. The speed of the revolving shaft for different torque values is measured by means of a tachometer or counter, and therefore the horse power is immediately ascertainable.

The peculiar advantages of the electric dynamometer that make it preeminently suited for testing gasolene engines, are as follows:

(1) The speed may be varied throughout the entire speed range of the engine, say from zero to 3000 r.p.m.

(2) The load can be varied from no load or minimum load up to maximum or breakdown load, while the equipment is running.

(3) The speed-load variations can be accomplished through practically the entire range above mentioned by simply turning a rheostat handle. The load can be held steadily at a given point as long as desired—for hours or days at a time.

(4) The readings of torque and speed are the only readings required, and the horse power values are obtained without any calculation.

(5) The dynamometer is extremely accurate, and its operation involves no variable factors or corrections.

(6) The electric dynamometer is reversible, that is, it can be used to measure the power required to drive the engine idle, as well as the output delivered by the engine under its own power.

(7) The power delivered by the engine is dissipated at a point remote from the dynamometer, and therefore the operation of the test with the electric dynamometer involves no objectionable heat, water waste, smoke, noise or danger.

(8) Very little attendance is required. It is possible for one man to run off a test.

Construction of the Electric Dynamometer

The electric dynamometer consists of a specially constructed direct current machine, the stationary field frame of which is constructed of electric steel and is rigidly secured to end brackets, which are supported on ball bearing trunnions so that the field structure is free to turn through a small arc. The armature or moving part of the dynamometer revolves within the field structure. Its shaft is supported on bearings within the end brackets, and is coupled direct to the shaft of the engine in test. The electric dynamometer is fitted with commutating poles, and is separately excited. The electromagnetic reaction of the internally revolving armature on the field poles tends to turn the whole field structure. The tendency to turn is directly proportional to the torque exerted by the armature, and this torque is measured directly on a beam scale or spring balance, which counteracts the turning effort of the field.

It should be noted that all of the torque delivered to the armature shaft by the engine, which is directly coupled to it, is measured on the scale, and that there are no corrections to be made on account of losses in the dynamometer; because the shaft bearing friction, and the brush friction, and even the bulk of the armature windage have a retarding effect and so tend to turn the field.

The field structure, mounted on its ball bearings, is carefully balanced before being placed in service. Counter balancing is necessary, owing to possible unbalanced masses on the field frame, weight of links and knife-edge for connection to beam scale, etc.

The accompanying illustrations, Figs. 1, 2 and 3, show the prevailing method of mounting the dynamometer and the engine in test. The pedestals carrying the ball bearings are bolted to T-slots cast in a heavy bed-plate. This bed-plate is extended to support a set of adjustable stands or pedestals on which the engine is mounted. The engine supports are adjustable vertically, longitudinally and laterally, to facilitate rapid mounting and alignment. Very accurate alignment is made unnecessary by the use of a double universal joint between the engine and dynamometer shafts.

The torque is measured by means of a standard beam scale, a spring balance, or a combination of the two. The torque arm of the dynamometer is made a convenient length, to give a simple horse power constant. A commonly selected length is $15\frac{3}{4}$ in., which gives a brake formula:

$$\text{H.P.} = \frac{\text{Pull in lb. on scale} \times \text{r.p.m.}}{4000}$$

The speed is indicated on a belted tachometer or electrical tachometer, or on both, and for careful readings usually checked with a revolution counter. The electrical tachometer, which is illustrated in Figs. 3 and 5, consists of a low voltage direct current magneto geared to the shaft of the dynamometer, and a voltmeter calibrated in revolutions per minute. The magneto is specially constructed to give a voltage absolutely proportional to the speed. To prevent variable brush drop, the commutator is made of platinum and the brushes of gold. The voltmeter, which is the standard D'Arsonval type, is calibrated with its particular magneto and connecting cable before shipment.

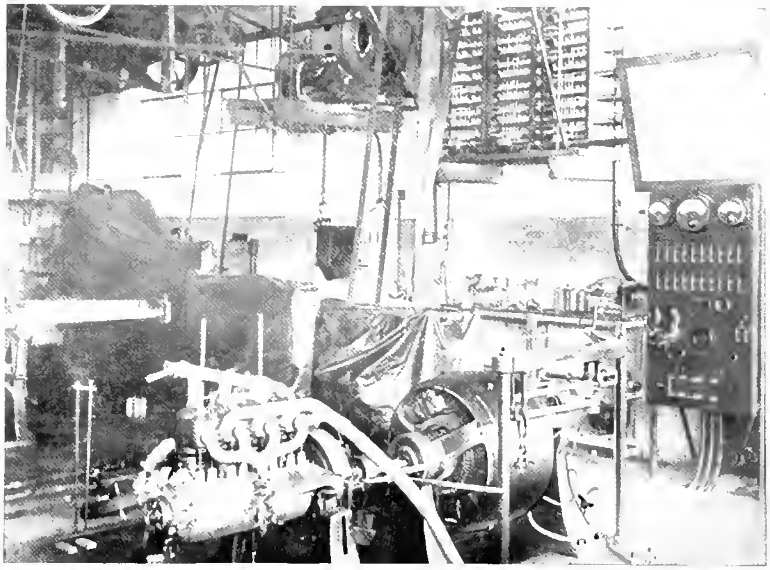


Fig. 3. Testing Laboratory of Large Automobile Factory Equipped with Electric Dynamometer. Willys-Overland Co., Toledo

The electric dynamometer is operated by means of a controlling panel, which is shown in Figs. 2, 3 and 5, mounted beside the dynamometer at a point convenient to the operator, so that he can adjust and read the beam scale or balance and manipulate the field rheostat without moving his position.

The control panel has mounted upon it the dynamometer field rheostat, a number of single pole switches for cutting into circuit sections of the load or absorption resistance, a circuit-breaker, a double-throw transfer switch for connecting the dynamometer terminals to the line or the load resistance, a voltmeter and ammeter, and the dial of the electric tachometer. The voltmeter and ammeter are used merely as a protection and as a check on voltage and current values, to insure that neither exceeds reasonable limits during operation. They have, of course, no part whatever in the measurement of horse-power.

It is possible, and entirely feasible under certain conditions, to operate the electric dynamometer back on the shop mains if the circuit is direct current. When making an extended run at a speed higher than that necessary for the armature to generate the line voltage, the dynamometer may deliver to the system the power represented by the fuel consumed in the engine, less the losses. As the dynamometer is shunt wound and separately excited, and as the gasolene engine has a "series characteristic," the operation in parallel with the supply generators, or with other dynamometers, will be perfectly steady. The armature voltage and current will be independent of the rheostat setting, provided only that the speed is at least normal or above. Variation of the field strength will merely change the speed of the set, provided the engine throttle is unchanged. If the field is weakened, for example, the voltage will tend to drop; this will cause the load to decrease, and the engine will speed up, restore the voltage, and so bring back the load to normal. An increase in throttle opening at the engine, however, increasing the power, will increase the current output for a given speed.

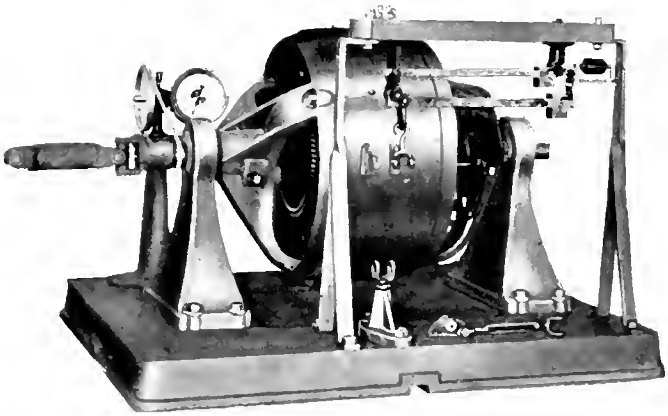


Fig. 4. 75 H.P. Electric Dynamometer. Used by U.S. Naval Academy, Annapolis, for Aeroplane Engine and other Tests

The operation of the electric dynamometer on the line, while of very great importance in connection with chassis-test dynamometers, later described in detail, is seldom employed during laboratory or experimental testing, for in such cases it is necessary to operate the engine through a speed range from the lowest at which it will turn over up to the maximum which it will stand. For experimental testing, therefore, a load resistance is always furnished to absorb the power generated by the dynamometer.

Conducting a Test

In conducting a test on a gasolene engine with the electric dynamometer, the method of procedure is as follows: The engine is firmly bolted or clamped in place on its supports and coupled to the dynamometer. The dynamometer is then connected to the line and started as a motor, driving the engine. The engine may be run for a time in this way, while the bearings and other moving parts are studied in action, compression pressures measured at different speeds, and power required to overcome friction and inertia at different speeds ascertained. The ability of the electric dynamometer to crank the engine and drive it at a great variety of speeds and measure its power input under varying conditions, is one of the great advantages of this type, and is a feature not found in any other form of dynamometer.

When ready to run the engine under its own power, the transfer switch is thrown over connecting the dynamometer to the load resistance, the throttle is opened a little and the ignition circuit completed. The engine is now turning over at low speed and light load. If it is desired to plot the speed-torque curve of the engine, beginning at the lowest speed, the field of the dynamometer is left at full strength, the throttle opened wide, and the load resistance reduced until the engine will just turn over. The speed and torque are noted. The dynamometer field is then weakened, and the engine will rise in speed, giving another point on the curve. In this way, by simply turning the field rheostat handle, the entire speed torque curve can be obtained. The dynamometer, being fitted with commutating poles, will operate sparklessly under conditions of full or overload current, with a very weak field.

It should be noted that the test can be conducted by one operator if desired, stationed beside the control panel and in front of the scale, with spark and throttle levers conveniently located, as shown in Fig. 2.

With the electric dynamometer it is possible not only to vary the load through the widest range while in operation, but to hold a perfectly steady load at any value, and at any speed at which the engine can operate steadily. This is due to the unchanging character of the absorption resistance. This characteristic of the electric dynamometer is one not shared by the hydraulic dynamometer or by the prony brake, and is an element of much importance in careful testing. This feature cannot be obtained, however, if the ordinary water barrel is resorted to for a load resistance, as it is apt to boil over and so change its resistance by varying the strength of the solution.

In making carbureter tests, it is often desirable to use a portable wattmeter, set beside the carbureter, to observe relative variations in power for different adjustments. As an increase in torque accompanying an adjustment may be coincident with a reduction in speed, the time of making simultaneous readings of torque and speed is saved by the wattmeter; though, of course, only relative changes and not absolute measurements of power are made in this way.

Complete engine tests with the electric dynamometer will include, beside the power output, the measurement of fuel consumed, (and in many cases the measurement of air consumed), the heat absorbed by the water in the jackets, the oil consumption, the analysis of exhaust gases, etc.

As the speed range of the dynamometer is coextensive with that of practically any gas engine within its rated capacity, as the short time overload capacity is enormous, and as

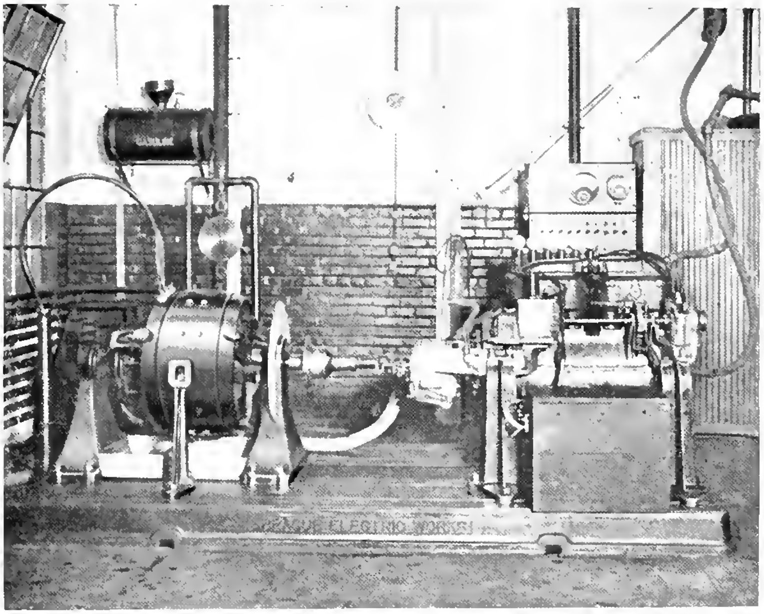


Fig. 5. Testing Laboratory of Large Automobile Manufacturing Company, Equipped with Electric Dynamometer. Hudson Motor Car Co., Detroit

it is equally accurate at all loads, one size of machine is suitable for testing a very wide variety of engines.

Electric Dynamometer for Chassis Testing

A very important field for the electric dynamometer is the testing of complete automobile chassis. Before the application of the device to this use, it had been customary for cars to be given their regular commercial tests on the road, after more or less unsuccessful attempts had been made at purely mechanical testing devices.

The road test has always been regarded as of great importance in automobile manufacture, and many companies have gone to great expense in securing "road conditions" sufficiently strenuous to give a severe test. The road test is, however, open to a number of objections, both from the manufacturers' and the users' points of view, and the demand for a really successful substitute was keenly felt.

To begin with, the road test is extremely expensive. The wear on test tires is very great. One large concern placed their annual loss due to test tires alone at more than $50,000. Other items of expense are the time spent in changing wheels and tires, cost of cleaning chassis, repairs due to road breakdowns, high cost of fuel, and the relatively high cost of labor for testing.

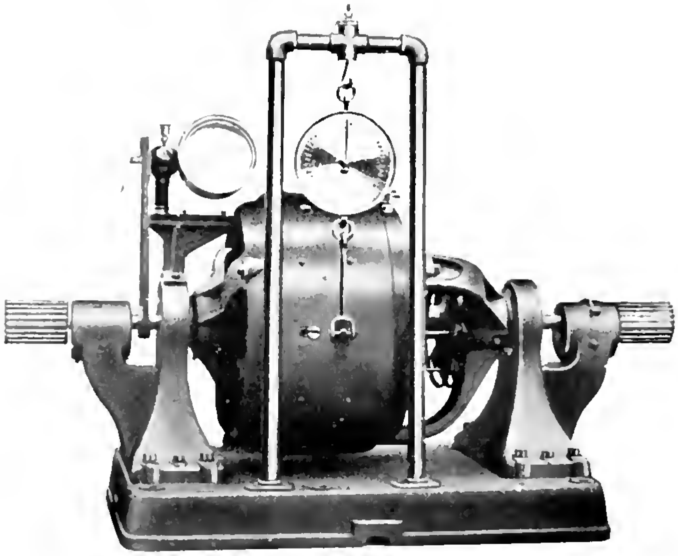


Fig. 6. Electric Dynamometer for Chassis Test

Another trouble with the road test is the difficulty of securing a really severe test. Hills are not always encountered near the factory, and sixty-miles-an-hour speeds are not permitted in all jurisdictions. In a large city like Detroit, opportunities for hills and speedways are very limited, and there are numerous restrictions placed by the city on speeding automobiles. Specially built testing tracks and sandpits are expensive to construct and maintain. With the dynamometer these difficulties are overcome as the car can be loaded to the breaking point, or engine and transmission speeded to their maximum, by the turning of a rheostat handle. With the road test method, results are not uniform and are hard to check. The best testing force cannot always be relied upon away from home. Repairs and adjustments on the road are difficult to make.

It was to fill the demand for a device by means of which the chassis could be tested right in the factory that the electric dynamometer for chassis testing was developed. It was designed to supplant the road test for regular commercial production, and for experimental or developmental tests on new designs. It does not reproduce the jolting of the road test, nor does it tend to jar the car to pieces. Weaknesses of this sort are presumably well eliminated when the design has been fully tried out, and when parts are interchangeably machined and subject to rigid individual inspection.

Construction of Chassis-Testing Dynamometer

The general appearance of the electric dynamometer for chassis testing is illustrated in Fig. 6. It is mounted on an individual base; and on each end of the shaft, which is extended for the purpose, is mounted a sprocket, these two sprockets being connected by silent chains with two corresponding sprockets mounted on the rear wheels of the car under test. The sprockets for the rear wheels are arranged so that they can be quickly attached by means of spacing pieces secured to the hubs. These spacing pieces are designed by the manufacturer to suit his particular requirements.

Provision is made for jacking up the rear wheels and tightening the chains after the car has been backed into place, the two operations being usually done simultaneously. The time required to back in place, mount the sprockets, raise up the rear axle, tighten the chains, apply the load, and begin to run, varies under ordinary conditions from five to ten minutes.

Torque measurements are made on a spring balance and speeds taken on a belted or electrical tachometer. Horse-powers are obtained in the usual way from the power chart.

Each equipment includes a control panel on which are mounted a voltmeter, ammeter, field rheostat, the necessary switches, and a wire-wound absorption resistance. The dynamometer current can be delivered to the line or absorbed in the resistance. The latter method is desirable when making tests over a wide range of speeds, while the former is practicable when running at normal speed or above, provided the dynamometer is wound to deliver line voltage at normal speed. Switching arrangements are provided so that the desired loads can be obtained at different change-gear ratios. The load and speed can be varied though a very wide range by simply turning the handle of the field rheostat.

Advantages of the Electric Method of Chassis-testing

With the electric dynamometer method of testing chassis, the cars are at all times during the test under the eye of a foreman; tests can be run under standard loads and speeds; results are more reliable and better recorded than on road tests; engine and transmission defects are instantly detected and quickly remedied; and carbureter adjustments can be made with the engine in the chassis, and with the equipment running. A more severe load can be placed on the engine and transmission than under the road test method. The engine can be run, if desired, at its maximum load and speed, for as long a time as desired. The effects of very high speeds, or of heavy pull at low speeds, can be determined to any desired extent. Manufacturers who use the electric dynamometer method assert that they are getting better tests and better cars than ever before.

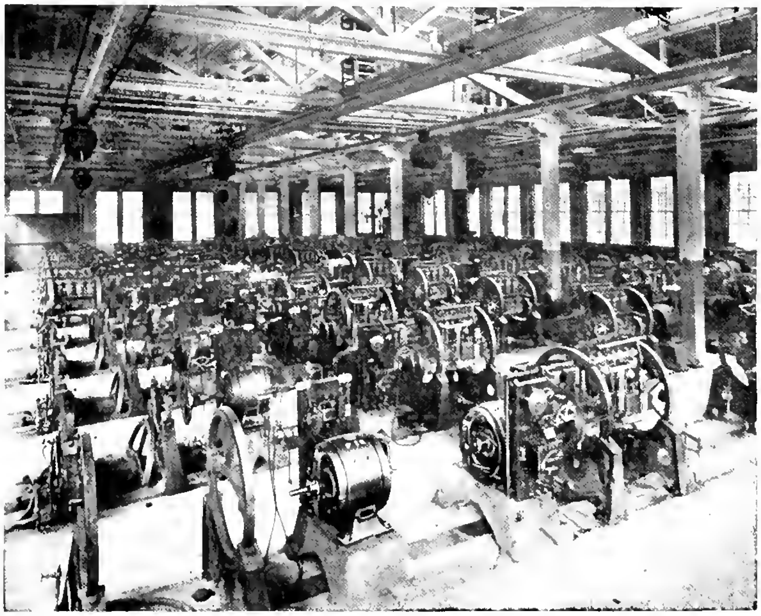


Fig. 8. Engine Testing Dynamometer, Cadillac Company, Detroit

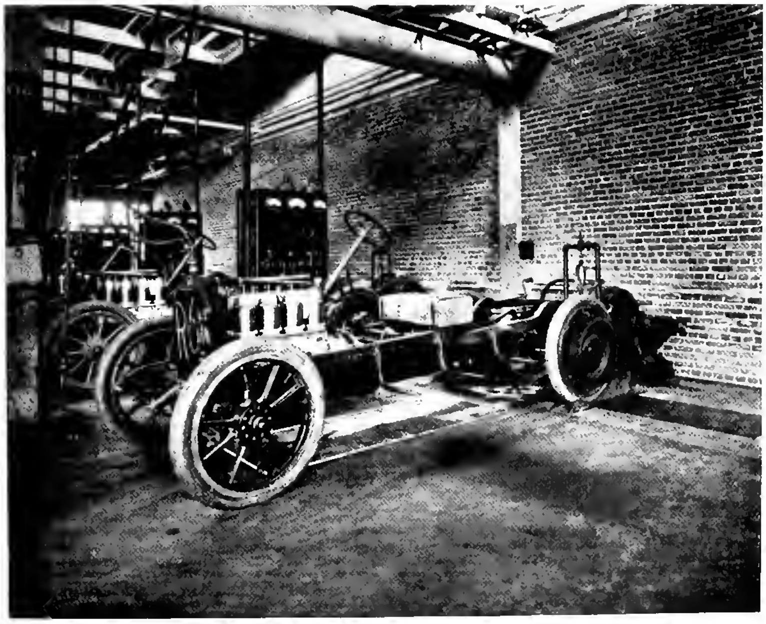


Fig. 7. Chasis-testing Dynamome'ers in the Plant of the Cadillac Motor Car Company, Detroit

An important feature of the dynamometer is that it makes possible the operation of the testing department twenty-four hours a day during periods of rush production—something impossible with road testing. Eight cars per 24-hour day can be tested on each dynamometer, giving each chassis a severe and thorough test; and this rate of production, with proper arrangements, can be kept up for any number of dynamometers in the plant.

As pointed out above, the use of the electric dynamometer for chassis testing effects an enormous saving in test tires; but this is not the only saving which is accomplished by its use. Testing cars by this method effects a considerable saving in labor over the road test method. One man can test twice as many cars per day on the dynamometer. The time and labor of cleaning cars that have been on the road is eliminated. The loss of time and labor incident to accidents on the road is obviated when the cars are tested under one roof where everything can be carefully watched.

The electric chassis-testing dynamometer is arranged so that during a run at normal speed the current generated can be delivered to the shop line. In this way a great saving in power is effected, and the manufacturer derives very material return for his outlay on gasolene. Where large numbers of cars are manufactured, the value of the current which may be saved annually assumes great proportions, which fact alone would justify the system.

The dynamometer generates direct current. If the shop supply is alternating current, a motor-generator set is installed to change the current.

As the cars when under test with electric dynamometers are stationary, circulating water must be provided. In one large plant this water after circulating through the engines and radiators, is returned to the heating system at a considerable increase in temperature. In this way the chassis-testing dynamometer has made possible a very great saving in water expense. The total decrease in manufacturing and testing expenses resulting from the use of the dynamometer in plants manufacturing cars in any considerable quantity has been found sufficient to more than pay the first cost of the installation in a single year.

Fig. 9. Chassis-Testing Dynamometers in the Plant of the Cadillac Motor Car Company, Detroit

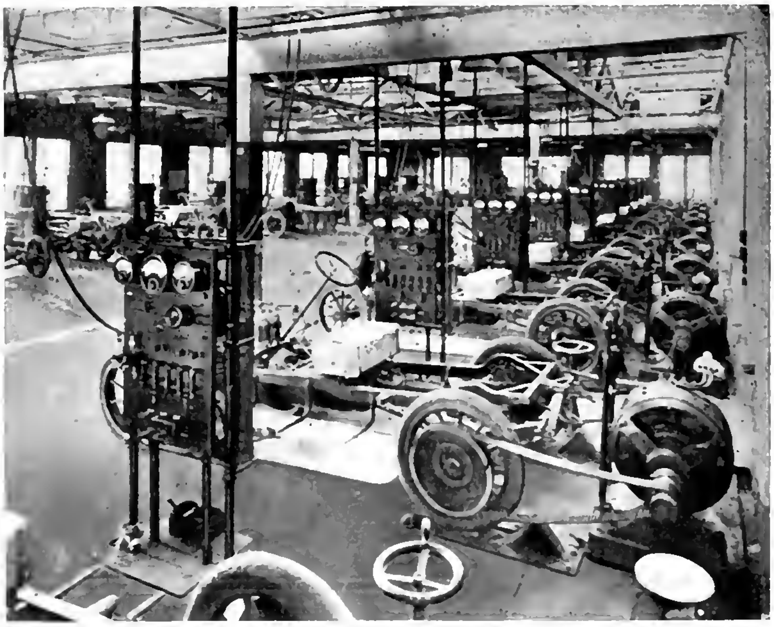


Fig. 10. Chassis-Testing Dynamometers in the Plant of the Cadillac Motor Car Company, Detroit

RECENT DESIGNS OF SYNCHRONOUS CONVERTERS

By J. L. Burnham

Direct Current Engineering Department, General Electric Company

No radical changes have been made in converter construction since Mr. Burnham's article in our February, 1912, number, and it will probably still be some time before there is any striking departure from existing practice. This article, however, points out some of the more interesting features embodied in recent designs, and is illustrated with a number of excellent cuts showing representative types of converter. Very sound engineering is put into the building of these machines; and a good idea of up-to-date construction can be obtained from a glance at Fig. 6, showing a complete railway converter, and the more detailed views of individual parts which follow.—Editor.

Improvements in the design of synchronous converters have had the effect of widening very considerably the field of application of this class of apparatus. The greater stability of alternators, with closer regulation and more uniform speed throughout a revolution of the prime mover, has helped greatly to eliminate the causes of pulsation or hunting. More efficient bridges or damping devices have made the converter more stable for adverse conditions; while better line construction and protection have reduced disturbances on the alternating side which are transmitted directly to the direct current side.

Commutating Poles

In a previous article in the Review* a treatment has been given of the general advantages to be obtained by the use of commutating poles. By the addition of commutating poles the commutation may be so improved that the output per pole with good commutation may be nearly doubled. With this increased output per pole, however, the necessity arises for more careful ventilation of the machine; and this particular matter has received very close study. In the two views of a converter armature shown in Figs. 1 and 2, the liberal air-duct allowance can easily be seen, while the spacing of the end conductors is a further point which may be noted. In some cases it may be found necessary to equip the machine with brushes of high efficiency, and to provide special cooling devices for keeping the commutator temperature within the desired limits. The commutator of a 1000 kw. 240/300 volt converter (shown in detail as a frontispiece to this issue) is provided with cooling vanes, one of which is attached to the end of each commutator bar. The vanes are of copper, which conducts the heat to the air rapidly. The vanes are covered by an inverted trough to protect the operator and, at the same time, more effectively to guide the cooling air past the vanes.

The net result is that a machine may be built which costs less, occupies less space in the station, has very materially improved commutation, and a resultant lower maintenance charge. Commutating poles are specially desirable for the larger size of machines having an output of 750 kw. and

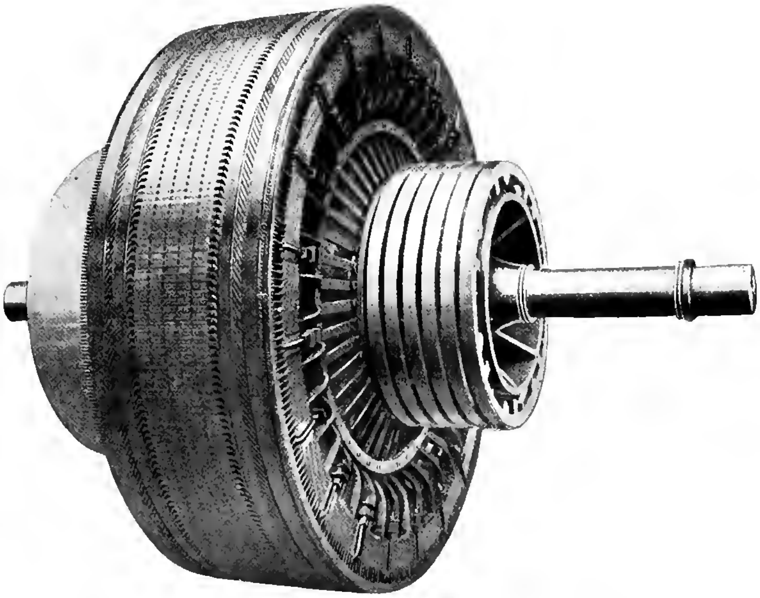


Fig. 1. Armature and Collector Rings of Six-Phase 3000 Kv-a. Railway Converter, Showing the U-Clamps for Equalizer Connections

* Modern types of synchronous converters, by J. L. Burnham General Electric Review, Feb. 1912.

Fig. 2. Partial View of Armature of Fig. 1, Showing Air-Ducts and Liberal Spacing of End Conductors

upwards, while they may be used to advantage on all smaller machines which are required to commutate any overloads in excess of 100 per cent.

Control of D-C. Voltage

The application of the synchronous converter to an increasing variety of services has brought with it a demand for greater flexibility in the control of the voltage at the d-c. end. To meet this there are several types of machine available, each possessing some particular advantage for the various load conditions to be encountered in practice. The various arrangements may be considered under four heads: (1) Split pole converters, and (2) a-c. booster converters in self-contained units; (3) with reactance, or (4) induction regulator, or taps on the transformer external to the converter.

(1) *Split pole converter.* This type of machine may have either (a) shunt or (b) series wound regulating field.

(a) The shunt regulating winding may be controlled, either by hand or automatically, to hold a certain voltage or a certain load. Machines so equipped are particularly suited to constant-load service; but they should not be employed if required to carry light loads (say less than one-third of full load) at the lower part of the voltage range, if they are to do so for periods much longer than is necessary for adjusting to the required voltage of the load before switching into service. At low voltage the field for commutation is too strong for light loads, although excellent for heavier loads.

(b) With the series regulating pole winding a greater degree of over-compounding can be obtained than with the reactance method (3), and with less change in power-factor; although if the reactance is also provided still greater over-compounding can be obtained. This machine will give good commutation at all loads. The series regulating-pole winding for a 250 kw. converter can be clearly seen in Fig. 3, although it should be noted that the machine shown in this picture carries a shunt winding on the regulating pole in addition to the heavy series coil. The compounding is from 500 volts no load to 550 volts full load.

Fig. 3. 250 Kv-a 500/550 Volt, Regulating Pole Converter Note Shunt Winding in Addition to Heavy Series Turn on the Regulating Poles

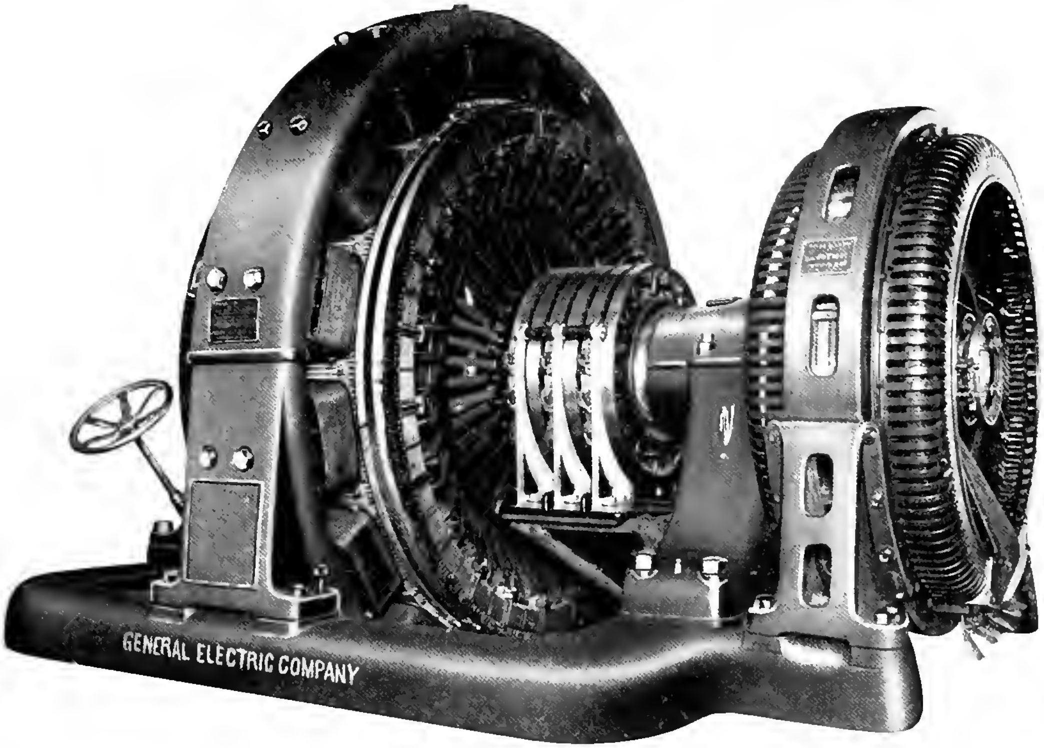


Fig. 4. 2000 Kv-a. 530/700 Volt Converter with Revolving Field A-C Booster

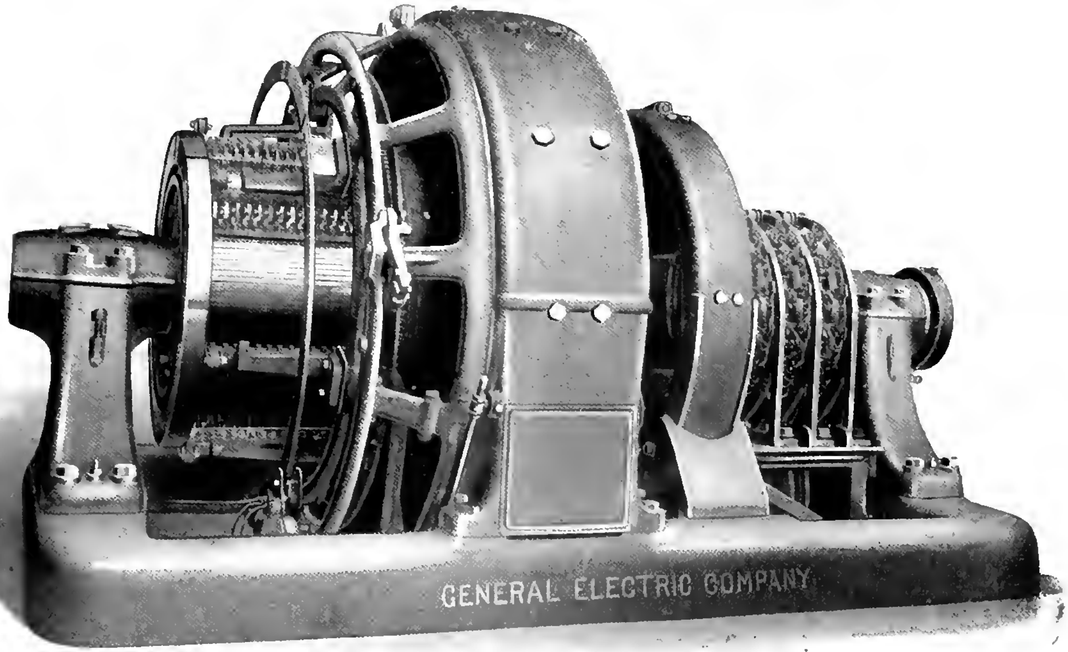


Fig. 5. 1000 Kv-a. Converter with Revolving Armature A-C. Booster. The commutator cooling vanes of this machine (already shown in detail in the frontispiece on page 278) are here covered

With the direction of rotation such that an armature conductor passes the regulating pole before the main pole, this machine will commutate almost the same as a commutating pole machine. Thus both large over-compounding and improved commutation are obtained with this arrangement without excessive change in power-factor. The shunt winding on the regulating pole permits hand adjustment of the voltage for changes in service conditions.

The A-C. Booster. This combination makes use of an alternator having the same number of poles as the converter with which it is used, and from which it is driven. Its winding is connected in series with the source of supply, so that its voltage may be added to or subtracted from that of the supply by the required amount, depending on the direction and amount of alternator field excitation. The booster may have either a revolving field or revolving armature, each type possessing certain advantages over the other. With the revolving field booster, a standard converter may be used; the booster may readily be disconnected from its converter in case of trouble; while testing and adjustments may very easily be made on this class of machine. Ventilation, moreover, is a very simple matter and the whole unit becomes very accessible for cleaning, inspection and repairs. A good view of a revolving field a-c. booster combination is shown in Fig. 4.

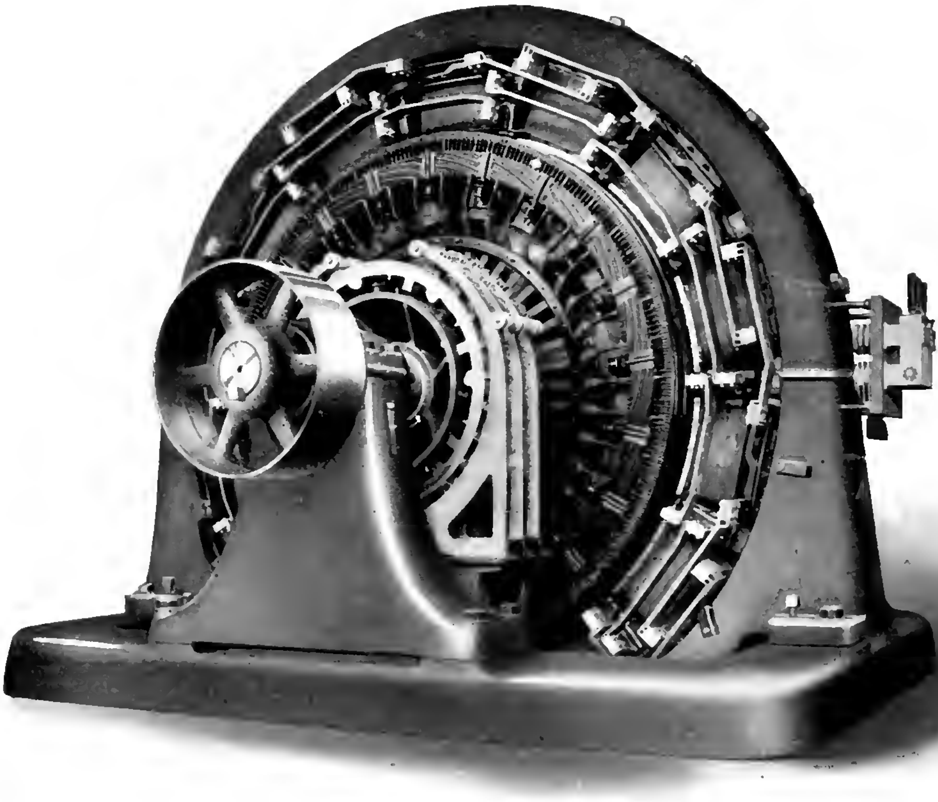


Fig. 6. 3000 Kv-a. Compound Wound Commutating Pole Railway Converter, 300 R.P.M., 600 Volts. The field connections of this machine are explained in the text. The pulley, it need hardly be explained, is on the shaft purely for testing purposes

Heavy bus rings are required for paralleling all of the armature circuits into their respective phases in order to connect to the main collector in series with each line. This disadvantage, which, after all, is merely a manufacturing handicap and is never of any consequence to the operator, disappears with the revolving armature booster, in which the necessity for these heavy bus rings is, of course

Fig. 7. Nearer View of Shunt Winding, Series Compounding Turn, and Commutating Poles of Converter Shown in Fig. 6

Fig. 8. Pole Face and Commutating Field Connections of Converter Shown in Fig. 6

eliminated. A converter of this latter class is shown in Fig. 5.

The effect of the booster on the converter is to add motor current in the armature windings when boosting, and generator current when lowering the voltage. These additional currents have the opposite effects on the resultant excitation of the space occupied by

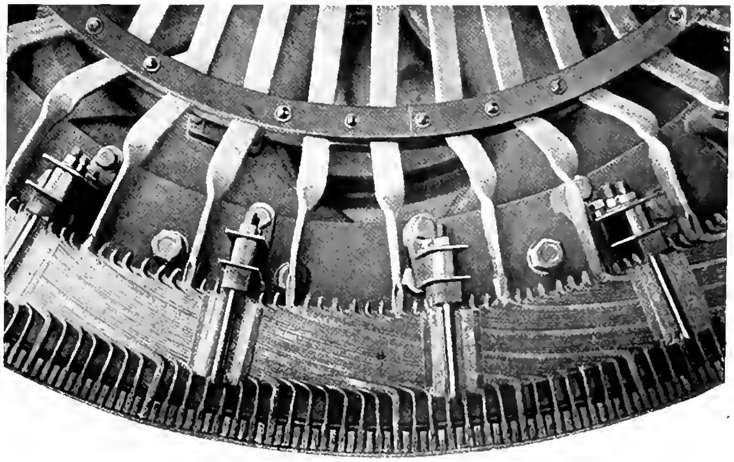


Fig. 9. Equalizer and Collector Ring Connections for Converter Shown in Fig. 6. Note U-shaped clamp for holding equalizer connections in place, secured at each end by a nut

commutating poles. When commutating poles are used with booster-converters, it is therefore necessary to provide auxiliary excitation, in addition to that given by the usual series winding, to cancel the changes in armature reaction due to the booster action.

(3) *Artificial Reactance.* Artificial reactances are used almost exclusively with compound converters, particularly for railway service. The combination possesses the advantage of simplicity, but is not to be recommended for services in which variation of power-factor is undesirable. Fig. 6 shows the collector end of a 3000 kw. converter for railway service. The series turns on the main poles here can be seen; and with converters of this class, it is, of course, apparent that the degree of effectiveness which is realized by this compound winding depends upon the total amount of reactance in the external circuit, whether provided by transmission lines, etc., or by this so-called "artificial" reactance.

(4) *Induction Regulator or Taps on Transformer.* With this arrangement variation of the voltage is obtained without the necessity of changing the power-factor. No complications are introduced hereby into the converter itself, so that the simplest type of machine (referring especially to commutating pole converters) may be used.

Three of the four remaining illustrations accompanying this article give partial views of the 3000 kw. railway converter shown in full in Fig. 6. That view has already shown one side of the field connections, and the reverse side, taken at somewhat closer range, is seen in Fig. 7. Fig. 8 is a view of the pole face, gives an idea of the bridge construction, and again shows the connections between commutating poles. These strips run in what is approximately a continuous circular path around the machine. Fig. 9 shows the equalizer connections as well as the ends of the armature conductors, and leads to the collector rings; and the U-shaped clamp for holding these windings in place should be noted. Fig. 10 shows a smaller railway converter, and illustrates the brush raising device with which it is necessary to provide commutating pole converters which have to start from the a-c. end.

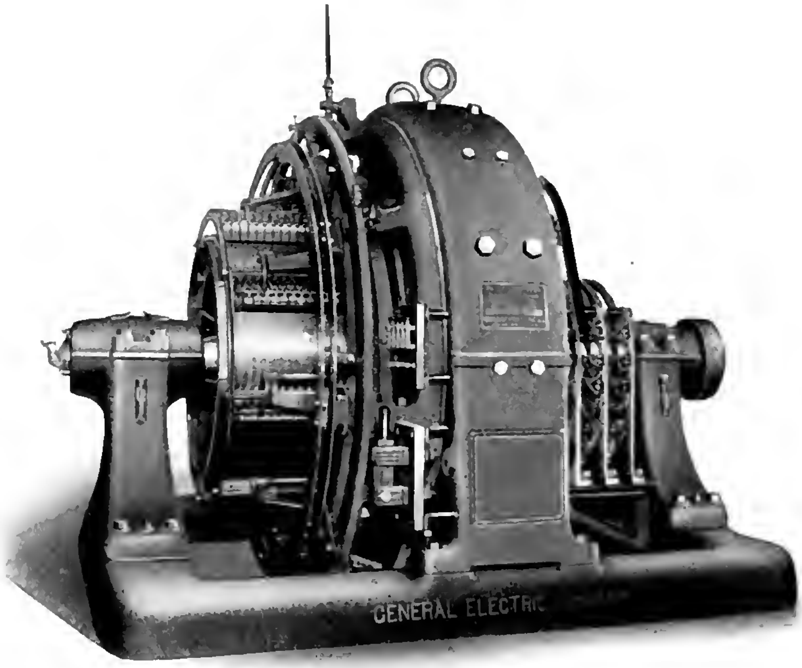


Fig. 10. Commutating Pole Railway Converter, Showing Brush Raising Device Which Must be Used When Machine is Started From A-C. End

THE ELECTRIC CEILING FAN

By H. S. Baldwin

Engineering Department, Lynn Works, General Electric Company

The relief from the uncomfortable effects of warm weather afforded by a free circulation of air is indisputable. This fact has been made the best of by the management of such places of public resort as hotels, restaurants, theaters, railway cars, etc., as also by owners of office buildings and factories, with the result that the electric fan is almost omnipresent with the incandescent lamp. In development, the fan motor has kept pace with the balance of the electrical industry and has been brought to a state very near perfection. Some of the recent forms of ceiling type fans for both alternating and direct current circuits are described and illustrated in this article.—Editor.

The electric fan, of the type designed to be suspended from the ceiling, afforded one of the earliest opportunities for the use of electricity; yet it is only in recent years that the possibilities of this efficient means for ventilation and cooling have been fully appreciated. This is directly due to the fact that the fan itself has been much improved, not only in mechanical and electrical detail, but in general appearance and adaptability to particular uses. Furthermore it delivers a large volume of air at low velocity, thus simulating a natural breeze, and by its location has the additional advantage that it can easily be fitted with electric lamps, thereby serving two purposes and eliminating the cost of separate electroliers. The last is a unique feature and excellent schemes of illumination can be worked out in this way.

Fig. 1. Carter Building, Houston, Texas, in which 650 Direct Current Ceiling Fans are Installed

Aside from these, a number of contributing reasons may be found; first, business conditions of today have caused rapid growth of city population, a large part of which must remain at work during the hot summer months; second, in the southern states of this country, in Africa, India and other localities where long seasons of hot weather prevail, it is now possible to obtain electricity where formerly it was less commonly found. With the introduction of alternating current, ceiling fans took on a more attractive appearance, the body of the motor being made of larger diameter and less vertical length.

Fig. 2. Direct Current Fan Designed for Subway

SOME MODERN BUILDINGS IN TEXAS EQUIPPED WITH CEILING FANS

Building	Number of Fans
Butler Building	50 d-c.
Carter Building	650 d-c.
Commonwealth Nat. Bank Bldg	426 a-c.
Littlefield Building	125 d-c.
Milby Hotel	100 a-c.
Praetorian Building	235 d-c.
Rice Hotel	256 a-c.
Rice Institute	206 a-c.
Scanlon Building	350 a-c.
Sanger Building	50 d-c.
Scarborough Building	180 d-c.
Southern Pacific Building	370 a-c.
Southwestern Life Building	475 d-c.
Sumpter Building	225 a-c.
Union National Bank Bldg	261 a-c.
Wilson Building	50 d-c.

Formerly ceiling fans were used singly or in small groups, whereas now many modern office buildings, especially in the South, are equipped with fans throughout, installations of from 200 to 500 being not uncommon.

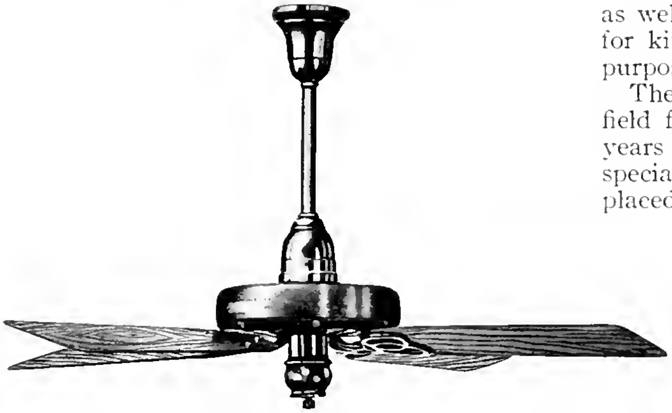


Fig. 3. Plain Type Alternating Current Fan

In all parts of the country, hotels, restaurants theaters and shops are working for increased comfort by the use of numerous ceiling fans, in many cases finished to harmonize with the attractive surroundings. A partial list of office buildings and their fan equipment may be of interest, and the accompanying cuts will give some idea of the magnitude of the demand that has been created.

Where ceilings are unusually high or not sufficiently strong to support ceiling fans, columns may be furnished for attaching to the floor, or of shorter length with separate ornamental socket, for counters or tables. Fans of special design have been supplied for use in cabins of merchant and naval vessels, as well as to aid in manufacturing processes for kitchens, laundries and other utilitarian purposes.

The railway car has offered an attractive field for ceiling fans. In a period of three years some 5000 direct current fans of special design and construction have been placed in the cars of the New York Subway of the Interborough Rapid Transit Company (see Fig. 2). This is undoubtedly the largest single group ever installed. The fans are mounted four in the monitor top of each car and are operated in series on a 600-volt circuit. Each fan delivers 7000 cubic feet of free air per minute; and although many elaborate and expensive systems of ventilating the subway have been tried and are now in use, it is safe to say that none has given the same degree of relief to the individual that is afforded by these fans. When it is considered that nearly 90,000 horse power of energy is

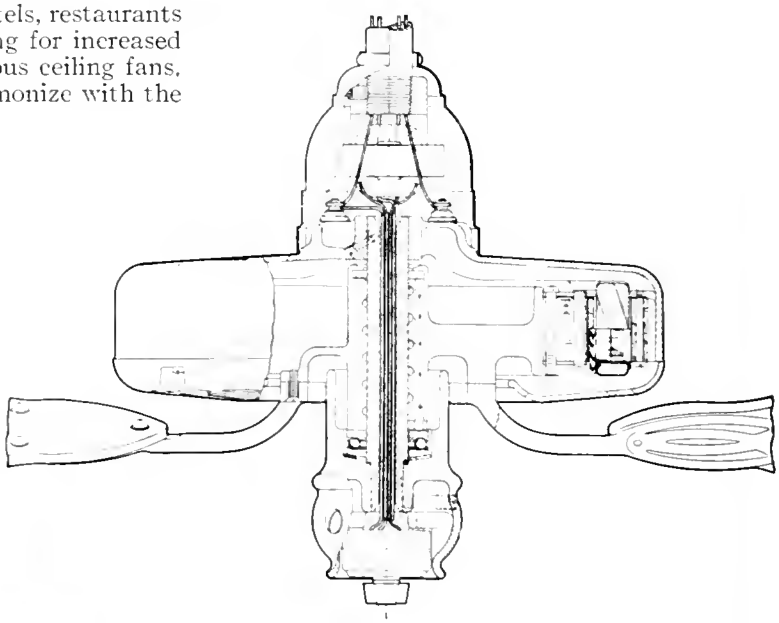


Fig. 4. Sectional View of Alternating Current Fan

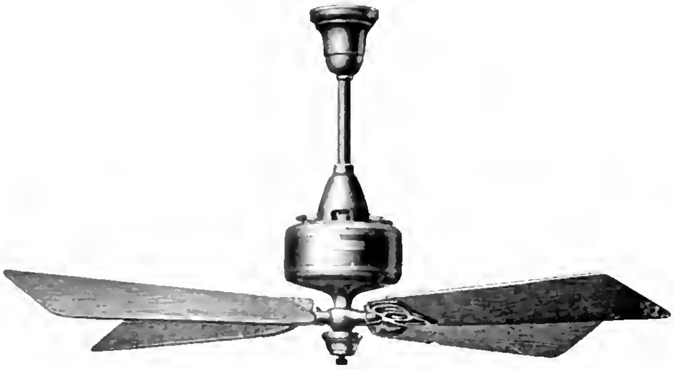


Fig. 5. Plain Type Direct Current Fan

being dissipated in the Subway during the height of traffic, and to this is added the body heat and exhalations of thousands of passengers, the necessity for artificial circulation of air within the cars during the hot summer months is apparent. It is not claimed that the fans actually reduce the temperature, but they do cause greater comfort by increasing the radiating capacity of each passenger. As a secondary consideration, yet not to be disregarded, is the salutary effect of air in motion, particularly when a train is standing in the station.

From indications based on orders, the ceiling fan is being more and more used in foreign countries, and a recent consular report states that the punkah is being rapidly superseded by the electric fan in the Far East. The principal demand has been from India, South Africa, China, Japan, Siam, and Australia, although good orders have been received from many other parts of the world. It might be mentioned that the requirements of the foreign trade are most exacting from the standpoint of quiet operation, and this condition is satisfied through special attention and great care in manufacture.

The accompanying pictures illustrate a number of different types of ceiling fan, adapted to use with direct or alternating current of usual voltages and frequencies. All these conform to a general scheme of construction in that the magnet frames or stators are built up of punchings assembled and leaded into a light cast-iron frame—a principle which was adopted, in the case of the direct current fans, to give ideal magnetic conditions with the least weight, although a further advantage of the laminated magnet frame is uniformity of operation. The stators of alternating current fans are of the shaded pole design; and there are four different punchings having 28, 24, 18, or 12 poles for frequencies of 60, 50, 40 and 25 cycles, thus insuring the same speed and air delivery in every case.

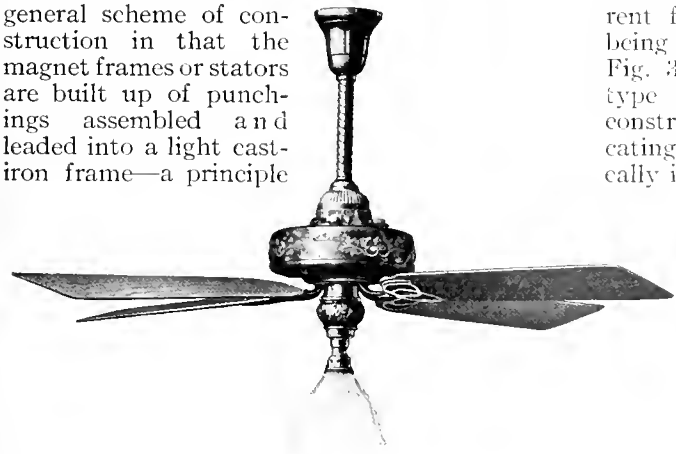


Fig. 6. Ornamental Direct Current Fan

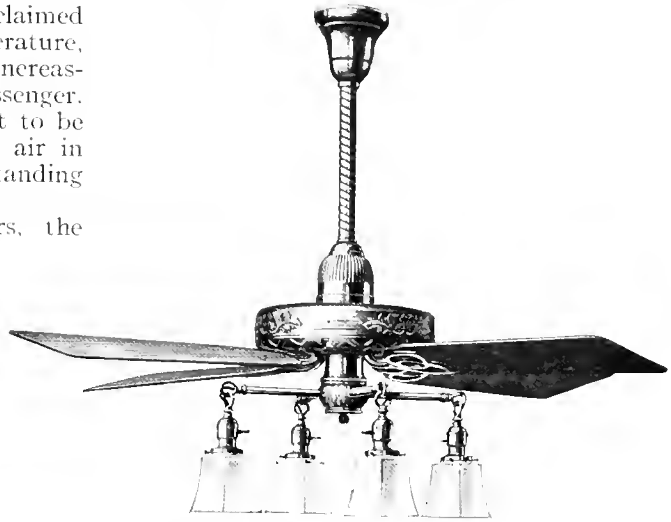


Fig. 7. Ornamental Alternating Current Fan

The same arrangement of blades with relation to the motor is maintained in the alternating and 4-pole direct current fans, both having stationary shafts and identical lubricating systems. The 2-pole direct current fan has a revolving shaft, the blades being attached to the holder at the bottom. Fig. 3 shows a partial section of the plain type alternating current ceiling fan. The construction of shaft, thrust bearing, lubricating system and switch support are practically identical with those of the 4-pole direct current fan. The speed of alternating and direct current fans can be varied by the control switch seen at the bottom of the switch support (Fig. 5); in the former case by means of a small reactance coil under the canopy at the top of the motor, and in the latter by resistance units between the field coils. If desired, extension rods can be supplied so that the switch key can be reached when the fan is suspended unusually high. The switch can also be omitted from the fan altogether and placed on the wall at a convenient place to operate one or more fans as required.

THE NEW MOVEMENT FOR CO-OPERATION IN THE ELECTRICAL INDUSTRY

By L. B. Judson

New York Office, General Electric Company

After mentioning the purposes of the new Society for Electrical Development (Inc.)—the outcome of the new movement for co-operation—Mr. Judson makes some comparisons of the present magnitude of the electrical business in dollars with the extent of other leading industries in this country; and, under five main headings, considers the directions in which accretions to the electrical industry may be expected in the near future. He then outlines the plan of campaign which is now being set on foot for going after and securing this increase.—Editor.

The plan and outline of the purposes of the new Society for Electrical Development (Inc.) were first presented at a meeting held at Association Island, Henderson Harbor, New York, in September of last year, attended by representatives of at least four of the main divisions of the electrical business—the manufacturers, central stations jobbers, and dealers and contractors, the interests embraced in the last three classes being also largely represented in the National Electric Light Association, the National Electrical Supply Jobbers' Association and the National Electrical Contractors' Association.

The Society* is an organization for the promotion of electrical popularity, a clearing house for original, effective ideas in selling goods and extending markets. It is not organized as, or intended to be in any sense, a profit-earning venture for itself nor for the interests collectively; but the member-interests will stand to profit individually through the co-operation for business development which it makes possible, and for which sole purpose it was brought into being. A pioneer undertaking, it has been promoted on a co-operative plan more comprehensive than that of any other similar movement in the electrical business; and it may be, indeed that later its influence will be felt in other industries as its work becomes firmly established. Profiting by the results of the numerous, scattered endeavors to bring about effective general publicity and educational co-operation in the electrical field, the elements have now been joined in a campaign of publicity on a scale to which no single enterprise or group of enterprises could aspire, nor of the benefits of which can any of those in question afford to be deprived. Contributions thereto need figure but a small fraction of a per cent on the total business of respective member-interests, or of the industry.

Electricity as a "commodity" lends itself as hardly any other product of applied science to profitable use for its news, publicity and educational value. Publicity experts have long claimed that the business of selling electricity and electric service as "commodities" had exceedingly great possibilities for expansion. There are habitable sections of the country and possible fields for the application of electricity hardly more than surveyed by the commercial electrical engineer, and educational possibilities not yet developed beyond the primer stage. Localities already extensively served have possibilities of enormously greater productiveness, especially in the industrial and household field. Country life and industry have only made a fair beginning in responding to the opportunities for employment of electricity in the work of the farm and the marketing of farm products. Mining and other "frontier" enterprises are also a most inviting field for electrical expansion.

A few rough comparisons of the gross annual business of the electrical industry with a few of the other great industries may assist the reader in a review and a forecast. To compare on the basis of retail values, which is impossible in most cases, earnings would have to be added, in the case of the electrical industry, for electric railways, central stations, isolated plants, telegraph and telephone systems, etc. If the business done in the United States in manufactured

*The first conference of the Society was held in New York on March 4th and 5th, 1913, and attended by representatives of many of the electrical interests besides representatives of the press, publicity agencies and other professional men. As to the excellence of the addresses, a more complete description of the material and plans for work, and the cordial endorsement thereof and the enthusiasm shown at the five or six sessions held, reference may be made to recent issues of the electrical weekly press. The financial requirements of the Society, to carry out the program as tentatively laid down, are expected to be from $200,000 to $400,000 per annum a moderate contribution considering the resources of the interests that have the opportunity to contribute. The active work will be begun with subscriptions of a total amount of about $200,000, the larger part of which is subscribed and all of which soon will be.

electrical machinery and appliances be conservatively estimated at $300,000,000 per annum, then the volume of the electrical business may be shown to be:

Perhaps three-fifths of the value of blast furnace iron and steel products.

Less than one-half the value of rolling mill products, and about half the business of the United States Steel Corporation alone, if as much as half.

From three-fifths to four-fifths of the value of automobiles.

Hardly more than the value of copper produced at a normally profitable price (the electrical business uses roughly one-third of the output).

Something less than the value of cotton goods and something more than one-half the value of woolens.

About equal to the value of butter and cheese.

Three-fifths of the value of boots and shoes.

Probably one-thirtieth the value of farm products at farm prices.

The gross earnings of central stations, practically as represented in the National Electric Light Association, are computed at a present rate of about $400,000,000 per annum, and the gross of electric railways is $600,000,000 to $700,000,000 per annum. These seem like large amounts; but when the electric railway earnings, or even the round billion of the two amounts quoted, are compared to the $3,000,000,000 of annual earnings of the steam railways, and when we consider the advantages of electricity in handling moderately dense to very dense traffic, as in traction, or any other fairly continuous heavy power or lighting load, there is certainly abundant scope for speculation upon the transformation to be made as electricity shall come into its legitimate share of even the public service alone.

As giving some indications of the directions of important accretions to the electrical business which may be expected and as showing the promising opportunities for the work designed for the Society, we may consider the following: 1, central stations, i.e., broadly, the supply of electric energy for light, heat, and power; 2, electric railways; 3, electrical appliances for farms; 4, electrical heating and cooking devices; 5, electrical power appliances for industrial use.

(1) Central station business is growing steadily and rapidly. Its volume has practically doubled in each five-year period of the last ten or fifteen years—and this in spite of the "isolated" plant and municipal plant business which is known to be very considerable, even in the absence of complete or uniform statistics relating thereto or of any system for obtaining them. The present rate of increase of, say, ten to fifteen per cent per annum, in the classes of business to which the central station has catered for many years, may be expected to be maintained or even greatly exceeded for many years to come, if the interests enlist expert service in every bureau and department, including such diversified expert aid as this Society has been promoted to give.

The extension of the lighting business during the past five years has been coincident with the introduction and increasing popularity of the tungsten lamp, once looked upon with suspicion by the central station because of its so greatly cheapening the use of light, but now proven to have been the most potent element in the popularizing of electric light. The number of lamps used has grown with the public appreciation of good lighting, until the number of incandescent lamps sold in the United States equals about 90,000,000 lamps per annum. The higher efficiency lamps must inevitably attain wider popularity as their merits become more fully appreciated. There is abundant room yet for the substitution of drawn-wire tungsten lamps and metallized filament lamps for the old carbon filament lamps among all classes of users. Moreover, it is shown by the results of some years that the central station may expect to receive greater returns from the use of the newer lamps on its circuits in place of the old, due principally to the higher standards of illumination which the users have accepted, which, in turn, are directly related to the diminished cost per unit of illumination to be obtained. The growth of the lighting business, and its revenues, may be expected to follow the more general use of the higher efficiency lamps, and by all classes of interests keeping abreast of the development in the lighting art, in the art of creating business, and in the efficient control of operating expenses, all of which will be subjects of study and publicity by this Society. The very inviting field for expansion of central station business in the sale of energy for railway work, and for the manifold power loads embraced in the industrial and domestic fields, will be dealt with in sections (2) to (5).

(2) Electric railway business on urban and interurban frequent-service lines may be expected to increase by natural per capita growth. Growth of population and the prevalence of the traveling habit will act to enhance the demands on the railways: good traveling facilities produce their larger use and larger revenues.

One of the greatest opportunities for future applications of electricity is the electrifying of great railroad terminals, and trunk lines and their branches. A noticeable and successful beginning has indeed already been made in electrifying large terminals and some of the lines of large systems for handling dense passenger traffic or heavy freight traffic over heavy grades, and expansion in these directions grows daily more promising. The rate of expansion will be governed, to some extent, by the ease with which railroads will be able to achieve their desired financing under the regulation to which they are subject. The electrification of terminal trackage in conjunction with the installation of electrical freight-handling apparatus at terminals has a possibility for solving the urgently pressing terminal problems of great transportation systems. This is of overwhelming importance both on account of the greatly increased facilities which would be provided, as well as the elimination of the necessity for vast investments in new acreage.

The gas-electric car merits prominent mention as an item of equipment for profitable frequent service on portions of large systems, and one which is making an excellent beginning record.

(3) Electrical heating, cooking and other devices for domestic and industrial uses may be expected to have enormously increased sale whether with or without particular regard to relative rates for current, although favorable current rates would assist vastly to the rapid growth of the business. The sales of these devices, at wholesale values, amount at present to probably $3,500,000 per annum, and they have been built up to the present volume within less than ten years. They are increasing at probably something more than 25 per cent per annum; but at this stage, that is, from all points of view, a slow rate of growth. It would not be unreasonable to expect that within a very few years the total business of the country in these devices should reach a per capita per annum amount, on the basis simply of the urban population of $0.30 to $0.50, equal to a total of $10,000,000 minimum per annum. Although this would represent an increase, over the present rate of sales, of 200 per cent, this per capita amount is almost negligible, and the possibilities seem nowhere nearly fully implied by this conservative estimate.

(4) Electrical appliances for the farm have manifold uses, even aside from the work of plowing and tilling, which may be electrically practical in operations large enough to justify the investment in equipment. Much interest is being taken in the introduction of electric tilling in Germany. If practical in that country it should be practical in the United States. For much of the work of planting, harvesting, threshing, feeding, pumping and irrigation, the dairy, laundry, wood cutting, grinding, hauling, etc., as well as the lighting of the house, the farm buildings and grounds and sections of country roads, electricity and electric appliances have peculiar, indispensable and easily popularized uses.

While systematized statistics, census or other, as to the extent that electricity is used on farms are meager, and the total volume of electrical business done in this field is not known with any precision, yet it is already of respectable proportions, and is rapidly growing. The Society can be no more effective anywhere than in devising means for reaching the scattered dwellers in the country.

As illustrating the past and possible future growth of electrical business in the industrial power field let figures for electrical business be taken for electric motors alone. Figures below for years up to 1905 are obtained from United States census reports, and are the latest of the kind published under the head of power drive. Figures for later years are estimated conservatively from data available from other sources, but not compiled with such completeness.

Figures in the table following relate to total power and electric motor drive in rated horse power in use in manufacturing establishments only.

Year	Total Power Installed in Use	Per Cent Average Increase Per Year	Electric Motors in Use	Per Cent Average Increase Per Year	Per Cent to Total Power
1890	5,954,000		15,500	...	26/100
1900	10,409,000	7.6	310,600	190.0	2.98
1905	14,465,000	7.7	1,138,000	53.0	7.88
1912	20,000,000	5.9	2,500,000	17.2	12.5

The conclusion from these figures is, first, that the proportion of electric drive to total drive installed is very small even after twenty years; and, second, that the possibilities for electrical expansion in the industrial field are enormous. The total power represented as installed probably represents an investment cost of anywhere from $200,000,000 to $300,000,000. Accepting the lower figure and imagining that in the not distant future even 50 per cent of this total drive will be by electric motors, there opens up the prospect for an increase in industrial electric motor business alone of over $80,000,000, or an average of $8,000,000 per annum for ten years, or $7,000,000 per annum for twelve years, or $5,000,000 per annum for more than fifteen years. This takes no account of the natural growth of business for quite general reasons; so that, while the application of electric drive will be catching up with the total industrial power installation as at present, the total installation will have increased in, say, ten years by perhaps 25 per cent or much more, so that the electrical possibilities are here even greater than may be first implied.

In the automobile and garage business; in metallurgical and electro-chemical processes, which have been multiplying with such bewildering rapidity; in sanitation and hygiene (as by ozone); in ice-making and refrigeration; in the refinement of metal products in electric furnaces; and in the many industrial uses of the high temperatures of the electric arc, we are witnessing achievements which are noteworthy in themselves, and prophetic of other profitable uses of electricity.

That about half the central stations in this country, chiefly the smaller ones, numbering about 3000, have practically no day load, and little but a short daily lighting load, is a condition full of suggestion for the business promoter. A goodly proportion of these plants could, by intelligent aid, develop a profitable business in some of the numerous kinds of power load among residences, industrial plants, farms, etc., in their vicinity. The increased uses of electricity will by so much increase the demand for the products of the manufacturer; and all together they call unmistakably for the specialized aid which the Society for Electrical Development can so readily command and economically render.

THE CAMPAIGN

The Society will embrace, for the present, three departments, namely, the National Advertising Department, the Publicity and Editorial Department, and the Field Department. Branch offices in a few of the larger and more distantly separated cities are in contemplation for the future.

The National Advertising Department will have for its set work the assembly and placing of popular general advertising with magazines and other periodicals, and of more specialized advertising with trade publications. It is proposed to utilize the most reputable publicity agencies in an advisory, or distributory, capacity, and take advantage of the specialized facilities which such agencies command.

The Publicity and Editorial Department will prepare matter for publication and issue it for distribution by local interests or for other ends, as the case may be; collect and disseminate news of the electrical industry which will assist to the helpful informing of the trade, or other trades, or the rest of the public with reference thereto. It will be a bureau for giving the widest currency to electrical commercial ideas in particular.

The Field Department is expected to have a variety of functions. Some of them are:

Conducting cooperative local advertising and selling campaigns in behalf of local interests, using, besides newspaper advertising, such means as lectures, demonstrations of uses of electric appliances, and the like; assisting local men to the opportunity of equipping a "specimen plant," and to the best methods and best appliances to use, and to equip it.

Developing a cooperative spirit among the central station or stations, the contractors, dealers, etc., in a given locality, by assisting to remove differences of opinions as to policies and methods, wherever they may exist.

Advising local interests upon technical commercial methods, such as the best means for wiring buildings, plants, etc., never before wired, or for improving imperfect wiring; the running and construction of suburban or rural distribution lines, etc.

Cooperating with other professions, as architects, illuminating engineers, builders, etc., upon matters of common importance, as the proper form of specification for wiring of a building or other structure, and for fitting it with electric control, distribution, lighting and other appliances.

Conferring with Boards of Trade, Chambers of Commerce, and public authorities to bring about better understandings upon disputed topics, and more harmony with respect to policies affecting both the electrical interests and the rest of the public.

Advising with such bodies as that of the National Board of Fire Underwriters as to commercial requirements, from the standpoint of the industry and of the consumer.

Some other important subjects which may be brought into the province of the field staff are: advising central stations as to rates for current so as to increase profitable business, and especially their day loads; the introduction of elementary electrical courses into public schools; and the enactment of equitable public utility laws and regulations.

In conclusion, it may not be out of place to advert to the faith which is shared at the present time both by manufacturers and other investors in electrical properties, such as public utilities, in the stable character and future growth of the electrical business. Of this there can hardly be any evidence more conclusive than that of the "large amount of new capital going into what are known as public utility undertakings, particularly those in which electricity is employed, such as electric light and power enterprises and electric railways."

There is no clear dividing line in numerous instances between investments in electric properties and others, such as gas properties; but on the very best authority the "new capital going into public utility undertakings" during the last three calendar years, and represented by major securities issued therefor, equals or exceeds the sum of $500,000,000. The principal investments in New York City during that time are not included in this estimate. Besides this amount of financing, there has been paid into such undertakings during the same time more than $100,000,000 on preferred stocks issued in exchange therefor. A common consideration in investments of this kind, beside the usually satisfactory rate of return on the capital, is that the values are backed by the reputed stability of settled communities. To be sure it has come to be the quite general rule that such utilities are operated under the surveillance of State Public Utility Commissions. Such regulation is not unusually of value to the properties, (if certain specific cases are excepted), as giving a measure of assurance that they will not be otherwise seriously interfered with in a manner to impair capital values.

THE CARE AND OPERATION OF COMMUTATORS

By H. S. Page

Direct Current Engineering Department, General Electric Company

The primary purpose of this article is to furnish a clear understanding of the operation of commutators and brushes, which, if intelligently applied, will eliminate or materially lessen commutator troubles. As a substitute for the blind trial methods, so commonly practiced, it gives directions as to the care of the commutator itself, such as the necessity of cleanliness, sparing use of oil, etc., and states the characteristics which are displayed by the various types of brushes, when correctly and incorrectly used. The article lays particular stress on the fact that, to secure best results, close attention must be paid to the every day duties of inspection. In conclusion it describes the various devices for resurfacing commutators and presents their relative advantages.—Editor.

The successful and economical operation of a direct current plant is to a large extent dependent upon the proper maintenance of commutators and brushes. Numerous improvements in the design of direct current apparatus are constantly leading to higher speeds and to greater capacity of units. This in turn necessitates not only better commutators, brushes and brush rigging, but a more definite understanding, on the part of operating engineers, with regard to the proper care to be exercised in order to minimize the maintenance expense.

The primary requirement in the construction of a commutator is that the mica and copper segments shall be held firmly in a compact arch and be so supported that there is a minimum tendency toward distortion, resulting from centrifugal stresses or from alternate heating and cooling. This is accomplished by two generally adopted methods. In the first (Fig. 1), the segments are built up in a cylindrical arch and are held in place by two wedge shaped clamping rings, which are secured by bolts and supported on a shell or spider. Such a commutator has an actual clearance between the shell and segments and is known as the arch bound type. In the second (Fig. 2), the segments are held in place by clamping rings, bolted together, as previously described and are also seated on the body of the shell. This is known as the body bound type. A few commutators, designed for exceptionally high speeds, are held together entirely by strings of high grade steel, which are shrunk upon the outside at a tension greatly in excess of the centrifugal stresses encountered at maximum speed.

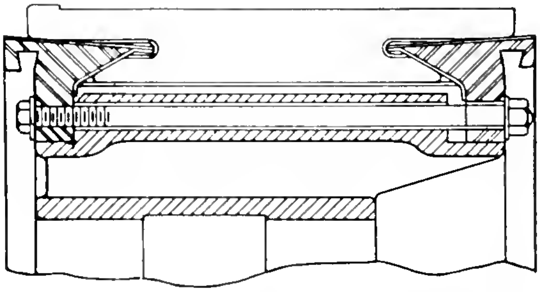


Fig. 1. Section of Arch-bound Type Commutator

It has been a common practice, especially on new commutators of the arch bound and body bound types, to tighten the bolts at the least indication of surface roughening. The necessity of tightening the clamping ring bolts

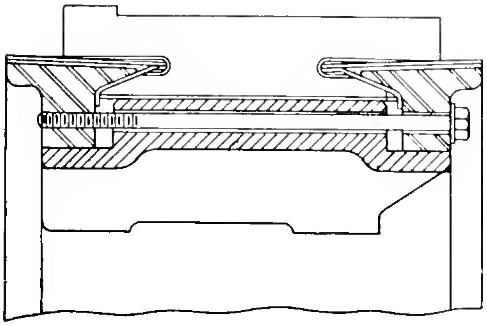


Fig. 2. Section of Body-bound Commutator

has been due to the whole structure loosening during the so-called process of "seasoning," i.e., while the excess adhesive compound worked out from the segment and clamp ring insulation, and the numerous laminations of mica in each piece of insulation arranged themselves in their final positions. Later methods have resulted in obtaining mica of a much more homogeneous structure, which shows practically no shrinkage with age. Commutators of recent manufacture, having an improved grade of mica together with better proportioned rings and bolts, require little or no tightening; in fact such a practice is liable to be very detrimental. It can readily be seen that if sufficient force is applied to the bolts (Fig. 3), two results may occur. First, the bolts may break. Second, the clamping ring may be drawn out of shape or "dished," as shown by the dotted line. Distortion of the ring will result in the clamping pressure all being applied at point *A*, instead of uniformly over the surface *A-B*; the mica at point *A* will be crushed and possibly the copper segments will be forced out of position, as shown in dotted lines. This action will not take place uniformly around the periphery and the commutator will accordingly have displaced bars, and show all the indications of being loose. Operating engineers should realize the enormous clamping strains resulting from the pulling of such a wedge shaped ring into positi n with several bolts and should bear in mind the fact, that displaced segments are very frequently caused by too much tightening.

Improper handling during erection or repairs is another source of commutator trouble, difficult to remedy. If any great pressure is brought to bear on the surface, especially at a point midway between clamping rings, the segments are liable to be displaced. An armature should therefore never be handled with a sling around the commutator, neither should it be supported by blocking placed under the commutator.

When assembling brush rigging, it should be borne in mind that the various mica and copper segments may not be absolutely equal in thickness and a division of the number of commutator segments, by the number of brush-holder studs, may not give equal spacing around the periphery. A better method is to cut a paper strip, which will fit snugly around the commutator, marking upon this the proper number of equal divisions and locate the brushes according to these marks. The brush studs must be set parallel to the segments, so that all the brushes of any stud will make contact with each segment simultaneously.

Too much importance cannot be placed upon the proper staggering of brushes in order to minimize, as far as possible, the wearing of grooves in commutators. With a generator, in addition to wear resulting from mechanical abrasion, there is an electrolytic disintegration of the copper segments passing under the positive brushes, and of the

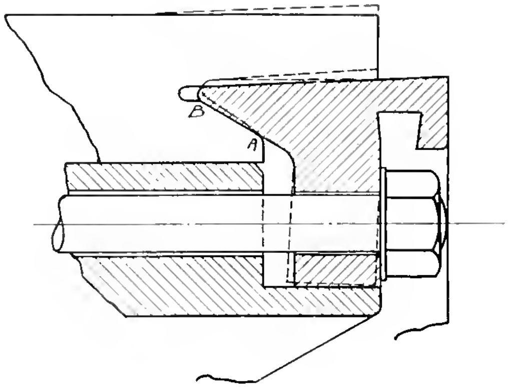


Fig. 3. Section of Commutator Showing Distortion Caused by Excessive Tightening of Clamping Bolts

negative brushes delivering current to the commutator. Hence, copper wears away more rapidly under the positive brushes of a generator than under the negative. For this reason it is best to so arrange the staggering that there will be as many positive brushes as there are negative brushes riding on any given section around the periphery. Of course, this scheme can only be followed when the number of studs is divisible by four; for example, a six stud commutator can have four sets of brushes staggered as recommended above and the brushes of the remaining two studs will have to be staggered with reference to each other. Frequently, in order to obtain sufficient radiating surface, commutators are made longer than is necessary to accommodate the brushes. On such commutators the brushes should not be crowded together, but should be so spaced that as much of the surface as possible is active.

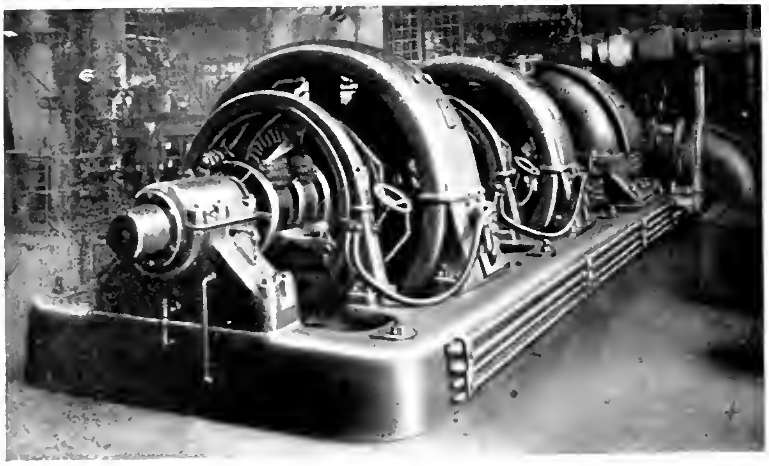


Fig. 4. Two 500 Kw., 600 Volt, 1500 R.P.M., Direct Current Generators Using Graphite Brushes and Slotted Commutators.
The commutators of these machines are designed with three shrink rings, the central one dividing the length equally and preventing any tendency of the bars to buckle.

The proper brush position is a point which must be considered for each individual machine and it is the practice of manufacturers to either locate the correct running position permanently, or in cases where this is not practical, to furnish instructions covering the proper setting of the brushes. Brush position not only affects commutation, but is a factor in determining the voltage or speed characteristic of a machine. However, the brushes should be set for best commutation and any adjustment for voltage or other characteristic, obtained by other means. The brushes of non-commutating pole machines are generally given a definite shift or "lead" from neutral position, in order that the coils undergoing commutation will be in such a flux as will assist in reversing the current. The brushes on commutating pole machines are run on the neutral point, the flux for reversing the current at the instant of commutation being supplied by the commutating poles.

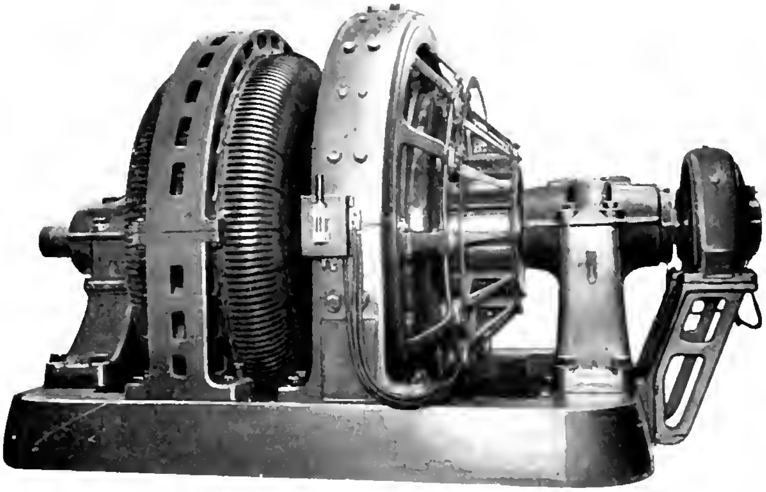


Fig. 5. Railway Motor-Generator Set. Generator is Rated 1500 Kw., 600 Volt, 360 R.P.M., and has a Flush Commutator Using Dry Carbon Brushes with a few Graphite Brushes for Lubrication

During the past few years great strides have been made by brush manufacturers towards producing special grades of brushes for various conditions of service. A consideration of the numerous local conditions affecting commutation, together with the multiplicity in types of motors and generators, emphasizes the importance of making the most careful brush selection. Valuable advice, regarding the best type of brush for any particular installation, can be obtained from manufacturers of brushes or electrical apparatus. It is impossible to make fixed rules governing the selection of brushes best suited for all cases, but a few comments regarding the characteristics of various grades of brushes, with some of their principal applications, may be of assistance to operators.

As compared with carbon, the general characteristics of graphite brushes are higher co-efficient of friction, lower contact resistance, higher current capacity, less tendency to chatter, greater lubricating properties and ability to give better commutator polish. On account of their low contact resistance, graphite brushes can be used on very few high voltage machines (500 volts and over) without producing sparking, while on nearly all low voltage apparatus they usually give most excellent results. It should be noted that graphite brushes have very little abrasive material in their composition, hence they will not wear the mica rapidly enough to keep it even with the surface of the copper. For this reason it is the general practice to slot the side mica to a depth of $\frac{1}{32}$ in. to $\frac{1}{16}$ in. below the surface, wherever graphite brushes are used. As an alternative to slotting, a certain percentage of dry carbon brushes may be used to keep the mica worn down, the remaining graphite brushes acting as lubricators. Successful results have also been obtained by using graphite brushes with a small percentage of abrasive material in their composition, which serves to wear the mica more uniformly with the wear of the copper.

A given grade of brush will give the best results only when fitted in a properly designed brush-holder and it should be borne in mind that no brush-holder suitable for universal application has yet been made. The question of brush-holders is an important one, as it is necessary to provide for free radial movement of the brush and at the same time arrange the brush support so that there is a minimum tendency to bind or chatter. Frequently, a change from carbon to graphite brushes necessitates new brush-holders so arranged that the brushes will ride at a different angle and have an entirely different scheme of applying the pressure. The angle at which a brush rides is an important factor, as regards reducing trouble arising from binding in the boxes and chattering.

Machines fitted with graphite brushes have been known to develop severe sparking after operating for some time with excellent commutation. In such cases, investigation usually shows that as a result of the commutator polish gradually improving, the brush friction is reduced with a consequent change in the position, which the brushes take in the holders. This in turn results in a tendency of the brush to ride on either its heel or toe, raising the opposite edge a very small amount away from the commutator; a short arc is set up under that portion of the brush which is raised slightly from the commutator and the heated particles are thrown out in the form of long yellow sparks. An increased brush pressure will frequently cure such trouble.

Cleanliness is always essential to best operating conditions, but, in cases where the atmosphere is filled with a foreign substance which it is impossible to eliminate, the nature of the substance must be considered and such treatment applied as will reduce its detrimental effect to a minimum. For example, the same brush equipment or treatment might not be applicable to two duplicate machines, one installed in comparatively clean surroundings such as the average railway substation, and the other installed at a coal mine or cement mill, where the air is liable to be filled with foreign matter. In the one case, carbon brushes with a slight amount of lubrication would probably give best results, while in the other, the use of any lubricant would have a tendency to collect the dust, and, in the event of such foreign matter being of a conducting or abrasive nature, poor commutation and destruction of both brush and commutator surfaces would undoubtedly follow. Under the latter condition dry carbon brushes would probably be satisfactory if machine was of a slow speed type, but if operated at high speed, chattering might result, and about the only alternative would be the use of some form of graphite brushes, if commutation permits.

Fig. 4 shows two 500 kw., 600 volt, 1500 r.p.m. generators driven by a mixed pressure turbine. The machines are built for steel mill service and operate very successfully with graphite brushes and slotted commutators.

Fig. 5 shows a 1500 kw., 600 volt, 360 r.p.m. motor-generator set which gives excellent service on railway work. The commutator has flush mica and is fitted with dry carbon brushes and a few graphite brushes which act as lubricators. Such a brush equipment requires no external lubrication.

Successful methods of keeping machines clean may be outlined as follows: In a fairly clean station, with machines using carbon brushes, unless proper care is exercised an accumulation of smut may appear on the commutator surface. This can be prevented by lubricating sparingly with a good grade of light engine oil and wiping off with a clean

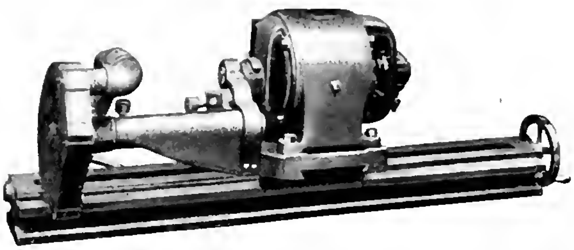


Fig. 6. Commutator Grinding Tool, Consisting of Motor, Grinding Wheel, and Warp. Exhaust Shroud to take away Abrasive and Copper Dust Shown Around the Wheel

cloth. In steel mills, mines, etc., where the atmosphere may be full of conducting grit and machines are equipped with graphite brushes, the commutators should be wiped frequently with a dry cloth and any accumulation of dirt removed from the brush rigging, as this is likely to fall on the commutators and be ground into the brushes. In such plants, screens should be placed to protect the apparatus from drafts of soot-laden air. For wiping commutators, such material as heavy canvas should be used, as the lint from waste or cheese cloth catches under the brushes and causes trouble.

Whenever brushes are replaced, the new ones should be carefully fitted to the commutator with sandpaper. To fit a set of brushes, the sandpaper should always be drawn in one direction, preferably the direction of rotation. The sandpaper should not be drawn first in one direction and then the other, as this will rock the brushes back and forth, resulting in a surface which does not conform to the curvature of the commutator.

When brushes wear down, sometimes the copper plating on them comes in contact with the commutator, causing burning. A new set of brushes should always be examined and any excess plating which may cover the wearing length, be removed. The purpose of the plating is to give better contact between the carbon and the pigtail terminal and to permit of a soldered connection, but it frequently extends too far toward the contact surface of the brush.

Brush pressure should be studied by the operating engineer to determine the degree which will give minimum friction loss and at the same time supply sufficient pressure to permit the brushes to ride properly on the commutator. Too high a pressure of the springs will result in excessive heating from friction and sometimes causes the brushes to bind in the holders. Too little pressure will permit the brushes to change their position in the holders and chatter, thus causing sparking.

Oil is very detrimental to mica and for this reason its accumulation on any part of the commutator should not be tolerated. Too lavish lubrication frequently causes disintegration of the mica segments and oil from leaky bearings has been known to so damage the clamp ring insulation, that the commutator had to be rebuilt.

Numerous methods have been devised for truing commutators which have become badly grooved, rough or eccentric, and brief comments will be made on those most frequently employed.

Turning Tool

This consists of a simple tool post, for holding the cutting tool, mounted on suitable ways and fitted with a cross feed screw. The tool must be mounted very rigidly to prevent chattering and a cutting speed of about 550 feet per minute has been found to be best. Unless such a tool is operated by an expert too much of the surface may be turned off before a satisfactory job is obtained. Another objectionable feature is that there are but few commutators whose normal peripheral speed is as low as the tool cutting speed required, and therefore the others will not have the same "throw" as will occur when under service conditions. Occasionally, a commutator is ground with a stone clamped in the tool post, but such a method is very slow and the tool is seldom sufficiently rigid to entirely remove "flats."

Sandpaper Block

This is a simple device consisting of sandpaper held in a wooden block, having approximately the same curvature as the commutator, and applied by hand or by means of a lever using the machine base as a fulcrum. Such a device is liable to aggravate flats and removes nearly as much material from between ridges as from their tops.

Grinding Tool

The grinding is accomplished by an excellent device, consisting of a rotating grinding wheel, so arranged that it can be fed back and forth by means of a lead screw. The grinder must be rigidly supported to prevent vibration. The advantages of such a tool are that the minimum copper is removed, a perfect cylindrical surface is obtained, and the work may be done with machine at full speed, where the commutator will have its normal "throw" or "swing," and will take its actual running position in the bearings. In cases of emergency, commutators have been ground with the machines actually operating on the line. The success of such a tool depends upon its being rigidly supported and having closely fitting bearings, so that there is no vibration of the grinding wheel. The grinding wheel must be of such composition, as will not wear away too rapidly or clog with copper. The grade of wheels for such work is constantly being improved and manufacturers of electrical apparatus should be consulted when a purchase is contemplated. Grinding is probably a slower method of truing commutators than turning, but it unquestionably gives a better surface.

Whenever any truing device is being used all windings should be protected from copper dust and the brushes should be raised to prevent their being coated with copper on the contact surfaces. Such protection is further assured by the use of a grinding tool provided with a wheel shroud and exhauster with bag attachment for collecting the dust. Fig. 6 represents a commutator grinding tool fitted with geared driving motor and having a wheel shroud with exhauster to collect the copper dust. A light application of fine sandpaper held in the hand will give a much improved surface after turning or grinding. Before bringing the machine up to voltage the segment insulation must be gone over carefully and any evidence of copper bridges from bar to bar removed. Slotted commutators should have the slots cleaned out with a hack-saw blade and the edges slightly beveled or rounded. The machine should then be blown out and all accessible parts cleaned thoroughly, followed by a final wiping of the holders and brushes, before being put in service.

In the long run, close attention to every day duties counts more than anything else toward keeping the electrical apparatus of a plant in prime condition. A study of the particular service requirements of each machine will suggest minor improvements far greater in value than any amount of printed matter, and will tend to keep the expense of repairs and replacements at a minimum. The operating engineer should study the air drafts in the station and, if they carry foreign matter from any source, such as a nearby railroad, coal pocket, or sandpile, suitable screens should be arranged for the protection of the apparatus. If the brushes chatter and spark it is probably due to high mica, rough commutator or incorrect angle of the brushes. When commutators are true and smooth, but show black bars, this is an indication of poorly soldered joints in the armature winding or equalizer connections, or possibly an insufficient number of equalizer rings.

These are only a few of the suggestions, which might be expanded into a more lengthy discussion of the subject of how to avoid and overcome commutator troubles. It is hoped, however, that they will serve to stimulate greater effort on the part of operators to give the most careful and intelligent attention to apparatus in their charge, which will in turn be more than repaid by continuity of service and elimination of trouble.

THE COMMERCIAL TESTING OF LARGE STEAM TURBINE UNITS

By E. D. Williams

Turbine Engineering Department, General Electric Company

This paper gives a complete summary of the equipment and procedure adopted in the factory testing of large steam turbine-generator sets. The author first indicates the requirements regarding boiler equipment, superheaters, steam piping, condensing facilities and pumps. The procedure for weighing the condensed steam is closely followed with the aid of diagrams showing tank arrangements. Recommendations are made as to exciters, switchboard equipment and loading rheostats; and the mechanical layout and relative positions of the complete testing equipment shown in a diagram. A section on instruments covers thermometers, pressure gauges and electrical meters; and the article then details the various readings which are taken in making the water-rate test and determining the consumption curves, and shows how the variables are controlled.—**Editor.**

The testing of both large and small steam turbine units, in this period of efficiency and economy, is of as great importance to the steam plant manager as any other detail of his plant. It is partly by a close study of the economics of the turbine room that he is able to meet the insistent demands for cheaper power, and in many instances to compete satisfactorily with those water-power plants which have sprung up at numerous places, where an abundance of water is available during the major part of the year. This interest is as great in those very water-power plants, which must depend upon steam auxiliaries to take care of either a sudden or extended failure of the water supply.

The testing of commercial turbine units serves several purposes. It is by this means that the manufacturer is able to determine more exactly the design of his machines. Small experimental machines may be run and, from these tests, indications obtained which will decide the bucket and wheel combinations that must be used to give the best results; but it is only by putting machines of commercial size through test that refinements can be made and the mechanical and economical design perfected. By running economy tests under various loads, speeds and steam conditions, it is possible to see how the combinations can be altered to give the consumer better machines, and also to advise him of the best conditions under which the turbines in his station can be run.

Another purpose of the economy test or water-rate is to determine if the machine has met the guarantee which has been made on the unit by the manufacturer, and probably based on his past experience as distinct from tests run with the particular turbine.

Tests of this character must be taken either at the customer's plant, or at the factory with the machine set up almost as elaborately as at its destination. In the former case such testing is often difficult, and, even if possible, is liable to provide only approximate results. A few plants are equipped to make accurate tests on all their units, and it is generally these that are striving the hardest to get every ounce of power out of the coal burned. In such cases the principal result sought is the amount of load obtained for a given amount of steam input, under given conditions. This is sufficient for the power plant man, but is hardly complete enough for the designer, who wants variations in order to make comparisons. Owing to commercial needs it is often impossible in the power plant to hold exact steam or load conditions. Most plants try in some way to check their economy; and this has been made easier since the advent of steam flow meters and more accurate water meters for the boilers.

It will thus be seen that the factory test becomes an important detail. To get the best results, the turbine must be set up in close proximity to the boiler plant and must have full condensing equipment to give the best possible vacuum.

The mechanical details, in so far as they may influence the economy of the machine, ought to be closely checked before and while setting it in place. At this time also all necessary drilling and tapping should be done for gauge connections and thermometer wells, or any other apparatus, which is to be attached to the machine or its piping. Wiring connections must be made; meters with their transformers for measuring the electrical output calibrated; and the scales and tanks for weighing water checked with standards.

To begin with, the boiler plant needs to be so designed and managed that it is possible to isolate boilers which are being used for testing purposes from those used for regular service. By this means fluctuations in the steam supply are reduced to a minimum, and tests are completed more rapidly than if the conditions varied widely. In order to obtain a large number of conditions for different machines, or different curves on the same machine, the boilers should be of a high pressure type (e.g., 200 pounds per square inch or greater), some being equipped with superheaters and some without, the latter for supplying saturated steam. By this means combinations of boilers can be made whereby almost any degree temperature of steam may be obtained. Unless an exceedingly high degree of superheat is wanted, this provides as steady and satisfactory a means of holding a superheat condition as with an independently fired superheater, especially where each boiler is equipped with an indicating steam flow meter by which the output of the individual boiler can be held almost constant. By this means it is possible to hold superheat, at the throttle, within a range of from 5 deg. F. to 10 deg. F., where the flow of steam is sufficient to obviate condensation troubles.

These isolated boilers should if possible be provided with independent feed water pumps, so that the water supply shall not fluctuate with the outside conditions. It is quite desirable to have a commercial load available

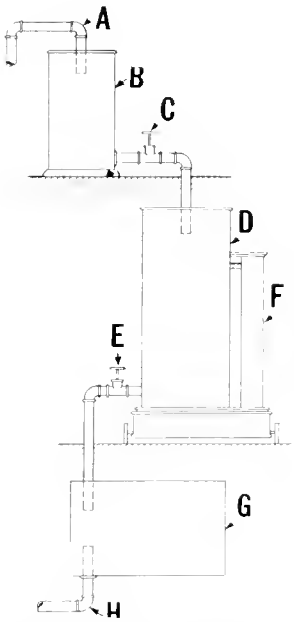


Fig. 1. Arrangement of Hotwell Discharge Pipes and Tanks for Weighing Condensed Steam in Water-Rate Tests of Steam Turbine Sets

for these boilers, so that if at any time it is necessary to shut the test machine down suddenly, the steam can be shut off with a quick closing valve and thrown into the main headers until the boilers can be cut out.

Each machine to be tested should have its steam piping run in as direct a manner as possible from the headers, in order to prevent all unnecessary loss of heat and drop in pressure. In this line there should always be a stop valve, a strainer, and a motor-operated valve for regulating the pressure at the throttle of the machine. Furthermore, such pipe lengths should be used as are necessary for the installation of steam flow meters. Thermometer wells and gauge syphons must be located close to the throttle valve, and also near the flow meter plug.

Next it is necessary to have an elaborate condensing equipment with good arrangement for weighing the condensed steam or "condensate." Surface condensers are therefore essential. With respect to circulating water, hotwell and air pumps follow very closely commercial power plant requirements. On occasion it is necessary to get the very highest possible vacuum; and when this is obtained it is easy enough to break it down to a lower vacuum, when the requirements of the test demand it.

A flexible arrangement of condensers is desirable; and they should therefore be large enough to handle the maximum load and should be adapted to setting in as many different machines as possible at the same time. Flexibility may be obtained by double openings on the condensers and by various connections between the exhausts of the turbines and the condenser openings, such as by connecting one turbine to two condensers to increase the total cooling surface available. These connections must always be made very tight, and it is often desirable to seal joints with water to prevent air leakage. These joints may even be made air tight, to a large degree, by painting them with heavy japan, allowing it to be drawn into any crevices.

The air piping must be so arranged as to draw the air from that part of the condenser which is farthest away from the opening which the turbine is using. In this way the best cooling effect is obtained before the air is lead to the air pumps or exhausters, as the case may be. Precaution must be taken to ensure that the variation in the loading and condition of the vacuum held on the condensers will not cause the condensate to be drawn over into the air pumps. This may injure them, as well as give incorrect results in the measured flow.

The hotwell pumps must discharge into tanks for weighing the water condensed. These may be arranged according to Fig. 1, in which *A* is the discharge pipe from the hot-well into receiving tank *B*, equipped with a quick closing valve *C* conveniently operated

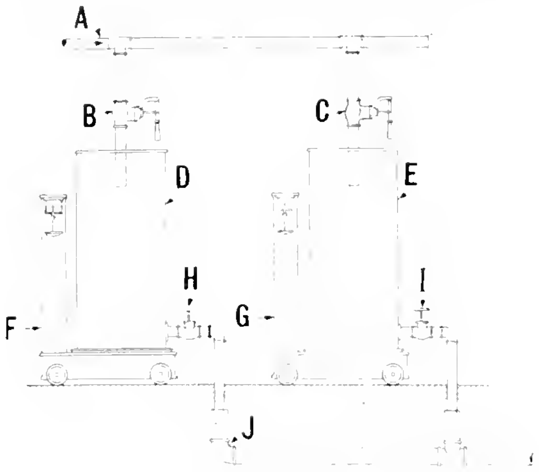


Fig. 2. Alternative Arrangement of Discharge Piping and Tanks for Weighing Condensed Steam in Water-Rate Tests of Steam Turbine Sets

by levers from a point near the weighing beam of scales *F*. *D* is a tank of similar size to *B* located on a platform scale of possibly 5000 lb. capacity. This tank must be provided with a valve *E* similar to *C*. Another tank *G* with pipe *H* must be provided, if it is intended to use the water again as feed water. It is also necessary to have a tank of some such character to serve as a funnel, if the water is to run to the sewer. This combination of tanks can be made of very large capacity, with larger scales to handle the flows obtained with big loads; or it can be furnished in duplicate, so as to give a more flexible arrangement and be more easily operated for light flows.

Where little headroom is available an arrangement can be made as in Fig. 2, where *A* is the line from the hotwell, *B* and *C* the quick closing valves leading into tanks *D* and *E*, respectively on individual scales *F* and *G*, and equipped with discharge valves *H* and *I* and sewer or boiler feed water line *J*.

In Fig. 1, the continuous flow of water through *A* is retained in tank *B* while the water in *D* is being weighed, emptied and the tare reading of tank alone taken, valve *C* being closed until valve *E* is again closed. Then *C* is opened and the accumulated water in *B* is discharged into *D*. The flow is allowed to continue for a given period, when *C* is again closed and the weighing of this water for the given period completed.

In Fig. 2, it is necessary to open and close valves *B* and *C* almost simultaneously after tanks *D* and *E* have been filled or emptied, as the case may be, in order to be ready for another period. The first arrangement is the easier to handle, but the second may be adapted to taking care of larger volumes of water. In either case, it is necessary that precautions be taken at all times to secure freedom of movement of all parts on the scales and also that the valves be tight.

The exciter plant and switchboards are another permanent requirement of the testing equipment for water-rates. Two self-excited 125-volt sets are to be preferred; but if only one exciter is used it should be of such capacity as will take care of any size of machine to be tested. By putting two in series, it is possible to handle machines of any excitation up to 250 volts. Turbine exciters are more desirable on account of their stability and constancy of supply. This might also be said of the other auxiliary apparatus, although motor-driven apparatus, if the supply of current is unfailing, is almost as good.

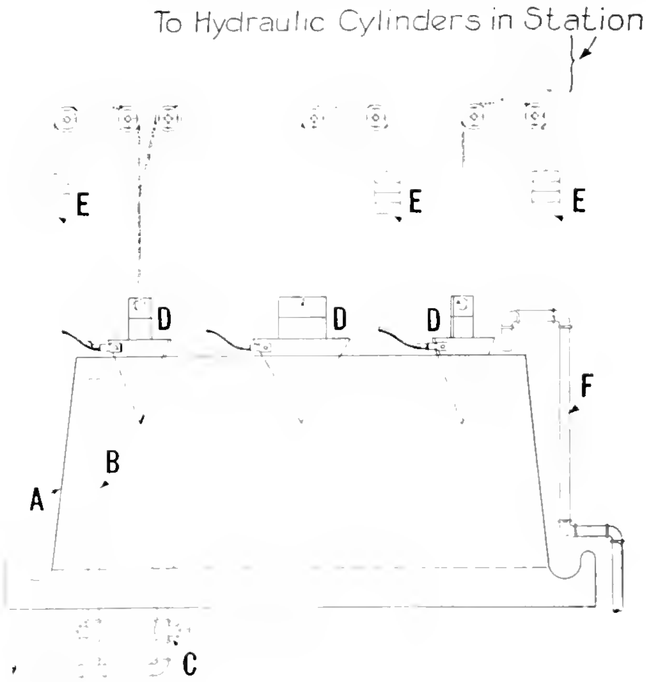


Fig. 3. Diagrammatic Sketch of Water Rheostat Used for Absorbing a Generator Load When Testing Turbine Sets for Water-Rate

Convenient switchboards are required in order to handle the wiring from the generator to the water rheostat used for absorbing the load. In order to handle all kinds of loads, with both high and low voltage, these water boxes must be specially constructed. To handle loads up to the maximum load and at the voltages which are usually encountered in factory testing, a suitable rheostat has been made from a large circular tub of staves, ten or twelve feet deep and twenty-five or thirty feet in diameter, into which the electrodes extend. For convenience' sake, the electrodes should be controlled from the switchboard and operated by cylinders under water pressure. Fig. 3 shows a diagrammatic sketch of such a rheostat arranged for a three-phase generator. *A* is the tub, provided with a water inlet pipe *F*, drain pipe and overflow, *C* and *B* respectively. The plates or electrodes, *D*, are either supported on rails and counterbalanced with weights, *E*, or they are supported directly from a superstructure. The leads come off directly from the electrodes and run to a terminal box from which connections can be made through the switchboards to different machines. Water circulation is kept up by admitting varying quantities of water to the tank, and draining by means of the overflow pipe. Steam piping should be so arranged that freezing is prevented in cold weather. Salt is always necessary to a large degree, when heavy loads at low voltages are to be carried. Various combinations of plates and tubes, as well as water circulation, can be used for different load conditions, or smaller cast iron boxes for the small loads and the testing of direct current units. Where a river is available, excellent results can be obtained by suspending electrodes in the stream. To handle different classes of loads, the same variation of the type of electrodes is necessary here, as in the water box rheostat.

The general arrangement of the turbine, as connected to condensers, headers, switchboard, and the hotwell arrangement, is diagrammatically shown in Fig. 4. Two machines are shown connected to condenser *A*. Exhaust piping *B* and *C* leads to the turbines *D* and *E*. Tables for meters and switchboards, *F* and *G* respectively, fit in very nicely over the condensers. The hotwell is represented at *H* with pumps *I*. Plates for throwing the condenser open on one side and closing it at the other are shown at *J*. The high pressure line is represented at *K*. Minor details cannot be shown on such a sketch, and will of course, vary with the particular machine.

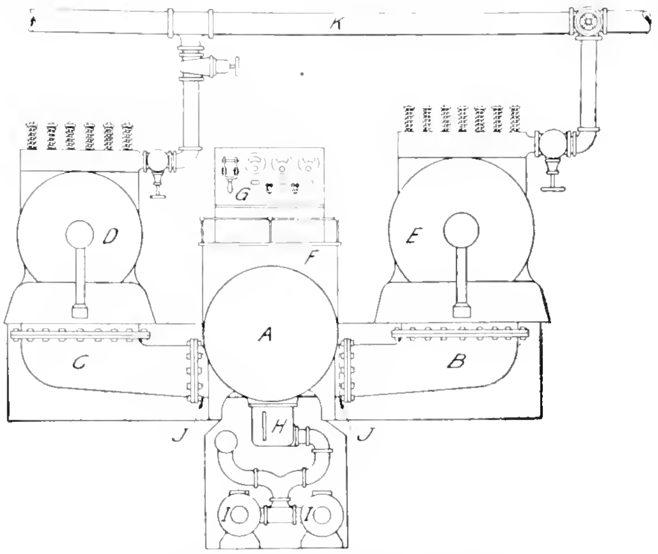


Fig. 4. General Arrangement of Turbines, Condensers, Switchboard, Piping, etc., as Followed in Water-Rate Tests

The turbine itself is always drilled and tapped for as many thermometer wells and gauge connections as are necessary for obtaining accurate data. These will vary with different machines to a large degree, especially as the number of stages in the machine changes, since at each stage the pressure must be taken. The nozzles of the turbine are accurately measured before setting into the machine; and the bowls are then fitted with gauge connections, so that a further check on the amount of steam flow is obtained. The upper stages of the machine will necessarily be provided with both Bourdon spring gauges and mercury gauges (U tubes), in order to take care of the different loads and corresponding stage pressures. These will vary from vacuum, through the light pressures that can be measured with the mercury column, to the higher pressures up to 60 lb. and 70 lb. per sq. in., when the spring gauges are used. The exhaust must have both U tubes and absolute gauges attached; so that, knowing the barometer pressure at any time, the accuracy of the gauges may be determined.

In addition to all gauges and meters, which may be put on the turbine, it is very important to have electrical instruments which can be relied upon to give the correct output of the generator. With alternating current machinery, meter transformers must be selected which will give good scale readings on the instruments. In order that a check can be made on the instruments, including any error which might occur in the transformers, separate transformers should be put in for the wattmeters and ammeters and voltmeters. In this manner errors in the instruments will be brought to light very quickly, especially since the water box load is non-inductive. A frequency meter is used for determining the speed of the machine, checks being made often with a speed-counter to see that no errors exist in this respect.

In testing direct current machinery, it is quite desirable to have oil-cooled meter shunts for measuring the current if good consistent results are to be obtained. In this way heating effects are eliminated. Two shunts must always be put in series, so as to have a continuous check on the output.

In running economy tests, the principal points which must be determined are the effects of load, speed, vacuum, superheat, pressure, and sometimes different settings of the mechanical parts of the machine, such as valves, clearances and the like. The effect of these latter changes are of course obtained by running speed or load curves under the individual conditions to be investigated, all other conditions being held the same.

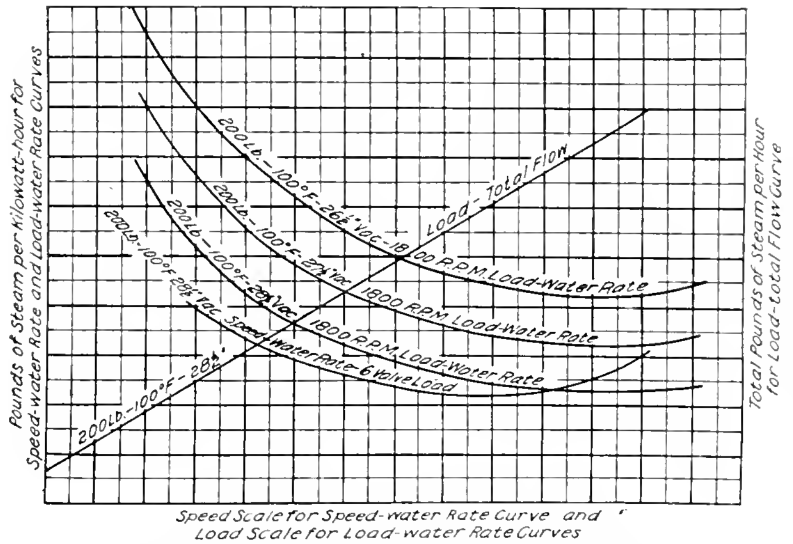


Fig. 5. Definite Values for Ordinates and Abscissae are Omitted from these Curves; but They Serve to Indicate the Shape to be Expected, and the Quantities to be Measured in the Water-Rate Testing of Turbine Sets

A load curve determines the economy of the particular combination at various points from light load up to as far as it is possible, or desirable, to carry it. In the test, the pressure at the throttle and on the bowl of the turbine nozzle is held constant, as is the superheat; the speed is held steady either by hand or by governor; and the vacuum on the exhaust of the machine is held by regulating a small leakage into the condenser. The load then is held at the various points by means of the water rheostat. While these conditions are set the condensed steam is weighed accurately in the tanks. Readings of all the conditions mentioned are taken at short intervals. This is continued for at least thirty minutes, with everything constant within the limits which have been determined as being possible by practice. For some special reasons it might be desirable to prolong the length of time for any one point; but ordinarily it is sufficient to maintain the conditions for the above length of time for each load.

When the steam used per hour for any given point has been determined, it is immediately plotted on the curves of total flow in pounds per hour and in terms of pounds per kilowatt-hour, both versus load. When a number of these points have been obtained and plotted, it is ordinarily quite easy to determine the correctness of the work and see if a repetition of any or all the points is necessary. Fig. 5 shows a set of such curves. There are three load curves, one flow curve corresponding to the $28\frac{1}{2}$ in. vacuum load curve and a speed curve at one load.

The vacuum correction may be obtained in several ways, one of which is indicated on the curves shown. As stated, this is a series of load curves run at three different vacuums, all other conditions being held the same. By this means corrections can be obtained for any load condition, in case this variation might change with the load.

Speed curves must be run with a constant flow of steam through the machine, and are obtained by blocking the inlet or controlling valves of the turbine in an open position. With all the steam conditions held, the speed of the machine can then be changed by varying the load; and curves obtained and plotted between load and water-rate conditions.

In like manner, the results of any other change of steam or mechanical condition of the machine are determined. The distribution and number of observers will vary with the design of the turbine. It is always necessary to have men holding and reading pressure, superheat, load and water weighed; and the time required for completing the tests depends largely upon the personnel of this crew.

In experimental work it is often desirable, even with moderately large sets, to use a brake instead of a generator for loading the machine. Here the same method is followed, except that there are torque readings instead of electrical readings. Generally some type of water brake is used. One form consists of steel disks rotating in a shell into which water is admitted, thus causing friction and resistance to the rotation of the blades. This reaction is measured by means of an ordinary platform scale, on which the lever arm, from the stationary portion of the brake shell, exerts itself.

Great care must be taken in the calibration of all gauges, thermometers, meters, scales and apparatus used to determine the conditions or the results. The tests must be calculated with all the necessary corrections made, with curves drawn giving the comparisons desired; and reports made in such a way that the true condition of the machine tested can be easily seen, when being compared with other machines. It is only by the greatest refinements in these various respects, that true results can be obtained, and good forecasts made on the large percentage of machines that will never be subjected to accurate test.

HIGH SPEED DIRECT CURRENT LOCOMOTIVE FOR THE NEW YORK CENTRAL

By S. T. Dodd

Railway Locomotive Engineering Deparment, General Electric Company

This new locomotive has recently been placed in regular operation in the terminal service of the N.Y.C. & H.R.R.R.; and nine additional ones of the same type are now under construction. The design is along the same general lines as that of the forty-seven direct current locomotives built for this road in 1906 and 1908, but the changes which have been made have resulted in a very much more powerful locomotive. The aggregate motor capacity is now 50 per cent greater than before, with 25 per cent increase in speed, giving a tractive effort of 9500 lb. at 60 miles per hour (continuous). This article describes fully the construction of the locomotive, the design and building of which represent a notable achievement in railway engineering.—Editor.

The following article describes a new electric locomotive built for the N.Y.C. & H.R. R.R. Co. This company is operating at the present time forty-seven electric locomotives in its New York terminal service. Of these thirty-five were built in 1906, and twelve in 1908, weighed 115 tons each, and were each equipped with four bipolar gearless motors. The satisfactory results which have been obtained from these locomotives have led the railroad company to adopt the same general design of locomotive in their latest order. with a few changes as described below.

The new locomotive (see Figs. 1 and 3) is a bipolar gearless design, equipped with eight motors each of approximately three-fourths the capacity of the motor used on the previous locomotives. The aggregate capacity of all the motors on the locomotive is thus approximately 50 per cent greater than before, and with approximately 25 per cent higher speed. The reasons which suggested this new design of locomotive, and the advantages which it presents, may be summarized as follows:

(a) Decreased total weight of the engine. The weight of the locomotive is approximately 100 tons as against 115 tons for the old locomotive.

(b) Increased tractive effort in starting. The present locomotive has its whole weight of 100 tons on the driving wheels, where the old locomotive had a weight of but 70 tons on the driving wheels.

(c) Decreased weight per axle. The weight on each driving axle of the new locomotive is 25,000 lb., where the correspoding weight of the previous locomotive was 35,000 lb.

(d) Increased total locomotive capacity. The old locomotives were designed for switch-

Fig. 1. Direct Current 600-Volt Electric Locomotive in the Service of the N.Y.C. & H.R.R.R.Co. Weight 100 Tons. Equipped with 8 Bipolar Gearless Driving Motors, Each Axle Being a Driving Axle. Capacity of Each Motor 325 Amperes (one-hour); or 250 Amperes (continuous) at 600 Volts. Capacity of Locomotive 13,500 lb. Tractive Effort at 54 Miles per Hour (one-hour rating); or 9500 lb. Tractive Effort at 60 Miles per Hour (continuous)

ing service; while the new locomotive has been designed with the view to continuous service, and has been supplied with ample forced ventilation in order to obtain this.

Considered from a mechanical standpoint, the running gear (Fig. 2) is made in two independent sections, hinged together and carrying a single cab mounted upon them through pivotal connections or center pins. Each section has a two-axle rigid truck carrying a platform which extends forward and is supported on its outer end upon the center-pin of a two-axle swivel truck. All these axles are equipped with motors, thus making an eight-axle locomotive, with a long flexible wheel base, and every axle a driving axle.

The cab is supported above the platforms through center-pins built into each of the platforms. In the extreme ends of the cab are compartments for the operating engineer, while the center compartment of the cab is devoted to the installation of apparatus. This construction and arrangement of apparatus makes it possible to concentrate the greater part of the weight of the apparatus near the center of the cab; while it removes from the motorman's compartment all operating apparatus except such as is directly required for the manipulation and control of the locomotives. The flash of circuits opening on contactors, or the noise of compressor and blower, which might tend to confuse the engineer or distract his attention, are in an entirely separate compartment.

As already stated, there are eight driving motors. These are bipolar gearless motors, the armature of each being mounted directly upon the axle and the field poles carried upon the truck frame, which forms the magnetic circuit. The motor is completely enclosed on the top and sides by the magnet bar and pole pieces, and on the ends next the wheels and the under side by sheet metal. There are no openings except those for the escape of the ventilating air, and these are covered by a wire-mesh screen. Each motor at its one-hour rating has a capacity of 325 amperes at 600 volts, or a continuous rating of 250 amperes at 600 volts under a forced ventilation of 3000 cu. ft. of air per min. For the

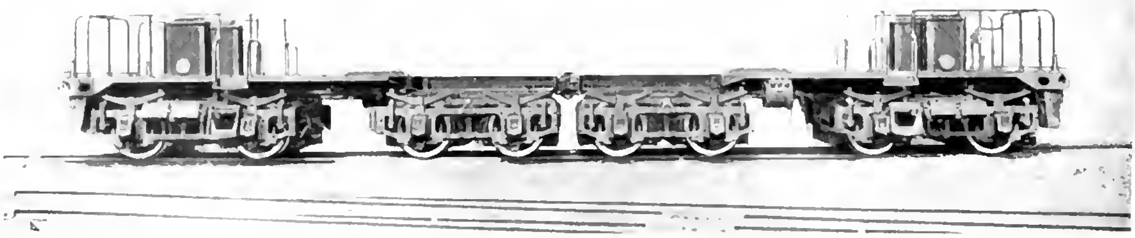


Fig. 2. Running Gear of Direct Current 600-Volt Locomotive with Cab Removed

complete equipment of eight motors this corresponds to a capacity of 13,500 lb. tractive effort at 54 miles per hour at the one-hour rating, and 9500 lb. tractive effort at 60 miles per hour continuously. The motors are connected in pairs permanently in parallel, and these pairs can be connected in three combinations, viz., series, series-parallel and parallel. The motors are insulated for 1200 volts with the idea that the same motors can be used on a 1200-volt locomotive if necessary.

The control system of the locomotive is the well-known master-controller method. The motors are connected in four groups of two motors, with regulating resistance in each. On the first notch of the controller all motors are in series with the resistance in. On the following notches, up to the ninth, this resistance is gradually cut out. The ninth is the first running notch. Between the ninth and tenth notches the transition is made from series to series-parallel grouping of the motors. This change is made by momentarily short-circuiting half of the motors. The resistance, which was all inserted again on this transition, is gradually cut out again until the seventeenth notch, which is the second running notch, is reached. Between the seventeenth and eighteenth notches the transition is made from series-parallel to parallel grouping of the motors by the standard bridging method. The resistance which was again inserted on the transition is gradually short-circuited again, until the twenty-fourth notch, which is the last running notch, is reached.

The auxiliary wiring circuits of the locomotive comprise two control circuits, two headlight and gauge light circuits, two lighting circuits, one compressor circuit, and one blower circuit. All these circuits are protected by individual switches and fuses, as well as by one large switch and fuse for all the auxiliary circuits. Current is collected by eight under-running third rail shoes, or by two trolleys when on gaps in the third rail

The locomotive is furnished with an air compressor having a capacity of 100 cu. ft. per minute when pumping against 135 lb reservoir pressure.

The control apparatus is located in the cab described above. The controllers and switches are located in the engineer's operating cab, while the remainder of the apparatus is in the central compartment of the cab which is entirely enclosed and shut off from the engineer's compartment. The rheostats are located in this central cab near the roof, which is arranged with hinged sections for facilitating repair and replaceal of rheostat sections. The contactors are suspended directly beneath the rheostats; and upon the floor of the compartment are set the compressor and the motor-driven blower.

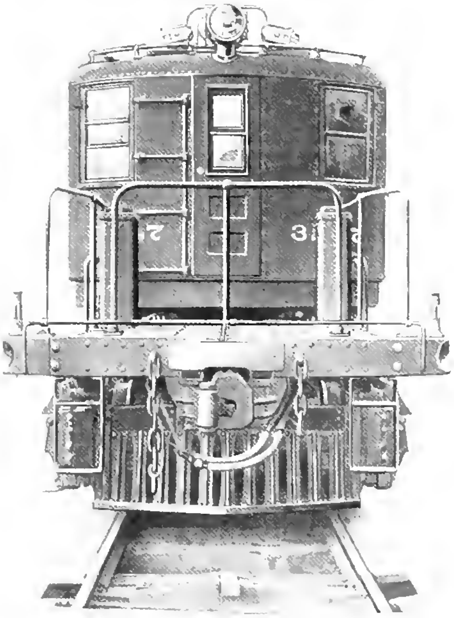


Fig. 3. End View of Direct Current 600-Volt Locomotive

The following are the most important dimensions and data of this locomotive: Length inside of knuckles 55 ft. 2 in.; length over cab 33 ft. 0 in.; height over cab 12 ft. 8 in.; height with trolley down 14 ft. 6 in.; width over all 10 ft. 0 in.; total wheel-base 45 ft. 7 in.; rigid wheel-base 5 ft. 0 in. and 6 ft. 6 in.; weight of electrical equipment 62,000 lb.; weight of mechanical equipment 138,000 lb.; weight of total equipment 200,000 lb.; weight per axle 25,000 lb.

The locomotive described has been given a very exhaustive series of test runs on the New York Central test track at Wyatts, N. Y., and is at the present time in regular operation in the New York terminal service. Nine additional locomotives of the same type are now under construction, for service on the same road.

SINGLE-PHASE MOTOR-CAR EQUIPMENTS FOR TRUNK LINE SERVICE

By E. F. W. Alexanderson

Consulting Engineer, General Electric Company

As the thin edge of the wedge has by now indubitably been driven into the opening for trunk line electrification, and since it is certain that every succeeding year will see the opening enlarged until the wedge is driven surely home and a firm hold secured on what will be the most notable of all electric applications, it is inevitable that the old question of "single-phase *versus* direct current" shall continue to exercise the minds of railway engineers, and that warm partisanship and sometimes embittered feeling shall be evidenced in its discussion. We have not the slightest desire to enter into this controversy, but desire only to gratify the wish of our subscribers, repeatedly expressed, that we give them more engineering matter relating to railroad electrification—a subject which is, so far as electrical men are concerned, the very livest question of the day. We trust therefore that they will find considerable interest and instruction in the preceding article on the 100-ton direct current locomotive, and the present paper dealing with a modern single-phase motor-car equipment. The latter article, besides presenting a statement of highly successful operation over a period of two years, explains fully the principles of the single-phase commutator motor, and deals in detail with the theory, design, mechanical construction, electrical characteristics and operation of the particular motors used in this instance of actual railroad service.—Editor.

In 1907 the author read a paper before the A.I.E.E. in which he described a new type of single-phase motor, presented the results of experimental tests, and indicated his reasons for hoping that the machine would become a successful type of single-phase motor for railway work. Many years have elapsed since the announcement of this type of motor; and some account of the history of its development in the meantime will probably be welcomed by those who remember the author's previous statements, and his predictions as to the motor's possibilities. It is a source of gratification to the author that, in giving a description of the new type of equipment, he is able to present a record of highly successful practical operation for nearly two years, which has been confirmed by the ordering of additional equipments on the part of the railroad in question—the New Haven road.

To give a general idea of the progress that has been made it may be enough to mention that the new motor was designed to fit the same space on the same trucks as the series motor which it was intended to replace. This latter motor was identical with that used on the Washington, Baltimore and Annapolis railroad, which was replaced there by 1200-volt direct current motors on account of unsatisfactory performance. The weight of the car hauled by four motors on the Washington, Baltimore and Annapolis railroad was 55 tons; whereas the weight of train which is now being successfully handled on the New Haven road is 110 tons in severe service with one stop per mile on a 1 per cent grade. As a matter of record it should be mentioned that an attempt was made to perform this service with two motor-cars carrying the old type of motor. The scheme was an entire failure, both cars being out of commission the greater part of the time; whereas, with the new equipment, the same service has been maintained for the last two years with only one motor-car and without any spare equipment.

For those not familiar with the performance of alternating current railway equipments, it may be explained that the best indication of the successful performance of the motor, apart from heating, is the "life" of the brushes. One of the principal criticisms of the old alternating current series motor was in regard to the short life of the brushes. The highest figure that was attained in the most successful equipment was 10,000 miles; while under bad conditions it often was as low as 1000 miles, an average with fairly good maintenance being about 6000 miles. This short life of the brushes necessitated frequent inspection of the equipments and considerable expense in purchasing and re-placing brushes. The performance of the alternating current motors in this respect appeared particularly unsatisfactory when contrasted with the direct current motor with commutating poles; while even the old type of direct current series motor, which was then, and is now, used extensively, had a standard of brush "life" from 15,000 to 30,000 miles. In view of this experience it has been a matter of great surprise to those engineers who had lost faith in the possibilities of the alternating current railway motor, that the new type of equipment, in spite of the heavy service imposed upon it, has given a brush "life" of 25,000 miles which was considered good for the old type of direct current motor.

To avoid any misunderstanding it should be pointed out that any reference in this article to the alternating current series motor applies to the 25-cycle series motor without resistance leads. It is generally acknowledged that it is possible successfully to design series motors either for 15 cycles without resistance, or for 25 cycles if resort is made to the so-called resistance leads for the improvement of commutating conditions. For the benefit of those readers who are interested in problems of design, a short account will be given of the development which led to the motor construction embodied in the new equipments. In making comparisons of different types of single-phase motors, however, considerations will be limited to those motors which do not employ resistance leads. This might in a way seem to be a one-sided point of view; but must be explained on the ground that the author does not consider himself sufficiently familiar with the details of construction and experience which have led to the modern resistance lead motor, to include the latter in the discussion. We will take up the theoretical as well as the practical considerations that have led to the design of the new type of motor; and at the same time make some comparisons with other less successful types of machines which have been superseded by this design.

Design Requirements for A-C. Single-Phase Traction Motors

The development of the motor which will be described here has been based on a combination of requirements, both in

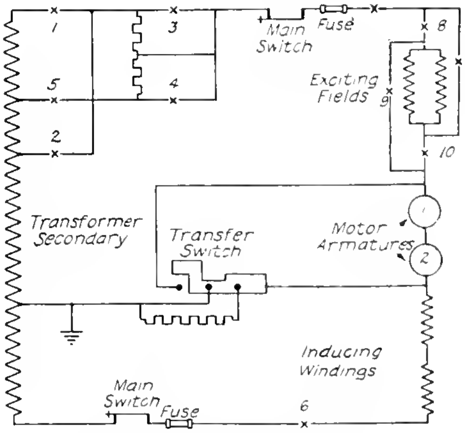


Fig. 1. Diagram of Connections of Single-Phase Traction Motor

regard to electrical characteristics and practical construction. Of these there cannot be said to be any one salient feature which might distinguish this motor from any other known type of alternating current commutator motor; but in it there has been effected a combination of the characteristics which have been found most adaptable for a railway motor, consistent with the practical limitations as to type of construction and form of winding which are imposed on the motor by the structure of the truck and the nature of the traction service.

Step	Contactors									
								F	R	F	R
	1	2	3	4	5	6	7	8	9	10	11
1St		●				●	●	●	○	●	○
2Nd		●	●			●	●	●	○	●	○
3Rd				●	●	●	●	●	○	●	○
4Th	●		●			●	●	●	○	●	○

F-Forward R-Reverse

Fig. 2. Diagram of Contactor Connections in Starting Single-Phase Traction Motor

As regards electrical characteristics the principal requirements that are expected of an alternating current railway motor are that it must be able to exert a high starting torque without injury or perceptible deterioration of the commutator and brushes; that it must at the same time be able to operate at high speeds with good commutation; and, further, that the relative values of field strength and current shall be such as to give the maximum efficiency during normal operation in order that the armature and commutator may not be unduly heated nor the brushes disintegrated. As regards the construction requirements it is important that the winding shall be of a simple uniform type; and that, if a commutating field is employed, this field shall be created by the natural current relations in the motor itself, without the necessity of employing a special commutating coil which necessarily interferes with the main winding of the motor and is apt to introduce a difficult and unreliable feature of construction. It is furthermore desirable that the various conductors in the main winding shall all carry approximately the same density of current, so that the capacity of the motor will not be limited through any tendency of one part of the winding to become over-heated before the rest. Such a condition may occur if a commutating field is introduced by superimposing a commutating field current on the main current in the same winding. A desirable feature in regard to the control of the motor is that the motor shall be able to exert its maximum torque without drawing excessive currents from the supply circuit, thereby necessitating an undue capacity of wiring and switches. It is further necessary that the desired starting and operating characteristics be produced through the inherent proportions

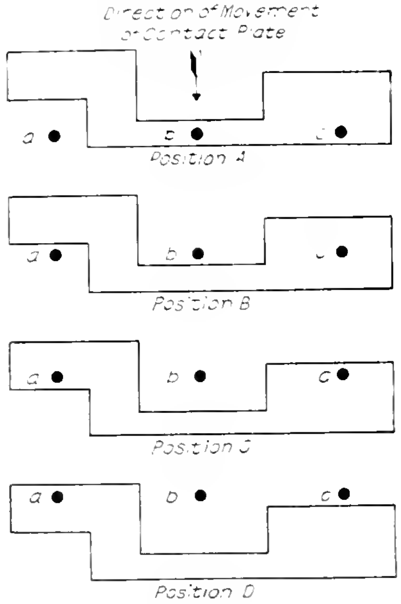


Fig. 3. Diagram Showing Different Positions of the Transfer Switch

of the motor and without the employment of an auxiliary transformer. Having thus stated briefly the considerations that led to the final design of the equipment, each phase of the problem will be treated in somewhat greater detail.

Electrical Characteristics of the Various Single-Phase Commutator Motors

The fundamental types of single-phase commutator motors known in the art are the plain series motor, the plain repulsion motor, and the Latour-Winter-Eichberg-Milch motor. Each of these types has been developed in several modifications. The plain series motor for instance can be built with or without commutating poles, and with either forced or induced compensation. The repulsion motor can be built with a single set of short-circuited brushes, when it is known as the one-circuit repulsion motor; or with a double set of short-circuited brushes—the so-called two-circuit repulsion motor. The two-circuit repulsion motor again may have one set of brushes movable for the sake of speed regulation, in which case it is then commonly known as the Deri motor. The series motor and the repulsion motor are characterized by the fact that the magnetization of a torque-producing field is given by the winding on the stator.

The Latour-Winter-Eichberg motors on the other hand are characterized by magnetization through a second set of brushes on the commutator. This general principle can be developed in several forms of construction, and can be employed for producing shunt characteristics as well as series characteristics.

Attempts have been made to introduce the principles of all three of these forms of motors into railway service. Each of the types has characteristics which are valuable for special purposes; but no one of them has all the characteristics that are necessary for a successful railway motor. This statement can be made at the present time without fear of contradiction, since the development of the art in all countries and by all manufacturers interested in this work have borne out this conclusion. To make this clear it may be repeated that the series motor can be used successfully if either a lower frequency (say, 15 cycles) or the use of resistance leads is resorted to. The repulsion motor, Latour-Winter-Eichberg and Deri motor have also been used successfully within certain limitations; but have finally been abandoned when the highest requirements of high torque and high speed have been imposed at the same time.

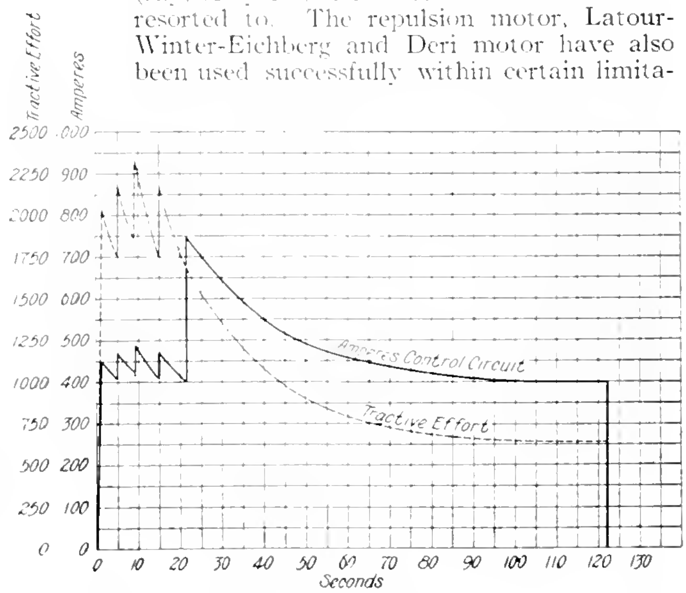


Fig. 4. Showing Current and Corresponding Torque Curves During Acceleration

Electrical Characteristics of the Single-phase Motor Described Herein

In order to design a motor that would fill the most severe railway requirements without resorting to resistance leads or a specially low frequency, the author found it necessary to combine the best features of the repulsion motor and the series motor with commutating pole. The design preserves repulsion motor characteristics at low speeds and those of the series motor characteristics at high speeds; while the advantage of a commutating field has been secured without the introduction of the mechanically objectionable feature of the commutating pole. A further object was to provide a motor of such design constants that the relative values of current and field strength most desirable in the repulsion connection for starting purposes, are automatically changed in those proportions that secure the highest efficiency and lowest heating for full speed operation.

From the diagrams shown in Figs. 1 and 2 it is apparent that the relative values of the currents in the motor circuit are such that this change in proportion is achieved through the very fact that the connections are changed from one type of motor to the other without the employment of any transformer or other auxiliary device for changing the relative values of the current in the windings. Fig 3 shows the different positions of the transfer switch. Incidentally this method of control also possesses the advantage that the heavy current in the armature circuit necessary to produce the maximum torque does not appear anywhere in the general control connections, but is produced by super-position of a locally-induced current on the main current that is drawn from the control circuit. Thus while the motor delivers its maximum torque with 1200 amperes current on the commutator, the control circuit handles only a current of 500 amperes; while after the transfer switch at the starting speed has been thrown into the series-repulsion connection, the armature current drops to approximately 700 amperes, which is then furnished directly by the control circuit. Fig. 4 shows the current drawn through the control circuit during acceleration and the corresponding torque delivered by the motors; while Fig. 5 shows the service condition (speed and distance) to the same time base. The repulsion characteristics (starting connection) are shown in Fig. 6; while Fig. 7 shows the characteristics of the second, or series-repulsion connection.

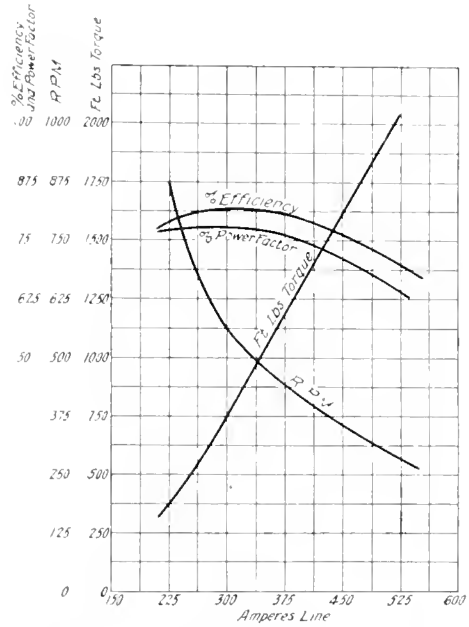


Fig. 6. Repulsion Characteristics (first connection at starting)

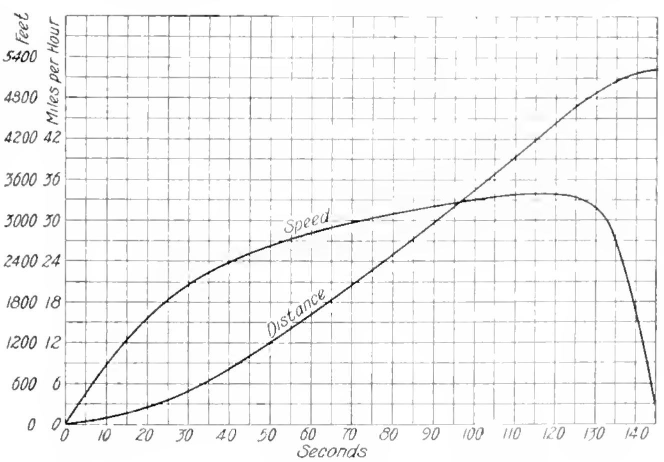


Fig. 5. Service Condition (speed and distance) During Acceleration

The arrangement which has been used in order to obtain the desirable characteristics in the second, or so-called series-repulsion, connection, possesses in itself some features of interest. As stated before it was desired to realize the benefits of the commutating field without complications of the winding. Fig. 8 shows the type of winding that is employed viz., a continuous distributed winding with uniform slots and conductors of uniform size arranged in a way known as the standard

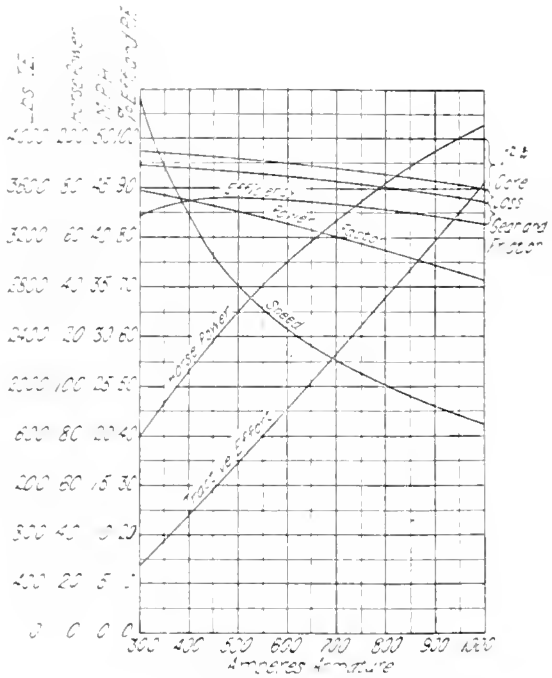


Fig. 7. Series-Repulsion Characteristics (second connection)

drum winding. Those familiar with the theory of the compensated motor are well aware that a commutating pole winding, if introduced at all, should occupy the space which is, in the simplest form of design, occupied by the field winding itself. If the introduction of an extra winding is to be avoided the magnetization for the commutating field can be obtained either by splitting the field winding in two sections and superimposing a circulating current between those two sections; or by introducing the magnetizing current by impressing a suitable voltage on the other winding (known as the compensating or inducing winding); or by a combination of these two methods. Here it is to be observed that in the alternating current commutating motor the commutating field must be correct not only in strength, but also in phase; or, in other words, the alternating current commutating motor must have two commutating fields, one to counteract the alternating e.m.f. in the armature coils and the other to commutate the current in the brushes, in the same way as in the direct current motors. These two phenomena are often, for the sake of brevity, known as the alternating current and direct current commutation; and, for successful operation, it is necessary that both of these requirements should be simultaneously fulfilled in an approximately correct way. Without going further into the theory it is sufficient to state that while, in a motor of ordinary design, the alternating current commutation may be made correct by impressing a suitable voltage on the compensating or inducing winding, the direct current commutation would not be correct: the field required for the direct current commutation would in fact be reversed. On the other hand, the direct current commutation might be corrected by splitting the field winding into two sections, using one section for one excitation in one direction and the other section for excitation in the other direction, thereby obtaining the same result as in the old type of direct current motor in which, by shifting the brushes, the coils were brought into a suitable commutating field. Apart from the complications of the double field windings, this has the disadvantage of requiring an

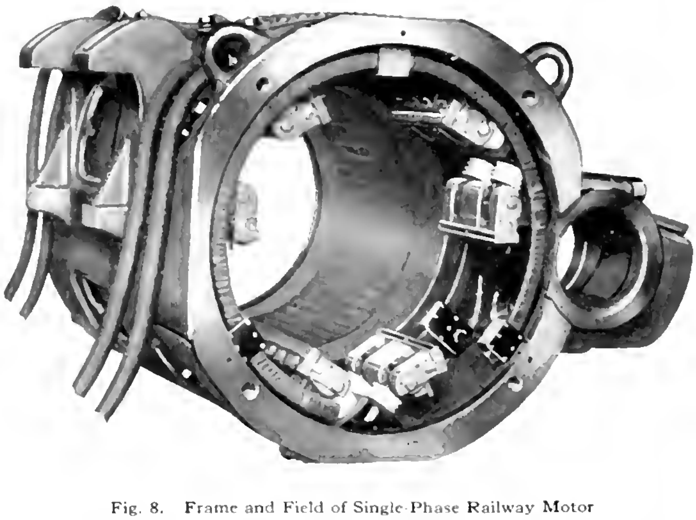


Fig. 8. Frame and Field of Single-Phase Railway Motor

excessive current density in the part of the field winding which is being used at any particular time, or the use of a greater amount of copper in this winding, which would have the effect, on the other hand, of destroying the general symmetry of the stator winding taken as a whole.

The solution which has been found and applied is the use of an armature with a winding step equal to the pole arc occupied by the inducing winding on the stator. The reason why this measure gives the desired results were given in the author's paper before the A.I.E.E. in 1907.

To render the argument more complete it may be mentioned that the commutating field obtained in this way is correct only within certain speed limitations; although as a practical rule it may be stated that this method gives satisfactory commutation up to a speed of two and one-half times synchronous speed. This is in most cases sufficient for a 25-cycle motor, at least for motor-car service; whereas, if the same type of motor is used for 15 cycles, it is often desired to operate it as high as four times synchronous speed, in which case a correction of the commutating field for direct current commutation may be made. The advantage of this method in attaining the desired result lies, however, in the fact that such connection as may be needed can be applied without any change of the motor construction itself, simply by the introduction of a reactive coil in the middle connection between the motor and the transformer. With suitable values for this reactance, which in fact is actually small, the field for direct current commutation can

Fig. 9. Armature of Single-Phase Railway Motor

be completely controlled at any speed. This last feature has, however, not been introduced in the motors which are the subject of this article since the necessity for it does not exist.

Mechanical Construction

An idea of the mechanical construction of the motor can best be obtained from the photographic views shown in Figs. 8, 9 and 10. Such features have been embodied as have

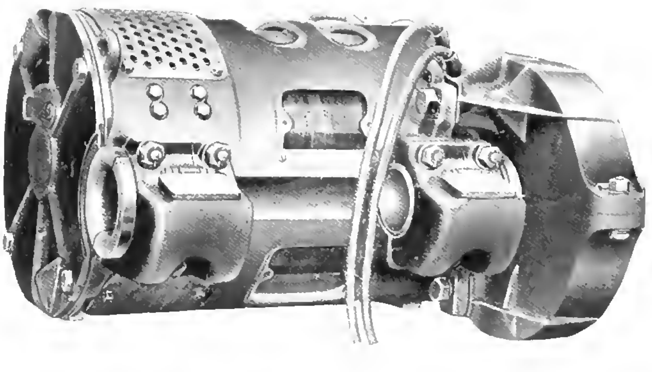


Fig. 10. Assembled View of Single-Phase Railway Motor

been in the past found essential for the success of any railway motor, particularly the alternating current motor. Large bearings, for instance, are used and a solid construction of windings employed, in which the conductors are completely formed and insulated before being placed in slots.

Special attention has also been paid to the cooling of the motor. In Fig. 9 are shown the air openings between the armature bars which serve as outlets for the air. The armature acts as a fan drawing in the air through the openings at the side of the frame. Thence the air passes through one side of the stator, and is drawn into the armature and expelled on the commutator side of the armature, where it passes over the commutator and is finally expelled through the perforated covers. Owing to the fact that the windings are completely enclosed, and that the bars on the armature carry an insulation of moulded mica on every exposed part there is no risk of short-circuit from any dirt that might be drawn in with the air even if it should deposit on the winding. It has also been found by experience that a motor ventilated in this way remains much cleaner inside, and runs less chance of break-down due to dirt, than a completely enclosed motor, since the air drawn through the motor is expelled at the commutator end and draws with it the carbon dust that is generated by the wear of the brushes.

In regard to the efficiency of cooling of the motor it might be worth pointing out that the motors used on the New Canaan branch of the New Haven road, while the service is a severe one, and while no provision has been made for forced ventilation by outside air pressure, yet have a temperature in service of less than 60 deg., or about one-half of the temperature that was obtained with the old series motor which it was designed to replace. It is also worth noting that the weight of this motor (5800 lbs. without gear and gear case) is no greater than certain direct current motors which are used extensively in service of the same character.

Fig. 11 is reproduced from a photograph taken on the road, and shows a two-car train (motor-car and trailer) driven with motors of this type.

A large locomotive which has been completed is shown in Fig. 12. It has four motors of the same type with a continuous capacity of 400 h.p. each. This locomotive has been given an endurance test covering several months on an experimental track and is soon expected to be placed in practical operation. It would be beyond the scope of this article to give any detailed description of this new locomotive, which may well serve as a subject for a future paper.

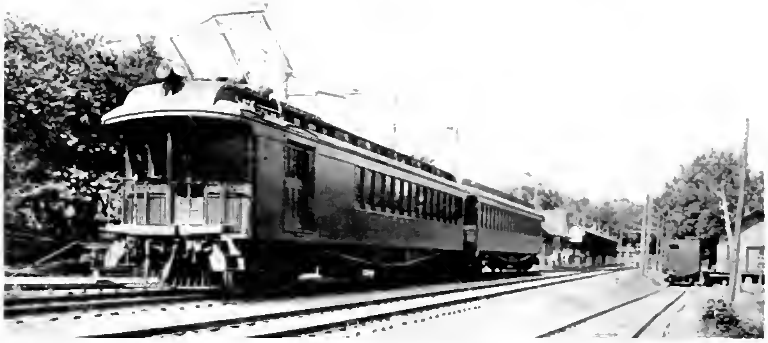


Fig. 11. View Showing Two-car Train, One Being a Motor Car Equipped with Single-Phase Motors

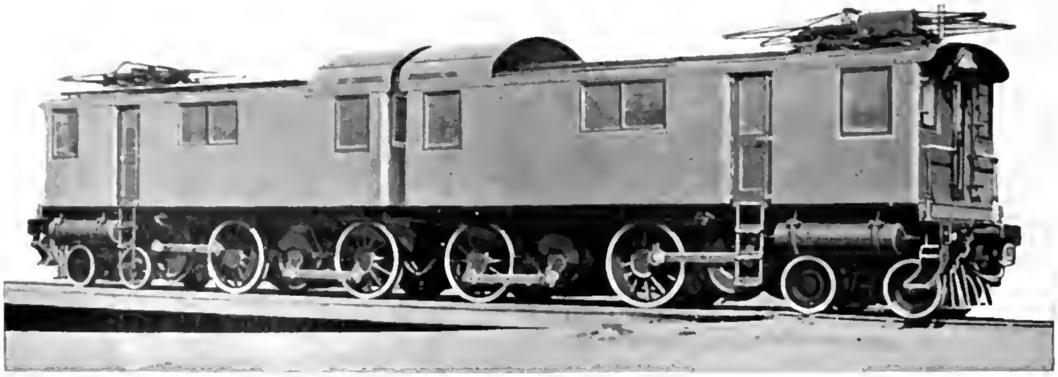


Fig 12. Locomotive Equipped with Four Single-Phase Motors, Each of 400 H.P. Continuous Capacity

MEASUREMENT OF ILLUMINATION

By S. L. E. Rose and H. E. Mahan

Illuminating Engineering Laboratory, General Electric Company

Color, intensity and distribution of the light are the important factors that enter into any plan of illumination. The character of the first of these is determined by psychological and physiological considerations; it is not measurable, and its discussion consequently has no place in this article. The authors are concerned here only with the intensity, the measurement of which at several points on a surface determines the distribution over that surface. A number of reasons are stated why illumination tests are desirable and often necessary, and an outline is given of the requirements that must be possessed by an instrument for making the tests. Instructions are given for conducting a test and for interpreting the results as read on the instruments.—Editor.

In engineering practice, wherever there is an expenditure of power for any purpose, the usual check, to determine whether the operation is carried on in the most economical way or not, is to find the efficiency. By efficiency in this sense we mean the ratio of output to input of power. The efficiency of a lighting system, if measured on this basis, would be very low due to the fact that only a small portion of the energy expended is converted into light. It is customary to express the efficiency of a lighting system by the ratio of effective to total flux. This is usually of secondary consideration in a system of lighting, the final criterion being the impression made upon the eye. No matter how successfully a lighting system may be designed from the standpoint of minimum consumption of power with maximum production of light, if it does not provide sufficient illumination where needed and present a pleasing atmosphere, it is a failure.

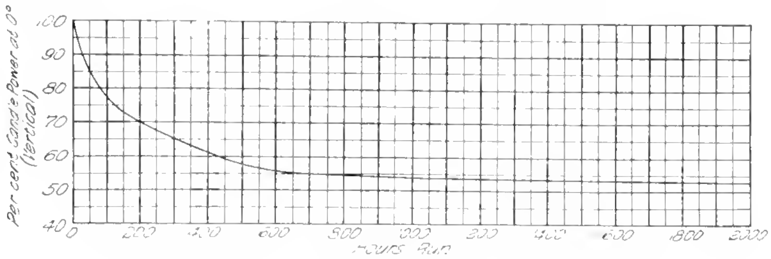


Fig. 2. Curve of Inherent Depreciation of a Mercury Vapor Lamp

The illumination tests described in this article are usually made for one or more of the following reasons.

First: To determine the condition of an existing lighting system.

Managers of modern industrial plants are becoming alive to the relation between satisfactory illumination and production, as well as the safety and contentment of employees. While satisfactory illumination may vary through quite a wide range of intensities, the minimum satisfactory value is very well agreed upon for the various processes of the different industries. For purposes of investigation, therefore, it is desirable first of all to find out, by means of a test, the prevailing illumination in the place under consideration.

Second: To obtain data for use in planning future installations.

In planning a new system of lighting, the most valuable guide the engineer has in determining the quantity of light necessary is the results of tests made on similar installations which have proven satisfactory in practice.

Third: To determine the relative effectiveness of different systems or equipments.

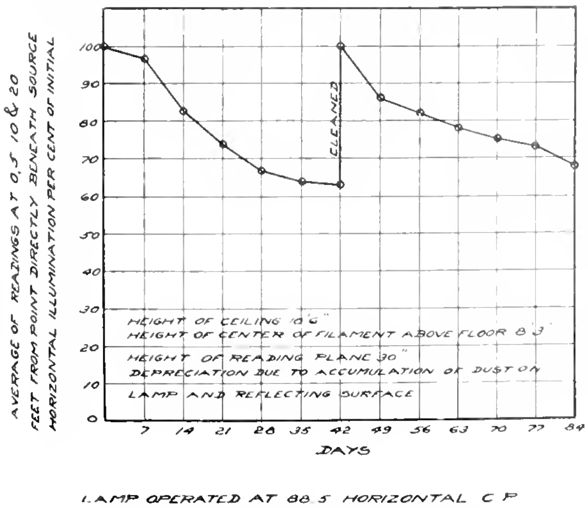


Fig. 1. Curve of Acquired Depreciation. Lamps Only Burned at the Test Periods to Prevent Inherent Depreciation

White paint walls and ceiling, dark green paint wainscoting 38 in. high.
Lamp operated at 85.5 horizontal c-p.
Watts per horizontal c-p. 1.13.
Silver plated spirally corrugated reflecting surface.
Test made under average office conditions.
Readings taken once every week.
Lamp burned only while taking readings.

Buyers frequently demand competitive tests to determine the type of unit most applicable to their needs.

Fig. 3 (a). Complete Sharp-Millar Photometer with Supply Battery

Fourth: To determine whether specifications have been fulfilled by the contractor.

Specifications covering lighting equipment are becoming more stringent, as the art advances. Clauses are oftentimes included specifying minimum allowable intensities and requiring that these be checked by test.

Fifth: To ascertain depreciation, distribution, etc., of light sources.

Laboratory tests are usually conducted in dark rooms from which all external light is excluded and with the lighting unit operating under ideal conditions, that is, the lamp is operated at its correct rating, the equipment is clean and in good condition. These conditions are rarely obtained in practice but are influenced by depreciation, surroundings, etc., the effect of which may only be determined by test. Depreciation is perhaps the most important of these factors and may be considered as acquired and inherent. Acquired depreciation (Fig. 1) is that due to the accumulation of dust and dirt on the lamp, globe and reflecting surfaces, and may be reduced to a minimum by periodical cleaning. Inherent depreciation (Fig. 2) is the deterioration of the light source and reflecting surfaces, and is beyond the control of the operator.

In measuring the illumination of actual installations, it is necessary to have some form of portable photometer. The following are the essential points of photometers of this type.

First: A photometric device (an optical arrangement which brings the light, from the unknown source and the standard source, into one field).

Second: A comparison light source (working standard).

Third: A test plate to receive the light under investigation.

Fourth: A means of varying the illumination intensity upon the photometric device.

The photometric device most widely used is the Lummer-Brodhum prism or some modification of it.* In nearly all portable

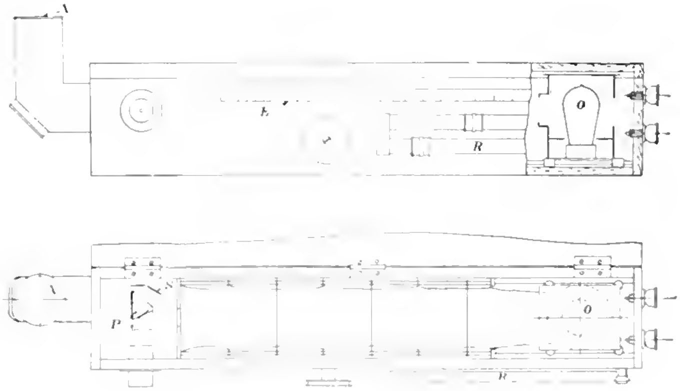


Fig. 3 (b). Section of Sharp-Millar Photometer

* See "Lectures on Illuminating Engineering," Johns Hopkins University, Volume I, Page 11).

photometers, to-day, miniature incandescent lamps are used as the working standards. These are so far superior to the flame standards, which were formerly used, that the latter are practically obsolete. The standard lamp is usually of low voltage, and is operated from a portable battery in series with a variable resistance for use in maintaining constant current or voltage on the standard lamp. It is sometimes advisable to operate the standard lamp from the circuit supplying power to the installation under test, in which case an external resistance is inserted in series.

A satisfactory test plate must have a surface which approximates a perfect diffuser of light and be so located that no shadows will be cast on it by the operator.

There are a number of ways to vary the illumination intensity on the photometric device and many ingenious arrangements for accomplishing the same, among which may be mentioned the following.

First: The comparison source may be movable.

Second: The comparison source may be fixed, and a diffusing screen moved back and forth between it and the photometric device.

Third: A variable sector disk may be interposed between the comparison source and the photometric device.

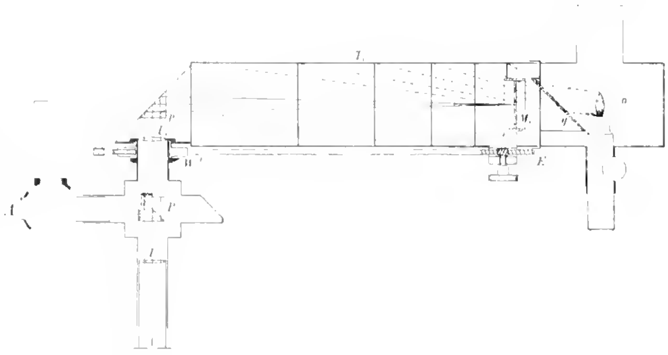


Fig. 4. Section of Weber Photometer (Beckstein Type)

Typical examples of the above are shown in Figs. 3, 4 and 5.

Fig. 3 illustrates the Sharp-Millar photometer.

A is the test plate of translucent glass,

P the photometric device (modified Lummer-Brodhum comparison prism),

O the working standard (miniature tungsten lamp),

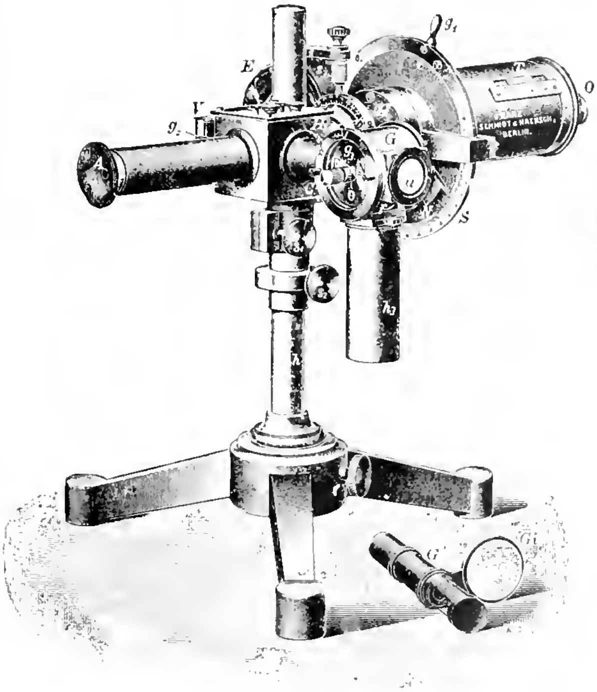


Fig. 5(a) Exterior of Beckstein Photometer

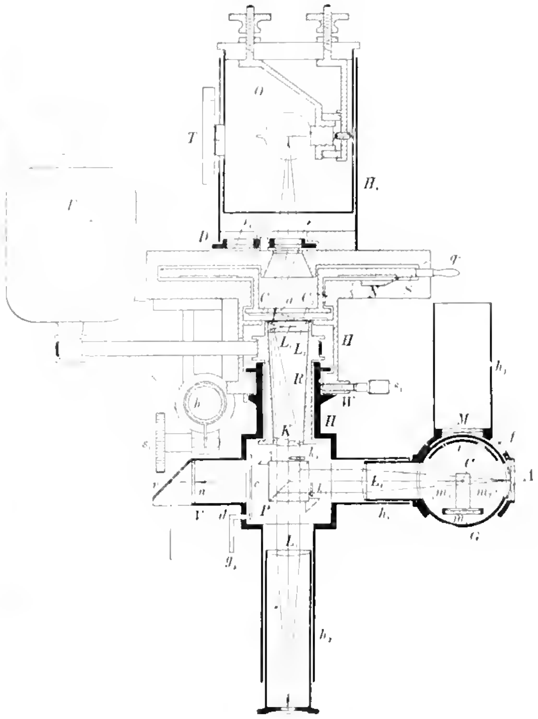
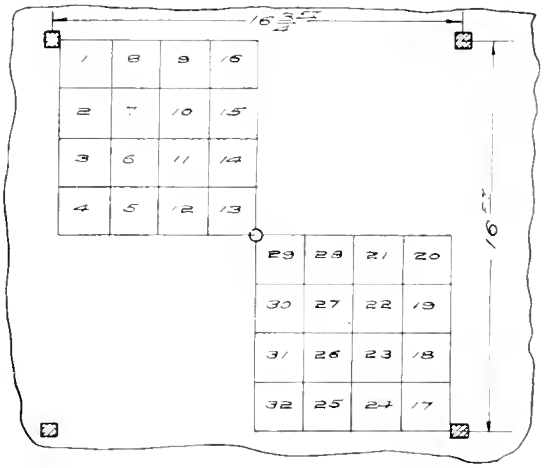


Fig. 5(b). Section of Beckstein Photometer

E the scale,
R the variable resistance, and
S the absorbing screens for increasing range of instrument.



Station	Ft.-Candle	Station	Ft.-Candle	Station	Ft.-Candl
1	2.7	12	6.2	23	3.95
2	3.0	13	9.75	24	3.5
3	3.6	14	7.2	25	3.95
4	3.85	15	5.0	26	4.95
5	4.7	16	4.2	27	5.5
6	4.3	17	2.85	28	7.25
7	3.5	18	3.6	29	13.5
8	3.4	19	4.2	30	8.25
9	3.85	20	4.3	31	6.25
10	4.5	21	6.5	32	4.4
11	4.35	22	4.9		

250 watt multiple tungsten lamp, clear with diffuser
Height of lamps, 9 ft.
Height of ceiling, 10 ft. 2 in
Color of walls, light.
Area per bay, sq. ft., 268
Watts per bay., 250
Watts per sq. ft., 0.93
Average foot-candles, 5.07
Lumens per watt, 5.45.

Fig. 6. Layout for Minimum Work in Making an Illumination Test

The illumination intensity on photometric device is varied by moving *O* back and forth by means of a cord and pulley.

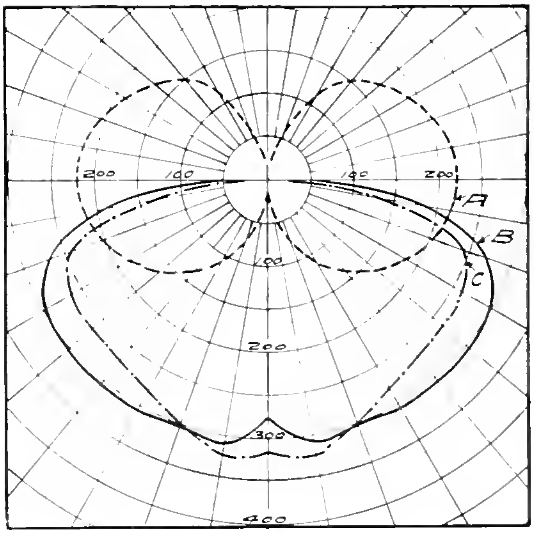
Fig. 4 illustrates the Weber photometer (Beckstein type).

A is the test plate of translucent glass.
P the photometric device (Lummer-Brodhum contrast prism),
O the working standard.
E the scale, and
M the diffusing glass screen, moved back and forth by means of a rack and pinion to vary the illumination on the photometric device.

Fig. 5 illustrates the Beckstein photometer.
A is the test plate,
P the photometric device, Lummer-Brodhum prism (comparison or contrast),
O the working standard (miniature tungsten lamp),
S the stationary variable sector with scale,
N the pointer to indicate scale reading, and
E the motor to rotate the lenses *L*.
R and *M* are absorbing screens to increase range of instrument.

The beam of light from the lamp *O* is rotated by means of the revolving lenses *L* and the illumination on the photometric device is varied by opening or closing the variable sector disk, through which the rotating beam passes. The above instruments are calibrated by checking with the test plate illuminated by a source of known candle-power.*

* For a more detailed description of portable photometers see "Industrial Photometry" by Palaz and "Photometrical Measurements" by Stine.



PHOTOMETRIC TEST

Diffuser 250 watt multiple tungsten lamp.

	A	B	C
Reflector	None	Diffuser	Diffuser
Lamp	Clear	Clear	Bowl Frosted
Watts	250	250	250
Mean hemispherical c-p.	171	256	224
Watts per mean hemispherical c-p.	1.46	0.98	1.12
Mean hemispherical c-p. per watt.	0.68	1.02	0.89
Mean spherical c-p.	172	130	113
Watts per mean spherical c-p.	1.45	1.92	2.21
Mean spherical c-p. per watt	0.69	0.52	0.45

Lamp operated at 221 horizontal c-p. (international).
Watts per horizontal c-p. 1.13.
White porcelain enamel reflecting surface.

Fig 7. Photometric Curve in a Vertical Plane of a Lamp and Reflectors

After deciding the purpose for which the test is to be made, it is usually not necessary to explore the whole area, but sufficient to select a representative section of the area lighted. This is divided into a number of rectangles, the center of each being a test station. This is illustrated by Fig. 6, which represents a test made in a factory building. The number of stations will depend upon the distribution of light, whether uniform or variable, and the degree of accuracy desired, the number of readings at each station depending on whether the light source is steady or fluctuating. Photometric readings are made at each of the stations selected and the mean of all observations assumed to be the average illumination over the entire floor area. This assumption is allowable because, as stated above, we have selected a representative area in which, theoretically, all the different intensities would appear. The sources of error in this assumption are the variation of light units and condition of surroundings. The illumination is expressed in foot-candles, this unit being defined as that illumination which falls upon a point one foot distant from a source of one standard candle-power.

The efficiency of an installation is usually expressed by the ratio of useful or effective flux to total or generated flux. The unit of flux is the lumen and may be defined as that flux of light radiating with unit intensity through a unit solid angle or steradian, which is equivalent to the quantity of light necessary to illuminate an area of one square foot to an intensity of one foot-candle. Useful or effective flux is that falling upon the reference plane, which may be at any angle to the horizontal, as in the case of a workbench or table, or to the vertical, as in the case of a picture gallery or blackboard in a schoolroom.

Power readings are taken simultaneously with the light measurements. We may determine the quantity of useful flux by substituting in the following formula: $F=EA$, where E is the average illumination in foot-candles and A is the area lighted in sq. ft. In the example shown in Fig. 6, light measurements were taken on a horizontal plane approximately 30 in. above the floor level, which represented the average height at which the work was done. The data accompanying a test of this nature should include the following.

(1) The place, date and purpose of test.

(2) The description, condition and number of lighting units.

(3) The spacing and height of suspension.

(4) The type of building construction.

(5) The color of walls and ceiling.

(6) The entire area lighted.

(7) The nature of work carried on.

(8) The power consumed per unit.

(9) The height of reference plane above floor.

(10) The average illumination.

(11) Mention of all conditions tending to modify results.

The total or generated flux may be obtained from the photometric curve of the lighting unit illustrated in Fig. 7. The curve should be taken with lamp rating and equipment corresponding to that of the lamps installed. This curve gives the distribution of intensity about the light source in a vertical plane passing through the axis of the lamp and is, for a symmetrical source such as that under consideration, a figure of revolution. The total light flux emitted in lumens is obtained by multiplying the spherical candle-power by 4π. This is the total light flux generated by the lamps, while that obtained from the test is the flux effective upon the reference plane. The ratio of the latter to the former expresses the so-called efficiency of the lighting installation.

The above method of test is usually adopted where it is desired to determine the average illumination for the entire area. However, for investigating the distribution, it is important at times to measure the illumination in certain definite directions. Fig. 8 shows an illumination curve plotted from a test made across a building by taking photometric observations at intervals of a few feet along the lines shown. A complete survey of the lighted area will give the data necessary for constructing an isolux chart—one in which lines are drawn through points of equal illumination.

From this general description of the method of measuring illumination, it will be clear that very valuable data can thus be obtained, which will be of great assistance to the engineer responsible for the design or upkeep of a lighting system.

As stated elsewhere, it must not be thought that the merits of a lighting system hinge only upon the physical quantities shown by test. Such results are important, it is true, but enter merely as a compromising factor with the aesthetic and ocular considerations. The relative importance of these factors depends upon the character of the installation. The physiological or ocular considerations should receive equal attention in all problems; the importance of efficiency will be greatest in industrial installations and will gradually become less important as we approach the ornate.

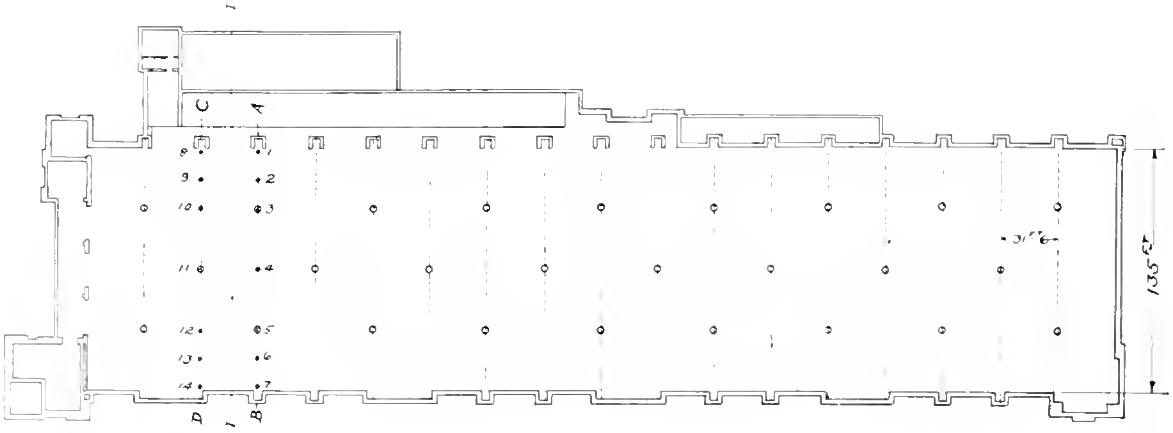


Fig. 8 (a). Sectional Plan Showing Location of Lamps in Riding Hall at the West Point Military Academy

Type of building—steel, masonry and brick walls, light brick, ceiling finished white, floor dark tanbark, skylight in roof.

Area, 76275.	Watts per lamp, 780.	Average foot-candles, 1.83.
Height to top of roof truss, 52 feet.	Total watts, 20,280.	Diversity factor, 2.65.
Height of lamps, 36 feet 6 inches.	Watts per sq. ft., 0.265.	Lumens per watt, 6.90.

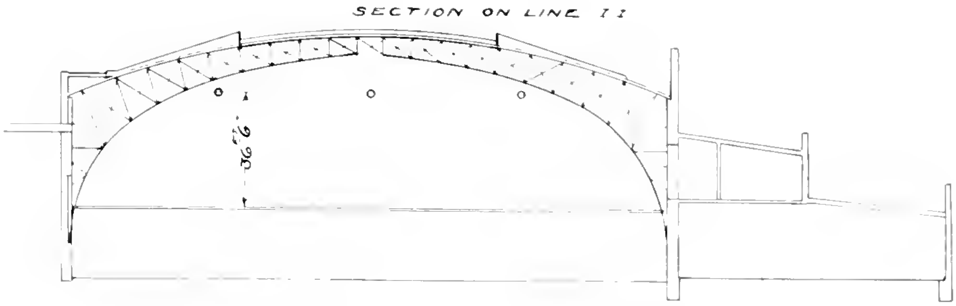


Fig. 8 (b). Sectional Elevation Showing Location of Lamps in Riding Hall at the West Point Military Academy

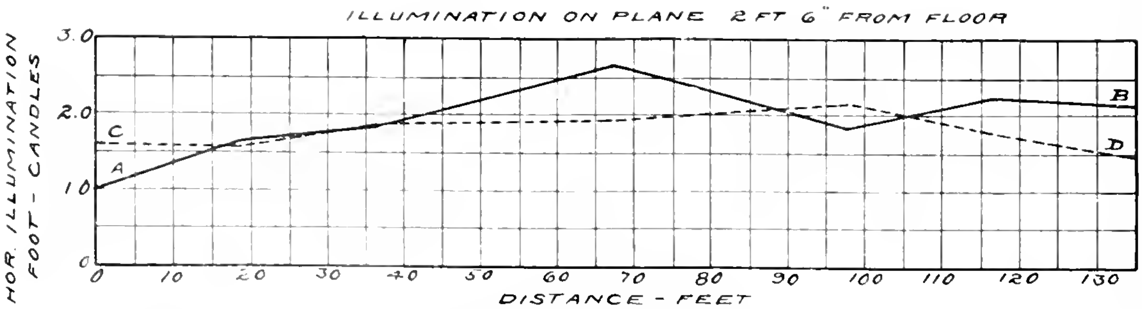


Fig. 8 (c). Chart Showing Intensity of Illumination in a Plane 2 Ft. 6 In. from Floor in the Lines AB and CD in the Riding Hall. See Fig. 8 (a)

FOUR YEARS' INVESTIGATION INTO THE PROPERTIES OF LIGHT

By G. H. Stickney

Edison Lamp Works, Harrison, N. J.

BEING A REVIEW OF THE ABSTRACT-BULLETIN OF THE PHYSICAL LABORATORY OF THE NATIONAL ELECTRIC LAMP ASSOCIATION, CLEVELAND, OHIO, DR. E. P. HYDE, DIRECTOR ISSUED JANUARY 13, 1913

The Physical Laboratory of the National Electric Lamp Association enjoys the distinction of being the leading laboratory devoted to purely scientific investigation of the physical and physiological properties of light. Since its establishment (in 1908) it has contributed a large proportion of the new knowledge on the subject, and this during a period of activity which far excelled any which preceded it.

On this account, the *Abstract-Bulletin*, which brings together under one cover abstracts of the earliest investigations carried on in the laboratory, is of the greatest interest and importance to scientific men interested in light. All of the papers have appeared in scientific engineering periodicals and have unquestionably done much to advance the art of illumination. In the *Bulletin* the reports are abridged as much as possible and it will often be found desirable to go back to the original report, to which complete references are made.

Owing to their nature, the abstracts can hardly be said to have a popular interest, although the conclusions deduced in some of them have a direct bearing upon general lighting practice. So extensive is the ground covered and so varied are the interests that, in reviewing the *Bulletin*, it has seemed best to list the subjects, including just a comment supplementary to the title to indicate the particular points of interest, in order that one who wishes to look up the subject may refer directly to the abstract or to the report itself.

ABSTRACT NO. 1, Radiation from Metals, by Edward P. Hyde. (Presented before the American Physical Society, April, 1910.) A study of selectivity of radiation, particularly with reference to platinum, with theoretical deductions regarding black body radiation, applying Wien's equation to incandescent lamp filament materials.

ABSTRACT NO. 2, A Study of the Energy Losses in Electric Incandescent Lamps, by Edward P. Hyde, F. E. Cady and A. G. Worthing. (Presented before the Illuminating Engineering Society, February, 1911.) An investigation of the energy losses by conduction and otherwise of the carbon, tantalum and tungsten filament lamps. A description is given of methods utilizing the optical pyrometer, as well as curves and tables showing results.

ABSTRACT NO. 3, A New Determination of the Selective Radiation from Tantalum, by Edward P. Hyde. (American Physical Society, April, 1911.) This is a study by the method of color matching, and contains a table giving the lumens per watt for tantalum and carbon filament lamps corresponding in color to black bodies at certain temperatures. The paper brings out the approximate agreement of an untreated carbon filament with a black body in color and temperature performance.

ABSTRACT NO. 4, Slit-Width Corrections in Spectro-Photometry and a New Form of Variable Sectored Disk, by Edward P. Hyde. (Presented before the American Physical Society, April, 1910, and December, 1911.) A mathematical paper covering the theory of slit-width corrections, describing also an ingenious form of sector disk, the ratio of which can be varied through a wide range simply by moving the disk with reference to the slit.

ABSTRACT NO. 5, The Synthetic Development of Radiation Laws for Metals, by Edward P. Hyde. (Published in the *Astrophysical Journal*, 36, page 89, 1912.) Covers the determination of formulæ and constants for deriving the radiation values of incandescent lamp filament materials at various temperatures.

ABSTRACT NO. 6, Luminous Intensity and Energy Relations in Incandescent Lamps, by F. E. Cady. (Published in the *Electrical Review & Western Electrician*, 59, page 1087, 1911.) Formulæ and constants for calculating candle-power and wattage relations for treated carbon, tantalum and tungsten filament incandescent lamps.

ABSTRACT NO. 7, A Visual Acuity Test Object, by Dr. Herbert E. Ives. (Published in the *Electrical World*, 55, p. 939, 1910.) Describes a new test object for visual acuity observations. An ingenious arrangement makes it possible to produce dark bands of any width within a wide range by super-imposed gratings. The test object is a considerable improvement over previous ones on account of the gradation steps, which avoids variations due to change of distance ordinarily necessary to get accurate readings with the former types.

ABSTRACT NO. 8, The Influence of Illumination of the Eye on Visual Acuity, by Percy W. Cobb. (Published in the *American Journal of Physiology* 29, p. 76, 1911.) Tests to show the effect on visual acuity of lights of different intensities and at various angles with respect to the object viewed. The results of the work are shown in curves of relative visual acuity, and general conclusions are drawn.

ABSTRACT NO. 9, Monochromatic Light and Visual Acuity, by M. Luckiesh. (Published in the *Electrical World*, 58, p. 450, 1911.) A study of the effect on visual acuity of lights of the same apparent color, but different composition. The showing is in favor of monochromatic light, rather than one of widely spread wave lengths. The author calls attention to the fact, however, that this does not indicate that monochromatic light is better for constant use in distinguishing fine detail. The information is given in the form of tables and a photographic chart of the spectra of tungsten filament lamps with various colored screens, mercury arcs, etc.

ABSTRACT NO. 10, The Dependence of Visual Acuity on the Wave Length of Light, by M. Luckiesh. (Published in the *Electrical World*, 58, p. 1252, 1911.) Previous tests of visual acuity for different colors showed certain inconsistencies, which the author believed to be due to neglect of wave length. The investigation here reported gives relative visual acuity for different wave lengths, which seems to confirm his hypothesis. The maximum visual acuity for a distance of 14 in. was found in the yellow-green. At this normal reading distance no appreciable difference in acuity, due to difference in eye focus, was found for red and blue rays. Since ordinary seeing depends more on light, shade and color, the spectral character of the illuminant is unimportant except in a few special cases.

ABSTRACT NO. 11, A Form of Neutral-Tint Screen for Photometric Use, by H. E. Ives and M. Luckiesh. (Published in the *Physical Review*, 32, p. 522, 1911.) A description and test of a neutrally tinted screen for reducing the intensity of light in photometry. The general conclusions of the paper are indicated in the summary, as follows: "Perfectly neutral-tint screens may be made of opaque line gratings on glass. Their transmission is a function of the relative size of opaque and transparent space; also of their size, the fineness of their spacing, and their position. The method of calculating the variations of transmissions due to these causes is developed, and the magnitude of the variations discussed. They may in most practical cases be made negligible.

ABSTRACT NO. 12, A Variable Absorption Screen for Photometric Use and Its Application to Portable Photometers, by H. E. Ives. (Published in the *Electrical World*, 59, p. 598, 1912.) Carries the investigation reported in Abstract 11 still further. It describes a screen made from two superposed gratings, the absorption of which can be varied continuously.

ABSTRACT NO. 13, Scattered Light in Spectro-Photometry and a New Form of Spectro-Photometer, by H. E. Ives. (Published in the *Physical Review*, 40, p. 446, 1910.) This article calls attention to errors in spectro-photometry caused by scattered light due to imperfections in lenses, etc., and suggests an arrangement to eliminate such errors by making the instrument symmetrical with regard to the two light sources. At the same time, it retains a wide field.

ABSTRACT NO. 14, Studies in the Photometry of Lights of Different Colors, by H. E. Ives. (Presented in sections before various societies and serially in volume 24, 1912, of the *Philosophical Magazine*.) As is well known, considerable difficulty has been encountered in photometering lights of different colors. The first section of the paper, which compares the equality of brightness photometer and the flicker photometer, indicates a greater sensibility and accuracy in reproducing results for the latter method. It calls attention to the opposite actions of these two photometers with regard to the Purkinje effect with decreasing intensities. The second section treats of the method of critical frequencies and shows it to be less sensitive than either the flicker or equality of brightness methods. The third section covers the distortion of spectral luminosity curves produced by different conditions, and shows that less deviation is found by the flicker photometer method. Curves are shown for different conditions, from which the author concludes that the flicker photometer measures true brightness. The fourth section treats of the addition of luminosities of different colors, obtaining correct results with the flicker photometer, and showing the equality of brightness method, as ordinarily carried out, to be inadequate. This section also brings out the failure of the visual acuity method of photometric comparison, due to chromatic aberration of the eye. The final section covers a luminosity curve of the average eye, and suggests the flicker photometer as a convenient means of obtaining such a curve.

ABSTRACT NO. 15, Note on Crova's Method of Heterochromatic Photometry, by H. E. Ives. (Published in the *Physical Review*, 32, p. 316, 1911.) "Crova suggested the comparison of the intensities of two illuminants at a single spectral wave length as a means of overcoming the difficulty of making photometric settings on lights of different colors." The tests reported by curves show the errors which would accrue in comparing black bodies of different temperatures by this method, from which the conclusion is drawn that in no single wave length is the change in intensity the same as that of the total light within a reasonable range of error under the conditions noted. This indicates that the Crova method cannot be applied generally to all conditions.

ABSTRACT NO. 16, Color Measurements of Illuminants—A Resume, by H. E. Ives. (Presented before the Illuminating Engineering Society, March, 1910. *Trans. Illum. Eng. Soc. 5, p. 189, 1910.*) This paper brings together all the previous comparative spectro-photometer tests of ordinary artificial illuminants, to which the author adds his own measurements, both by means of the spectro-photometer and the Ives colorimeter. The advantage noted for the colorimeter method is that an estimate can be had on light sources such as the vapor tube which have discontinuous spectra. The spectral curves compare the Hefner, 3.1-watts-per-candle carbon incandescent lamp, acetylene, tungsten, d-c. arc, Welsbach, black body at 5000 deg. absolute and blue sky. The colorimeter measurements shown in the table and chart compare black body at 5000 deg., blue sky, overcast sky, afternoon sun, Hefner, and eleven artificial illuminants. The results of the spectro-photometric measurements seem to show that the energy distribution for a black body at 5000 deg. absolute coincides very nearly with that of average daylight, and this is confirmed by the colorimeter test.

ABSTRACT NO. 17, Study of the Light from the Mercury Arc, by H. E. Ives. (Published in the *Electrical World*, 60, p. 404, 1912.) "This article describes a study of the light of the mercury arc lamp equipped with a Cooper-Hewitt rhodamine reflector." •Colorimeter measurements on the mercury arc are compiled along with those of various other illuminants. Reference is also made to spectro-photometric measurements which show a deficiency in the spectral blue-green. This makes the unit far from perfect for color matching, although for general purposes much preferable to the uncorrected mercury arc. The efficiency of the combination is low, since the fluorescent red light is obtained at the expense of the green.

ABSTRACT NO. 18, *Effect of Yellow Glass on the Efficiency of Incandescent Lamps*, by H. E. Ives. (Published in *Illuminating Engineer*, 6, p. 89, 1911.) For some conditions of decorative lighting, the tungsten filament incandescent lamp has been considered too near white, and the warm glow of the carbon incandescent lamp has been preferred. The test shows that, by means of a yellow absorption glass, the color of the light may be modified to correspond approximately to that of the carbon lamp and still retain an efficiency corresponding to 1.5 watts per candle, showing a loss in efficiency of only about 20 per cent. This indicates that the warm tinted light can be produced with the tungsten filament lamp with a color screen much more efficiently than with the carbon filament lamp.

ABSTRACT NO. 19, *Subtractive Production of Artificial Daylight*, by H. E. Ives and M. Luckiesh. (Published in *Electrical World*, 57, p. 1092, 1911.) This article is of especial interest at the present time, due to the growing demand for accurate color-matching light from artificial sources. Practically all of the artificial illuminants which approximate anywhere near daylight are deficient at the blue end of the spectrum and have an excess of red. The author calls attention to two methods of correction, viz., one by adding light to make up the deficiency, and the other by absorbing selectively through a colored transmission screen. The latter method is, of course, the more simple and practical to apply, although liable to result in a considerable loss of efficiency. The author describes a screen for correcting the light from the tungsten filament lamp, which is composed of signal-green glass with a cobalt glass and rozazeine dye. The measurements are confirmed by spectro-photometric and colorimeter tests, the spectro-photometer test approximating very nearly the curve of average daylight.

ABSTRACT NO. 20, *Ultra-Violet Radiation from Common Illuminants*, by M. Luckiesh. (Published in the *Electrical World*, 59, p. 1314, 1912.) The importance of this subject is indicated by the Introductory, from which the following is quoted: "The ultra-violet radiation from common illuminants is of importance on account of the deleterious physiological effects which may arise therefrom. It is of secondary interest when choosing an illuminant for photographic purposes or in roughly estimating the time of exposure of plates." The author calls attention to the fact that there is no general agreement among authorities as to the extent of the harmful region. The author made tests of the various common illuminants, including daylight, which were compared by means of the spectro-photometer with the light from the tungsten filament lamp. Photographic charts of the various spectra are included. The tests show that with a photometric intensity of ten times that of daylight, the tungsten light contains less of the harmful short-wave radiations than daylight. This clearly demonstrates that, assuming daylight to have no ill-effects, there can be absolutely no danger on this account from the light of the tungsten filament lamp or other ordinary illuminants.

ABSTRACT NO. 21, *The Distribution of Luminosity in Nature*, by H. E. Ives and M. Luckiesh. (Presented before the Illuminating Engineering Society, September, 1911. See *Trans. Illum. Eng. Soc.* 6, p. 687, 1911.) As a guide in determining what is desirable in artificial illumination, the authors made a study of certain conditions in nature which they found to be pleasing or displeasing to the eye. The brightness at different angles of elevation for these conditions was measured photographically by a very ingenious arrangement. Some of the results obtained are shown in curves. One fact brought out by the investigation is that the eye will tolerate a greater brightness above than below the horizontal. A case of an overcast sky shows that the eye will not tolerate too great a flux above the horizontal. In the best landscapes studied the ideal condition seemed to be a preponderance of brightness in the sky with a foreground showing marked varieties of light and shade occasioned by the direct light of the sun falling rather obliquely . . . . The ratio of the brightest and darkest points of the average vertical distribution of the most varied landscape was about 20 to 1. The brightest white cloud measured about one-half the intrinsic brightness of a Welsbach mantle.

ABSTRACT NO. 22, *The Analysis of Glare from Paper*, by M. Luckiesh. (Published in the *Electrical Review & Western Electrician*, 60, p. 1070, 1912.) "It is well known that glare in any of its various forms diminishes the effectiveness of an illumination. Glare from polished objects has become recognized as a very serious matter. For instance, take the case of reading from glazed paper. We are able to see printed letters because of the contrast between the dark letters and the bright background. If this contrast is greatly diminished the ability to read with ease is decreased. The reflection from commercial papers is a combination of diffuse and specular reflection. The effect of the specular reflection, the source of the glare, is well illustrated by placing a clear sheet of glass over white blotting paper." The author draws the following conclusions: "Sources of low intrinsic brightness are desirable from the standpoint of glare from paper. When the unit is not too close to the paper, there seemed to be little practical difference between the direct units examined. With indirect lighting the glare is much less than with direct lighting. When the reader is free to change his position or that of his paper, the system of lighting is of considerably less importance, but it becomes of great moment when glare from paper cannot be avoided owing to the fixed position of the work and the individual. For desk lighting where the unit is not far from the work, properly designed reflectors with large diffusing surfaces produce less annoyance from glare than a mirrored reflector."

ABSTRACT NO. 23, *Measurements of Intrinsic Brightness by a New Method*, by H. E. Ives and M. Luckiesh. (Published in the *Electrical World*, 57, p. 438, 1911.) The method employed is on the order of the optical pyrometer. "The bright object under measurement is viewed against a background of known brightness, and one or the other is varied until the object disappears against the background. The object and background are then of the same brightness." The table of intrinsic brilliancies, as

(*Mr. Stickney's Review of the Abstract-Bulletin is continued on fifth page following*)

FROM THE CONSULTING ENGINEERING DEPARTMENT OF THE GENERAL ELECTRIC COMPANY

Educational

Dr. E. J. Berg, who was Dr. Steinmetz's assistant from the time of the re-organization of the Engineering Department in Schenectady in 1894, until a few years ago, when he undertook the re-organization of the Electrical Engineering Department of the University of Illinois, has accepted the chair of Professor of Electrical Engineering at Union College, held by Professor Steinmetz since 1901, and expects to return to Schenectady during the coming summer. Dr. Steinmetz has accepted the chair of Professor of Electrophysics at Union College, and as such will continue his educational work.

Western Trip of Consulting Engineers

Mr. C. W. Rice and Mr. S. Thomson of the Consulting Engineering Department, are making an extensive trip through the Southwest, for the purpose of studying the conditions of long distance power transmission and electrical distribution, and gather engineering information for the department.

Experimental Demonstration of Standing Electric Waves

A very instructive experimental lecture on Electric Waves has been given by Professor Creighton, of the Protective Apparatus Laboratory of the Consulting Engineering Department, under the auspices of the Schenectady Section of the A.I.E.E. In this lecture, Professor Creighton demonstrated the existence of high frequency electric waves in an experimental circuit arranged in the lecture room, by showing the crests and the nodes of the standing waves by the lighting up and the darkening of vacuum tubes placed at different points of the oscillating circuit.

Vacuum Tube Lighting

A very interesting investigation on vacuum tube conduction, on the effect of the gas pressure, the action of the noble gases in the vacuum tube, and a study of the terminal drop in the vacuum tube, is being carried out by Mr. W. S. Andrews of the Consulting Engineering Department, for the purpose of determining the possibilities of the vacuum tube as illuminant.

High Voltage High Frequency Phenomena

The extensive experimental study on the high voltage high frequency phenomena occurring in high potential transformer coils as the result of the distributed capacity of the winding, which has been in progress for a considerable time, by the Transformer Department at Pittsfield, with the co-operation of the Consulting Engineering Department, is being concluded and it is expected that a number of important and valuable papers dealing with these phenomena will soon be presented to the engineering world.

Student Engineers of the G.E. Company

An extension course in general engineering, under the direction of the Consulting Engineering Department*, has been designed and authorized by the Students Committee of the General Electric Company. These courses prepare for a position in the Engineering Departments of the Company. They extend over nine months, and require for admission a minimum of twelve months experience in the Testing Department.

* See G.E. Review, Feb. 1913, p. 140.

NOTES ON LIGHTNING ARRESTER DESIGN

By Dr. Charles P. Steinmetz

1. *Effect of resistance in discharge path.*

In any electrical disturbance occurring in a circuit, such as a transmission line, cable, high potential transformer winding, etc., whether a standing wave, traveling wave or impulse, a constant relation exists between the transient voltage e and the transient current i.

$$\frac{e}{i} = \sqrt{\frac{L}{C}},$$

where L is the inductance, and C the capacity per unit length of line.

This quantity $\sqrt{\frac{L}{C}} = r_0$ is of the nature of a resistance, and is called the "surge resistance" or "surge impedance" of the line. In overhead circuits, it is usually between 300 and 600 ohms, much lower in underground cables, much higher in transformer coils.

If a line is connected to ground, for instance through the lightning arrester, by the surge resistance r_0, a disturbance traveling along the line, as by lightning, passes over the surge resistance to ground, without reflection, that is without increase or decrease. If the discharge resistance is greater than r_0, reflection occurs at it with a voltage rise, up to a maximum of double voltage at open circuit. If the discharge resistance is less than r_0, reflection occurs with a decrease of voltage, which is the greater, the lower the discharge resistance; until at discharge resistance zero, the transient voltage is pulled down to zero, and the transient current doubled in the discharging path.

Thus a lightning arrester having a discharge resistance equal to the surge resistance, can not relieve the station from excess voltages entering from the line, but merely keeps line disturbances from building up by reflection at the station to voltages higher than those which exist in the line. Such a device would therefore expose the station to the same transient voltages as appear in the line. As the margin of insulation against momentary voltages in modern transmission lines with suspension insulators usually is higher than the possible margin of insulation in apparatus, such a lightning arrester would offer no material protection.

To pull the voltage of the line disturbance down by the discharge of the lightning arrester, and thereby protect the station against excess voltages, thus requires a lightning arrester with a resistance lower than the surge resistance r_0; and the lower the discharge resistance is, the more the abnormal voltage strain will be relieved. Thus, if the surge resistance is $r_0 = 400$ ohms, and the discharge resistance of the lightning arrester $r = 100$ ohms, the discharge over the arrester reduces the voltage of the line disturbance which arrives at the station, to one-quarter the value which it has out in the line.

(To be continued in our June issue)

QUESTION AND ANSWER SECTION

The Q. and A. Section has been started with the sole object of increasing the practical usefulness of the REVIEW; and in order that it may be made of real value, we invite correspondence from any of our readers who are looking for information on any technical matter in the field covered by this magazine, and which they think we can furnish.

Where possible the answers to such inquiries will be the work of this office; where desirable we shall obtain our authority from that engineering or commercial party in the General Electric Company's organization best fitted for handling the particular subject. We hope our readers will not hesitate to avail themselves of the expert engineering opinion which should be made available through this section of the REVIEW. Information on matters of general importance and interest will be published here; questions of interest solely to the querist will be handled by mail.

Sketches should accompany questions in all cases where this is necessary to give us complete and accurate information on the point at issue. Scale drafts will be made up here from correspondent's rough pencil sketches Questions must be accompanied with the name and address of the sender, although these will not necessarily be for publication, and should be addressed to the Editor, Q. and A. Section, GENERAL ELECTRIC REVIEW, Schenectady, N. Y

USE OF ENAMELED WIRE FOR WINDING FIELDS

(19) Is enameled wire used in shunt fields of commercial machines to-day and what are its advantages and disadvantages?

Wire which is insulated with a covering of enamel is very frequently used in the winding of shunt fields. Provided the enamel coating has been properly applied, it possesses the following advantages over cotton covering: about a four times greater dielectric strength, a lesser amount of winding space required (which means a lesser weight of copper per ampere turn, owing to the shorter mean length of turn), and a greater heat radiating capacity. Where this kind of insulation is used, reasonable care must be taken that turpentine or its compounds, and vegetable or animal oils do not come in contact with it. The wire is uninjured by clean mineral oil. E.C.S.

IMPROVING THE REGULATION OF AN ALTERNATOR

(20) What is the most practical way of improving the regulation of a 400 kv-a., 60 cycle, 2300 volt alternator, which has been reconnected for 440 volts and is now delivering 460 volts at an average power-factor of 75 per cent. From no load to full load the volts field required range from 30 to 125.

It would be entirely impracticable to make any change in the construction of the alternator with a view to obtaining the result desired. When an alternator is to operate at or near unity power-factor, a slight improvement can sometimes be made; but if it is working on a low power-factor, the result of this effect would be negligible. It so happens, that the only means of bettering the given conditions is the one which gives everything to be desired—an automatic voltage regulator. This auxiliary will successfully maintain constant terminal voltage over a range requiring a change of field volts of 4 to 1.

T.S.E.

CONSTRUCTION OF EXPLOSION-PROOF MOTORS

(21) What is an explosion-proof motor?

The term "explosion-proof" is applied to such electric motors (mostly used in mines), as embody in their construction those special features which will prevent the explosion of a combustible gaseous mixture, which may be within the case, from igniting an atmosphere of the same gas surrounding the motor. There are two common types. One of them prevents the internal explosion from communicating with the outside gas, purely by mechanical strength of the enclosing case. The other gives the expanding gas an exit, through specially constructed relief openings or valves, which cool the gas passing through them below the point of ignition, using the principle of the Davy safety lamp. This latter type admits of a much lighter construction, since it relieves the enclosing case of the strain.

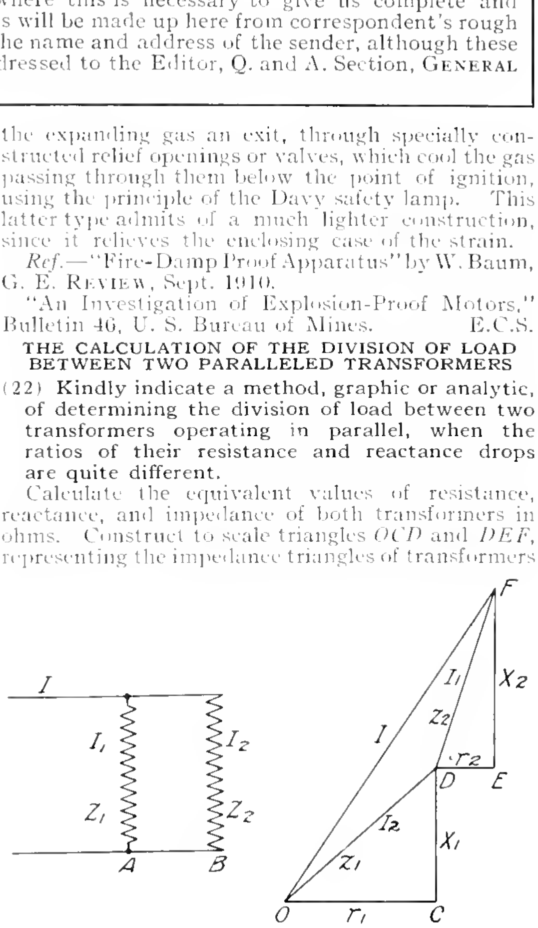
Ref.—"Fire-Damp Proof Apparatus" by W. Baum, G. E. REVIEW, Sept. 1910.

"An Investigation of Explosion-Proof Motors," Bulletin 46, U. S. Bureau of Mines. E.C.S.

THE CALCULATION OF THE DIVISION OF LOAD BETWEEN TWO PARALLELED TRANSFORMERS

(22) Kindly indicate a method, graphic or analytic, of determining the division of load between two transformers operating in parallel, when the ratios of their resistance and reactance drops are quite different.

Calculate the equivalent values of resistance, reactance, and impedance of both transformers in ohms. Construct to scale triangles OCD and DEF, representing the impedance triangles of transformers



A and B respectively. Draw OF. If the vector OF is allowed to represent the total load current I, then DF will represent the current in transformer A, and OD the current in transformer B, both in magnitude and phase relation. It should be noted that the vector representing the impedance of one transformer gives the load current of the other transformer. W.W.L.

ACTION OF A FIELD DISCHARGE RESISTANCE

(23) What is the function of a discharge resistance, when used in connection with a field switch?

Its function is to interpose a high resistance in the field when its circuit is being opened. This furnishes a local path, wherein the stored magnetic energy of the field may be dissipated in harmless current flow, rather than in the generation of a high induced voltage, which would result if the field were suddenly open circuited. E.C.S.

A PECULIAR TRANSFORMER BURNOUT

(24) During the replacement of an old transformer by a new one, a most surprising and unexpected phenomenon occurred, which resulted in the burning out of the former. The machine in question was rated 60 cycles, 400 kv-a., 33,000/6600 volts, and comprised one leg of a receiving circuit on a three-phase grounded neutral line. With all the secondary switches and that between the primary and neutral open, in addition to having the fuse in the high line removed, the transformer would have been dead. A slight static discharge was heard, however, and further examination of the connections revealed a one-ampere test fuse across the supposedly open fuse block, also one of the secondary leads lying on the case, which conditions are represented by Fig. 1. The opening of the high line switch, preparatory to correcting these faults, seemed perfectly logical, but proved disastrous by blowing the one-ampere fuse with great violence and causing a heavy arc between the transformer case and the end of the secondary winding not grounded, which was some six inches from it. So heavy was the rush of current that the secondary copper was melted.

How could this sudden "kick" current be generated when there existed neither in the primary nor secondary a completed metallic circuit?

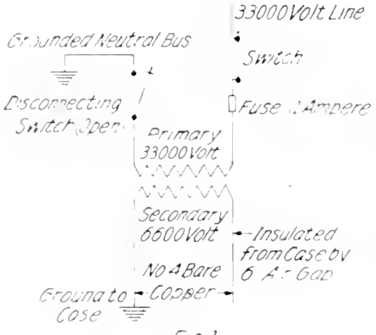


Fig. 1

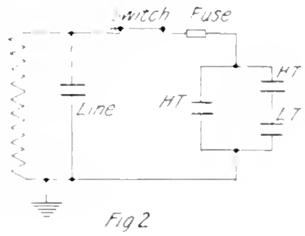


Fig 2

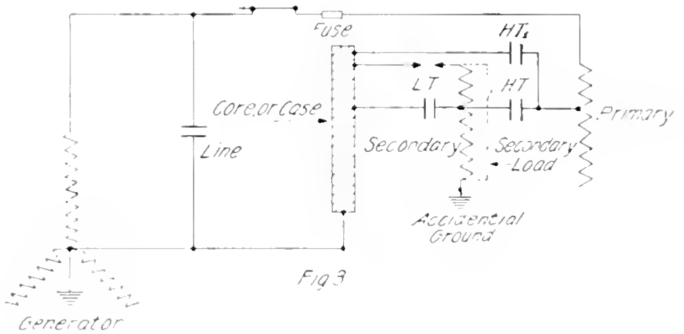


Fig 3

The conditions existing prior to the opening of the high side primary switch, which caused the disturbance, are illustrated diagrammatically by Fig. 2. This shows that the sum of the condenser capacities of the line to ground, that between the primary winding and the core or case, that between the primary and secondary windings, and that between the secondary and core or case, caused a charging current to flow out from the generator through the circuits. Referring to Fig. 3, which shows one phase complete, the condenser *L.T.* illustrates the condenser capacity from the secondary winding to the ground, *H.T.* that of the primary to secondary, and $H.T._1$ that from the primary to ground direct. When these connections were made, the generator and transformer adjusted themselves to a mutual state of equilibrium, although it was an abnormal one for each individually. Thus, a small balancing charging current flowed through circuits quietly and caused no disturbance until the link tying the generator and receiving station was broken, i.e., until the high side line switch was opened. Instantly then, being released, each half sought a new state of equilibrium, determined only by its own constants, which resulted in heavy surges of very high frequency passing over the whole system. That which flowed through the arc between the contacts of the line switch, before it was completely opened, blew the one-ampere test fuse.

The transformer itself now acted in the nature of a Tesla coil, since the surges of very high frequency current in the primary placed the secondary in inductive relation to itself, which resulted in the burning out of the secondary, accompanied visually by the severe discharge between the case and ungrounded end of the secondary. This arc completed the local secondary circuit comprising one-half the low tension winding, the condenser capacity between it and ground, and the ground. C.M.D.

SUBSTITUTION FOR FILM CUT-OUT

(25) Would any harm result from the substitution of a piece of paper or pasteboard for the regular film cut-out of a series incandescent lamp?

Nothing more serious is likely to happen than the extinguishing of all the lights on that circuit. This would doubtless be the result if the lamp, in whose receptacle the substitution was made, burned out; since it is probable that the paper or pasteboard would be too thick to perform the function of the regular cut-out, and would thus open the circuit. H.H.R.

CURRENT FLOW BETWEEN FRAME AND SHAFT

(26) What is the explanation for the flow of current between the frame and shaft of large alternators?

So far as we know, there has been, up to the present time, no thoroughly satisfactory explanation of this action. It may result from a similar principle as is made use of in generating electricity by a homopolar machine. It has also been suggested that perhaps the flow might be explained by an unbalanced condition of the magnetic paths in the frame, since on account of the base and other irregularities, but few machines are truly symmetrical about the shaft.

Ref.—"The Electrician," Oct., 1907, page 61. "La Lumière Électrique," Aug. 27, 1910, page 268. T.S.E.

GENERAL ELECTRIC REVIEW

Published Monthly by the

GENERAL ELECTRIC COMPANY'S PUBLICATION BUREAU

Manager, M. P. RICE Editor, D. S. MARTIN Associate Editor, B. M. EOFF Assistant Editor, E. C. SANDERS

Subscription Rates: United States and Mexico, $2.00 per year; Canada, $2.25 per year; Foreign, $2.50 a year, payable in advance. Remit by post-office or express money orders, bank checks or drafts, made payable to the *General Electric Review* Schenectady, N. Y.

Entered as second-class matter, March 26, 1912, at the post office at Schenectady, N. Y., under the Act of March 3, 1879.

VOL. XVI., No. 6

JUNE, 1913

CONTENTS

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THE FORE-RUNNER OF KEOKUK, IOWA

Waterwheels at Hama on the River Orontes, midway between Damascus and Aleppo. These and the other waterwheels of Hama serve not only to supply the town with water, but also perform an irrigation service for the adjacent gardens. "A large crowd of men and boys followed us around during our inspection. Small boys bathing in the river would, for fun, hang on the outside of the wheel and drop back into the water when half-way up." Note small boy. For some reason or other these waterwheels are not direct-connected to electric generators

GENERAL ELECTRIC REVIEW

THE ADMINISTRATIVE ASPECTS OF HYDRO-ELECTRIC DEVELOPMENT

The articles which we publish this month, dealing with some of the technical details of hydro-electrical development and more particularly with the transmission of the power so obtained to distant load centers, make up an interesting record of engineering progress. From the point of view of benefit to the ultimate consumer there are other questions of equal importance which are sometimes in danger of being overlooked. Briefly, these are the legal questions involved in the administering of the available water-powers of this country, to the end that they may serve to reduce the selling price of electrical energy to the householder, storekeeper, factory-manager, mine-owner, and so on.

If these articles serve any purpose as a record of engineering achievement, they are an even more eloquent proof of the utter folly of the present governmental attitude regarding the utilization of available water-powers, and of the crying necessity for a definite pronouncement on whether these powers are going to be developed, and, if so, who is going to do it, and upon what terms. In the *Electrical World* for January 4th, Dr. Louis Bell wrote: "The problem for the general government to undertake is merely to control these valuable privileges in the interest of the general public to the best advantage. This condition is certainly not met by setting up regulations which will discourage their utilization. . . . . To preserve the equity of the people as a whole some provision must be made for close, effective and continuing regulation, including regulation of prices. The projects for regulation now in force or on foot are open to criticism because of their establishment of a rental basis. The ultimate result of this must of necessity be an increase of the price to the consumer, an increase which in some cases might rise to a very substantial amount. It would seem to be more in line with the policy of ultimate public usefulness to charge no rentals, or at least no more than a nominal sum to cover the expenses of supervision; and to adopt such regulations as will keep the price of the product down to the irreducible minimum consistent with a suitable return on the capital actually invested; and, as a mere matter of decent fairness, this return, considering the laborious and uncertain nature of the development, especially in its early stages, ought to be a liberal one. . . . . If the government would bend its energies toward getting the available powers promptly and effectively utilized and protecting the public by rigorous supervision of the financing and operating involved in this utilization, it would do far more to benefit the ultimate consumer than it can do by hanging back, hesitating, and taking out in rentals the surplus that ought to be applied to reducing rates. It is to be earnestly hoped that the final straightening out of the difficulties will be undertaken by the new administration at an early date and carried to a conclusion; so that we may no longer have to see, so to speak, a golden stream pouring down our watercourses into an abyss from which it can never be recovered."

In a word, then, engineers must realize that further delay in the settlement of these questions is certain to discount the value of the work they are performing. It would hardly be an exaggeration to say that we could afford to waste entirely the fruits of a whole year's technical progress, if, by offering it in barter, we could achieve a settlement of the legal points involved; a definite national policy to show us where we are at, and tell us whether the hydro-electric "monopolist" is a criminal or a good fairy; and the establishment of law on the matter of federal or state control, the indeterminate franchise, the nominal rental, and the guarantee of an adequate return on the outlay expended. At present the indications of any such legislation being taken in hand are far from encouraging; and the gratitude of the whole industry should go out to the N.E.L.A. for their steady efforts, in the face of all kinds of discouragement, to set things moving at Washington in a direction which, while securing protection for the electrical interests, will advance enormously the public cause.

A REVIEW OF RECENT PROGRESS IN THE ENGINEERING OF HYDRO-ELECTRIC POWER PLANTS AND TRANSMISSION SYSTEMS

By David B. Rushmore

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The author briefly reviews recent progress under the headings of hydro-electric stations—syndicate control, waterwheel speeds; generators—temperatures, ventilation, insulation, braking; transformers—bushings, reactance, outdoor practice; low-tension switching *versus* high-tension; protection—busbar reactances, lightning arresters; line construction—ground wires, insulators, disposition of conductors; voltages for transmission and distribution. Nearly all of these matters are considered in greater detail in the articles which follow. The titles are for the most part descriptive, and we have therefore not keyed Mr. Rushmore's paragraphs with footnotes.—Editor.

The present problems in power transmission work are those resulting from an increase in the size of generator and transformer units, the increased capacities of power stations, the tendency toward complexity in transmission and distributing systems resulting from their growth, and from a combination of existing developments.

The rapid increase in transmission voltages is the dominating factor in forcing a new development in insulation and bushings, as well as in the transmission line itself; while a growing tendency toward more severe requirements with regard to continuity of service is at present focusing attention on the development of relays and automatic devices for isolating disturbances on high tension lines or apparatus connected thereto. New developments are constantly being made; and one of the most difficult problems at the present time is in meeting the conditions imposed by systems already in existence into which the new developments will fit. It will be the purpose of this article to review, in a broad way, recent progress in the development of apparatus for high-voltage power systems, which will enable the reader to form some idea of the problems which are still outstanding, and the directions in which further progress is likely to be made.

Hydro-Electric Stations

The recent development in the commercial field, whereby small electric systems have been grouped into large consolidations, has had a marked effect on both the financing and the engineering development of water powers. The condition under which such systems will operate can now be much more carefully pre-determined, and the hydraulic as well as the electrical apparatus best adapted to meet the requirements of service.

But few water powers in the country outside of those at Niagara Falls are suitable for development without auxiliary steam stations. Under present conditions it is often possible to know just what will be required of a hydro-electric plant, and to make plans to ensure that the maximum output of the station can be realized. The possibility of forecasting future conditions at the time of development more accurately results in installing a larger generating capacity in proportion to the minimum stream flow than was heretofore desirable, and in thus being able to utilize more of the stream flow under ordinary conditions. Waterwheels are now being built for both higher actual and higher specific speed, with very greatly increased efficiencies, and waterwheel governors now represent a highly developed mechanism giving almost entire satisfaction.

Perhaps one of the most serious problems from the hydraulic side lies in dealing with the variable head caused by the backing up of water in times of flood.

Generators

While naturally both 60 and 25-cycle generators are being installed as conditions determine, the increase in the size of the individual units has made it desirable to wind a large number of these for 11,000 and 13,000 volts. Generator temperatures are now being measured with exploring coils, with an indicating instrument on the switchboard, which serves as an excellent guide for the operator.

The slight corona effect noticeable on some coils at high altitudes is being taken care of by proper design of the insulation. Very satisfactory results are being obtained by grading the insulation of high-voltage generators in the same way as is done on cables, with respect to the specific inductive capacity.

Probably the greatest refinement in modern generator practice is in regard to ventilation, whereby the air in proper quantities is directed in its path of movement. Elaborate precautions are being taken in many cases to bring this air to the machine from the coolest part of the wheel-pit, and in some cases through proper filterers. Considerations of safety for apparatus have led to the development of generators with comparatively high inherent reactance, and with saturation curves more straight than formerly.

Bird's-eye View of the Niagara River at Niagara Falls, Showing the Water-Power Developments on the Canadian side

Most vertical machines are now equipped with a brake, the location and design of which have not yet been well standardized. By mounting the supporting bearing at the top of the shaft these units have been made comparatively short, and certain advantages have been gained in power house construction. Not a few of the later developments also have the exciter mounted on the top of the shaft above the bearing, these exciters in some cases being direct-connected to the generator fields without the interposition of generator field rheostats.

At the present moment a rapid development is taking place in vertical bearings, and the experience of the next few years will be valuable in determining the advantages of the different designs.

Transformers

As transformers have increased in size, factors which have been hitherto negligible have now become of much importance, and thorough and painstaking investigations have been made into the mechanical and electric stresses to which these windings are subjected.

The modern large-capacity high-voltage transformer is a triumph of engineering skill. It has never received the tribute which it deserves, doubtless because of minor defects which have drawn attention from the really wonderful development which has been attained in this apparatus. Something over ninety-five per cent of the large high-voltage transformers are never heard from, and perform their service continuously and without interruption. This is a truly wonderful record and redounds to the credit of the engineers who are responsible for the work.

The transformer bushing has become a feature of major importance, and much time and money have been expended in its development. The limitations of porcelain manufacture have here been a serious handicap.

The internal reactances of transformers have been increased with their increased size. Great improvements have been made in the methods of insulating transformers, as well as in their mechanical construction, and it is really surprising that the present satisfactory results with this class of apparatus are being obtained.

There is a very strong tendency to place transformers, switches and lightning arresters out of doors, and it is difficult to say just how far this will go. Results under these conditions, up to the present, have been quite satisfactory. For use in oil-insulated outdoor apparatus an oil has appeared on the market which does not freeze except at extreme low temperatures.

A very careful investigation into the electrical phenomena which occur in transformer windings under different conditions, has brought to light many points not hitherto known, and has allowed the designing engineers to take the proper precautions to prevent break-downs from these causes.

Switching

Investigations which have been made in a number of places indicate the danger to transformer windings of switching under load on the high-voltage side. There has not as yet been opportunity to investigate this problem as thoroughly as is desirable; but in the meantime it is recommended that all high-tension switching be reduced to a minimum, especially where large amounts of power and high voltages are involved. Wherever possible, high-voltage transformers should be made units with the line and the switching done on the low-tension side. This, however, is not always practicable; and it is probable that future conditions of operation may necessitate combinations of high-tension switches and relays for the isolation of sections of high-tension line in trouble.

Protection

The particular problems peculiar to each development are such that it has been found impossible to standardize systems of connection, and the proper arrangement for each installation is always the subject of much study with regard to the particular conditions affecting it.

One of the features of modern installations is the use of busbar reactances, and an adjustment of relays to the thermal storage capacities of the transformers. A careful balancing of the various advantages and disadvantages of the different systems, and a consideration of the present state of development of protective apparatus, have resulted in general consensus of opinion regarding the desirability of the delta connection for the high-tension side of transformers on transmission systems.

The development of switches and lightning arresters has kept pace with the use of increased voltages and outputs, and both classes of apparatus are giving very general satisfaction. The complex nature of electrical disturbances will probably prevent them from being exactly understood for some time to come, and our experimental investigations regarding their nature have been supplemented by theoretical considerations in the development of devices to protect against them.

Numerous accessory devices in the way of opening the generator fields, opening and closing the main switches, arcing-ground suppressors of various types, and line reactances have been used in different installations. The object, of course, is to prevent interruptions to service or to limit them to the shortest possible duration.

Line Construction

It has been suggested that a wire having a high surface-resistance be employed in the transmission line near the station, and also the use of line wires of a diameter which would always be below the corona break-down point. Many of these suggestions are interesting from a theoretical point of view and possess desirable, though unknown, values. Ground wires are being very generally used, and thousands of dollars are being expended upon them. It ought to be possible to determine, with a considerable degree of precision, just what their protective value is, but up to date this has not been done. Lightning rods on the steel towers have been suggested, in order to remove as far from the insulators as possible the point of break-down at times of discharge.

With the suspension insulators, and especially with the higher voltages where the insulator string becomes quite long, serious problems have arisen in connection with the mechanical features of the line, especially in regions where high winds prevail and where snow and sleet are a disturbing factor. Various shields and protecting rings have been suggested for use with these suspension insulators. One of the greatest causes of trouble in such lines has been in connection with the clamp holding the line wires. Owing to the flexibility of movement the position which this clamp assumes relative to the line and insulators undergoes considerable variation, and in times of high wind it has been the source of many breaks in the line conductor. In some cases it has been found necessary to anchor the wire to a cross-arm directly beneath it by a second string of insulators.

In a country where snow and sleet are to be expected, the practice of suspending the line wires directly beneath each other is to be avoided. Some unfortunate experiences have occurred where sleet has fallen from an upper to a central span, causing it to sag excessively—sometimes to such an extent as to bring the wires into contact with one another.

Wherever single-circuit towers are used, the placing of the three conductors in a horizontal plane appears to offer certain advantages; but it may be taken as an axiom that under present conditions, continuous service cannot be supplied over a single-circuit power line. Experience has shown the desirability of elevating the ground wires above the towers at a greater height than is to be obtained by placing them on the top of the arm supporting the insulators.

Voltages for Transmission and Distribution

The fact that high-tension transmission work has largely developed into high-voltage distributing systems, and the condition resulting from syndicating large numbers of heretofore isolated lighting and power systems, have resulted in the necessity of standardizing certain voltages. Owing to certain advantages in the apparatus and transmission line, 33,000 volts has in many cases been settled on as the best for distribution to the actual consumers. The transmission voltage can be 66,000 volts, and in some cases plans are being made to change this later to 132,000.

One of the present problems is to take off small amounts of power from high-voltage lines, and the development of inexpensive apparatus for doing this in a satisfactory manner is now the subject of very careful study. The tying of a new system into an old development brings with it many difficulties, especially where a considerable part of the power is used at a frequency different from that at which it is transmitted.

While, fortunately for the engineer, there are many present problems in power transmission work, it is gratifying to say they are being successfully solved, and that a standard of reliability of service is today being attained which a few years ago would have been thought impossible. Through the grouping of small developments into large systems, the ability to finance them has been made much easier; and the class of engineering which they have been able to obtain has been consequently very much improved. With the rapid increase in the grouping of lighting and railway properties, with the tremendous future extension of electrical power to mining and industrial work, and with the large field of railway electrification still before us, it is safe to say that the future of electric power transmission will be one of great magnitude and accompanied by noteworthy engineering developments.

COMPARATIVE DATA ON SOME HYDRO-ELECTRIC TRANSMISSION SYSTEMS

Name and Location of System	Transmission Voltage	Length of Transmission Lines in Miles	Present Capacity of Installation in Kw.	Frequency	Line Supports	Length of Standard Span in Feet	Type of Insulators	Number, Size and Material of Conductors	Min. Spacing of Conductors in Feet	Number and Size of Ground Wires
Eastern Michigan Power Co., Michigan	110,000△	125	10,000	60	Steel towers Single circuit	500	Suspension	Three No. 0 copper	12	None
Mississippi River Power Co., Keokuk, Iowa	110,000Y	140	108,000	25	Steel towers Double circuit	750	Suspension	Six 300,000 C.M. copper	10	One 1/2 in. steel
Georgia Power Co., Tallulah Falls ...	110,000Y	160	30,000	60	Steel towers Double circuit	500	Suspension	Six No. 00 copper	9	Two No. 0000 steel
Ontario Power Co., (Hydro-Electric Commission), Canada	110,000Y	280	78,800	25	Steel towers Double circuit	550	Suspension	Six No. 0000 and No. 000 aluminum	8	Two and three 5/16 in. steel
Grand Rapids-Muskegon Power Co., Michigan	110,000△	50	10,000	30	Steel towers Single and Double circuit	500	Suspension	Three No. 2 copper	8	None
Sierra-San Francisco Power Co., California	104,000Y	138	34,000	60	Steel towers Single circuit	800	Suspension	Three No. 00 copper	9	None
Yadkin River Power Co., North Carolina	103,900Y	150	27,000	60	Steel towers Double circuit	600	Suspension	Six No. 0 copper	9	One 3/8 in. steel
Great Falls Water Power and Townsite Co., Montana	102,000△	130	21,000	60	Steel towers Two single Circuits	600	Suspension	Six No. 0 copper	10	Four 3/8 in steel
Southern Power Co., North and South Carolina	100,000Y 50,000△	750 500	100,000	60	Steel towers Single and Double circuit Wood poles	600 150	Suspension and Pin type	Various sizes	8 6	One 3/8 in. steel
Great Western Power Co., California......	100,000△	154	40,000	60	Steel towers Double circuit	750	Suspension	Six No. 000 copper	10	One 3/8 in. steel
Central Colorado Power Co., Colorado.	100,000△	183	16,000	60	Steel towers Single circuit	750	Suspension	Three No. 0 copper	11	Two 3/8 in. steel

Shawinigan Water and Power Co., Canada	100,000Y	87	28,000	60	Steel towers Double circuit	520	Suspension	Six 250,000 C.M. aluminum	8	Two 3/8 in. steel
Appalachian Power Co., Virginia	88,000△	180	23,000	60	Wood pole Single circuit	125	Suspension	Three No. 0 aluminum	8	One 3/8 in. steel
Pennsylvania Water and Power Co., Holtwood, Pa.	70,000Y	40	54,500	25	Steel towers Double circuit	500	Suspension	Six 300,000 C.M. aluminum	7	One 3/8 in. steel
San Joaquin Light and Power Co., Fresno, Cal.	69,500Y	75	17,500	60	Wood pole Single circuit	350	Pin type	Three No. 000 aluminum Three No. 0 copper	7	None
Connecticut River Power Co., Vernon, Vt.	66,000Y	66	20,000	60	Steel towers Double circuit	410	Pin type	Six No. 2 copper		One No. 5 copper clad steel
Central Georgia Power Co., Lloyd Shoals, Ga.	66,000Y	65	12,000	60	Steel towers Double circuit	500	Pin type	Six No. 00 copper Six No. 0 Eqv. aluminum	7½	One copper clad steel
Pacific Gas and Electric Co., California	60,000△	1180	69,800	60	Wood pole Single circuit	132	Pin type	Various sizes	6	None
East Creek Electric Light and Power Co., Ingham Mills N. Y.	60,000△	28	5,600	25	Steel towers Double circuit	600	Pin type	Six No. 2 copper	6	One 3/8 in. steel
Washington Water Power Co., Washington	60,000Y	540	48,600	60	Steel towers Double circuit Wood poles Single circuit	650 300	Suspension Pin type	Various sizes	7	One 3/8 in. steel
Carolina Light and Power Co., North Carolina	60,000△	125	6,500	60	Steel towers Single circuit Wood poles Single circuit		Suspension Pin type	Various sizes	6	One 3/8 in. steel
Great Northern Power Co., Minnesota	60,000△	14	22,500	25	Steel towers Double circuit	500	Pin type	Six No. 00 copper	6	One No. 00 steel
Puget Sound Power Co., Washington	55,000△	150	55,250	60	Steel towers Double circuit Wood poles Single circuit	400 125	Pin type	Various sizes	6	None
U. S. Reclamation Service, Salt River, Arizona	45,000Y	65	6,500	25	Steel towers Double circuit	400	Pin type	Six 83,000 C.M. copper	4	None

This table, from an article by Mr. Eric A. Lof, of the General Electric Company, in the April, 1913, issue of the Engineering Magazine is reprinted here with kind acknowledgments to the publishers of that journal.

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BEFORE THE DEVELOPMENT

From a Photograph taken at the Shoshone Dam Site of the Glenwood Development of the Central Colorado Power Company before Construction of the Dam. The latter, which is 252 feet in length and 20 feet high above the bed of the stream, occupies a position in the middle foreground of this picture. The Central Colorado Company was one of the pioneer high-voltage hydro-electric undertakings; and, as long ago as 1908, commenced to operate a system with a transmission pressure of 100,000 volts

THE OPERATION OF HIGH-VOLTAGE POWER SYSTEMS

By H. H. Dewey

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Early in his article the author cites the remarkable case of the tying-in of the Southern Power Company with the Yadkin Power Company, the Georgia Power Company and the Tennessee Power Company into a network which will embrace nearly 800 miles of 100,000-volt lines, apart altogether from lines at lower voltages. In schemes such as this, voltage regulation is a much more difficult question than it ever was with the lower voltages, owing to the condensive reactance of the line. The charging current of a 120,000-volt line may be as much as 40 per cent of the economical capacity, as determined by its commercial regulation; and although the problem of utilizing some of this condenser effect has been given much study, no satisfactory solution has yet been found. The best practice now in obtaining economical regulation is to use a synchronous condenser at the receiving station controlled by a voltage regulator to maintain a fixed voltage on the low-tension busbars. The author cites a case to illustrate the effect on the regulation of a sudden no-load condition, and specifies the size of condenser. He gives an exposition of modern methods of operation by making a detailed analysis of the system of the Utah Power Company now under construction, in which a 22,000-kw. station is to be tied in with a 20,000-kw. station 25 miles away, feeding a terminal station 145 miles away. —Editor.

As large high-voltage power systems have developed and extended, many problems of operation have arisen that are to some extent not encountered in the systems of lower voltage. The transmission lines are becoming longer, the voltage at the generating end is going higher, more power is fed into a single network, and the question of properly handling such systems to the greatest advantage is one requiring much thought and study on the part of operators.

Many of the large systems started out with one generating station at a distance, transmitting all its power over one or two lines into a common receiving station at the end of the line. In most cases such power systems could depend upon auxiliary steam stations to take care of the most important part of the load in case of shut down. Voltage regulation at the substation could be maintained by occasional hand regulation at the power station without thought of the regulation at other parts of the line.

Some of these transmission systems have changed very considerably in the past few years. New generating stations have been developed, branch lines have been built, and the character of the load as well as its location has changed. There has gradually grown up a higher standard of service demanded; and greater foresight must be shown on the part of operating engineers to insure service free from interruptions, and of a character that will be acceptable to the large and important customers. Power companies are penalized for the shortest interruptions in service, and the voltage must be constant within a few per cent. Generating stations placed at different points on the system, with synchronous apparatus at various substations, must be operated with a view to maintaining an even voltage throughout the system rather than at one particular point. Some generating stations may be better equipped to carry the greater part of the wattless current than others, while in some cases better results will be obtained by over-exciting the synchronous apparatus at a substation to better the regulation at these points. Many of these problems are met with in the low-tension systems, but usually in a lesser degree.

As individual systems extend their lines they approach other high-tension networks, and find it of advantage to tie together for exchange of power. The difference in the load factor at the various substations allows both systems to operate more efficiently; and the difference in climatic conditions at the headwaters of the various streams that supply their power stations often insures a more continuous source of power. The increased generating capacity makes it possible to throw on or off large blocks of load with little effect either on speed or voltage regulation.

The economical operation of such systems as the Southern Power Company, a large network in itself, which is tied in with the Yadkin River Power Company at Method and is contemplating tying in with the Georgia Power Company at Easley, and the latter with the Tennessee Power Company at Rome, is a problem of considerable importance. The Southern Power Company is operating approximately 350 miles of 100,000-volt lines as well as an extensive network of 44,000-volt and 11,000-volt lines, and the Yadkin River Power Company has approximately 190 miles of 100,000-volt lines. The

Georgia Power Company will have approximately 200 miles of 100,000-volt lines and the Tennessee Power Company nearly 200 miles of 120,000-volt line, as well as approximately 100 miles of 66,000-volt lines, making a total of nearly 800 miles of 100,000-volt lines in the four systems and hundreds of miles of lower voltage lines all tied in in one vast system. The total distance by transmission line from Blewetts Falls to Nashville will be over 700 miles.

Fortunately there is little difficulty in the parallel operation of synchronous machines spaced miles apart on a system of this kind. The prime movers are of a type which have uniform rotation, and the ratio of resistance to reactance of the connecting lines is such as to have little effect on the natural synchronizing force of the alternators and synchronous motors distributed about the system. The synchronizing force of generators or motors is a maximum when overexcited and comparatively small when underexcited, a fact that may be of importance in some cases where regulation may demand lagging current on motors or leading current from generators to hold down the voltage on conditions of light load. However, there is usually little to fear from this source unless a sudden heavy load should come on a greatly underexcited machine, when it would probably drop out of step and trip its circuit-breaker.

The troubles that may be encountered on large high-tension networks are similar to those of smaller capacity and lower voltage, with the added danger from high frequency surges due to lightning, arcing grounds, high-tension switching and so forth. These high frequency disturbances are often of too low voltage to cause the lightning arresters to discharge, and pass on into the transformers. Should their frequency correspond with the natural frequency of the transformer or any section of the winding, internal resonance is set up and extremely high and dangerous voltages may be built up across sections of the transformer. Fortunately these disturbances represent only a small amount of energy and do not travel far; so that there is probably no more likelihood of trouble from this source in a large system than in a small one at the same voltage.

In protecting and operating a large power system the primary object in view should be to secure as nearly absolute continuity of service as possible at a reasonable cost both in equipment and operation. Long distance transmission lines are nearly always run in pairs, and one line should be able to carry the greater part of the load in case of trouble on the other line with reasonable voltage regulation. The system should be protected by oil-switches and relays whose function should be to cut out the line or feeder in trouble with minimum effect on the rest of the system. To accomplish this result most successfully the normal operation of the system should be in multiple so far as possible to avoid cutting off generators or load in case of line trouble. With trouble on a feeder circuit it is of course necessary to cut off this feeder.

There is a tendency on the part of some large customers buying power to specify that their lines shall be entirely independent of the rest of the system and that their load be supplied from separate generators, the expectation being that these generators will not be affected by the load fluctuations on the rest of the system and their service will be better in consequence. This is a fallacy in many cases, as changes in their own load will have a much greater effect on their line regulation and on the generator speed and voltage regulation than would these changes on several lines in parallel, or several generators in parallel. In a large system with many substations and several generating stations the load changes are superimposed to a large extent, and in any case are small on the individual generators. What would be fifty per cent load thrown on or off one generator if it were feeding a separate customer would perhaps be only five or ten per cent load on the entire system, and neither speed nor voltage would be affected materially.

The method of operation with everything in multiple reduces the work of waterwheel governors, and allows more sensitive adjustment and less deviation from normal frequency, than would be the case if the system were divided up into sections with individual generators supplying a given load.

There are many methods of operating large power stations with respect to the work the governors are required to do. In some cases one or more generators in a large station or one or more stations in a large system will do the governing, taking the fluctuations in load; while the other generators or stations work with constant gate opening and constant load. This is often an advantageous method of operating where perhaps one plant may have considerable pondage and be fitted to take the fluctuations, while another may have little or none and should be required to take the full flow of the stream. It is easier in such cases to change the frequency of the system if required, as it is only necessary to change the governor setting on a few machines for such a change.

In many cases it is preferable to have the governors on all or nearly all machines working, for the reasons pointed out above. A change in load then requires each governor to work through only a small range, and its action is necessarily quicker and surer than when a few have to work through a wide range. The governors on the individual machines can always be adjusted by hand to take any share of the load desired, and will then take their proportionate share of the fluctuations; or they can be so adjusted as to take more or less than their share of the fluctuations by changing their individual characteristics. The question of the best governor characteristics with a large number of stations operating in parallel, for automatically taking care of speed and load regulation, is one that requires a great deal of study and experiment. Hand adjustment for making desirable shifts in load is usually made at the telephoned orders of the load despatcher or chief operator. If the governors can be adjusted to work properly under average conditions a great deal of time can be saved; and hand adjustment need only be resorted to when changing conditions at different parts of the system require it. Much can be done to better the general operating conditions by making the governors do the work that they are able to do at all times.

The question of voltage regulation of high-tension transmission systems is more difficult to take care of than in the systems of lower voltage. At 100,000 volts and above the condensive reactance of the line becomes quite appreciable; and we not only get a considerable drop in voltage under load but a considerable rise at the substation end under no load, making the regulation on a long line the limiting feature in many cases, rather than energy loss. The charging current of a 120,000- or 130,000-volt line may be as much as 35 or 40 per cent of the economical capacity of the line as determined by its commercial regulation. Raising the voltage does not materially help the regulation, since, although it may increase the drop in voltage under load, it increases the charging current and the voltage rise at the end of the line under no load. The charging current of long high-voltage lines is often of such an amount as to require the capacity of one or more generators to build the line up to voltage. This leading kv-a. would be a benefit to the system if it were under control, as it counteracts to some extent the lagging kv-a. of the load, requiring the generators to supply less of it and reducing the losses and heating in generators and transformers accordingly.

The problem of making use of this leading kv-a. has been given much thought by engineers, but no entirely satisfactory solution has yet been arrived at. If the various generating stations could be placed at strategic points about the network and the lagging load placed accordingly, the effect of the charging current of the line would be almost wholly beneficial. In most of the large-capacity power developments, however, the bulk of the energy is generated at a distance from the load; and, since the wattless lagging current of the load varies, and the wattless leading current taken to charge the line is practically fixed, some sort of regulation becomes necessary.

To illustrate the importance of line regulation of a long-distance high-voltage transmission line we may consider an instance. A 130-mile 4/0 copper line delivering at the substation 21,000 kw. at 120,000 volts, 60 cycles would require a voltage at the generating end of the line of 146,000 volts full load. If the load went off and the generator voltage were maintained, the voltage at the substation would rise from 120,000 to 155,000, or a rise from full load to no load of 29 per cent. The energy loss in this line under these conditions would be only about 5 per cent. There would obviously be no advantage in going to larger copper with this small loss, and even if we did the regulation would not be materially improved. This regulation is of course practically out of the question on any line of sufficient importance to warrant construction; and the only solution in sight is to use a synchronous condenser at the receiving station controlled by a voltage regulator to maintain a fixed voltage on the low tension busbars.*

The use of a very large idle machine or machines at the end of a transmission line seems like spending money from which there will be no return; and, so far as any actual work that the condenser performs for which there is a direct return, that is probably true. The use of this machine does not allow any saving in copper in such a line, as the saving in line loss will be nearly counterbalanced by the losses in the condenser. A slight saving in the kv-a. capacity of generators and transformers can be made, as they will be

* See p. 428, "Automatic Regulators for the Control of Synchronous Condensers in Power Systems," by H. A. Laycock.

working at a higher power-factor; but these economies are of minor importance. The real object in the use of such machines is a very obvious one—i.e., one of practical necessity in order to supply voltage that is within commercial limits.

The size of condenser necessary to maintain an absolutely constant voltage from no load to full load on a long line carrying a heavy load is a very considerable percentage of the actual capacity of the line. The line cited above would require approximately a 10,000 kv-a. condenser to maintain a voltage of 120,000 at the receiving end with 130,000 volts at the generating end under all conditions of load. This assumes that the synchronous condenser and generator shall be controlled by voltage regulators set to maintain constant voltage. Under this condition the condenser would work from full leading kv-a. at full load on the line to full lagging kv-a. at no load. The power-factor of the generators under this condition would be close to unity, and the drop in voltage over the line not much more than the IR drop. A synchronous condenser of about 6500 kv-a. capacity would, however, maintain this voltage relation from about 3000 kw. load to 17,000 kw. load, causing a drop in voltage at full load of about 4 per cent and a rise in voltage at no load of about this amount if the generator voltage were maintained. If the receiving voltage were maintained the generator voltage would have to be varied by the same amount. This range in voltage would be entirely commercial, and to put in the larger condenser under such conditions would hardly be warranted. The power-factor at the generator end under this condition would be about 95 per cent and the excess heating small. The large condenser would bring the power-factor at the receiving end up to about 0.96, and the smaller condenser only to about 0.90. As in the case of a synchronous condenser for power-factor correction only, it is seldom economical to use a machine large enough to bring the power-factor very much above 0.90 on account of the large capacity required to accomplish this result.

Where transmission lines feed into a city network and a steam turbine generator station is available, these machines can economically be used to serve the purpose of the synchronous condenser by supplying just enough steam to supply their losses. When operated in this way they make a valuable standby to quickly take the important load in case of trouble on the transmission line.

In order to bring out some of the advantageous methods of operation of a high-voltage system reference may be made to Fig. 1, which shows a one-line diagram of the principal connections of the Utah Power & Light Company's system now under construction. The initial development will consist of a 22,000-kw. station having two 11,000-kw. three-phase, 60-cycle generators at Grace, Idaho, on the Bear river; and a 20,000-kw. station having two 10,000-kw. generators at Oneida, Idaho, approximately twenty-five miles below Grace on the same river. All the power generated at these two stations will be transmitted to a terminal receiving station near Salt Lake, Utah, a distance of approximately 140 miles from Grace. Ultimately it is planned to install two more machines at Grace and two more at Oneida, with several smaller stations in the vicinity, making a final capacity of about 88,000 kw. if conditions warrant the full development. When the future generators are put in there will probably be built two more transmission lines, each line having an economical capacity of about 22,000 kw.

The connections of the complete system are left out for the sake of clearness; and the method of operation likely to give as nearly continuous service as possible with the initial development will be discussed.

The transmission voltage selected as being most advantageous from a standpoint of present and future developments is 120,000 volts at the terminal substation. The voltage regulation without synchronous condensers on this line, consisting of 250,000 cm. conductor, would be about 30 per cent with 21,000 kw. over one line. For voltage regulation there will be installed two 7500-kv-a. synchronous condensers with automatic voltage regulators at the terminal station. With these regulators and condensers it is proposed to maintain a constant voltage of 130,000 at the generating station and 120,000 volts at the terminal station. To accomplish exact regulation throughout this range would require a condenser of about 11,000 kv-a. capacity; but the 7500-kv-a. units will maintain this voltage from 2500 kw. load to about 19,000 kw., beyond which extremes it will be necessary to change the voltage slightly at the generator end to maintain constant substation voltage.

In laying out this system the engineers had in mind a plan that should give maximum reliability, that should be as free as possible from the troubles encountered in high-voltage systems, and that should be flexible and could grow along lines in harmony with the original development. As far as possible the future requirements were predicted, and a method of taking care of them worked out that would add on to the initial scheme and allow a similar method of operation.

The plan in general was to avoid all automatic high-tension switching and to keep the high-voltage lines electrically apart from each other, in order to avoid the high-frequency disturbances caused by high-tension switching and to avoid communication between lines of such disturbances started from any other cause, such as lightning, arcing grounds, etc.

In the operation of the initial development the generators at Grace and Oneida will normally operate respectively in parallel on their own bus. One transformer bank in each station will be connected to one line, with the high-tension sides separated by means of sectionalizing switch in the high-tension bus. The capacity of each line will be 21,000 kw. At the terminal station each line will feed directly into a transformer bank of this capacity, and the two banks will be paralleled on the step-down side. The transformer banks at the terminal step down from 120,000 volts to 44,000 volts, from which feeders go directly into the existing network of the Telluride Power Company. The double low-tension bus arrangement shown will normally be paralleled, or one bus used as a spare.

The oil-switches on the low-tension side of the transformers at the generating stations will be automatic, with inverse time-limit relays; and the oil-switches on the 44,000-volt side of the transformers at the terminal station will be automatic, with reverse energy relays. All high-tension switches will be non-autor-atic.

In case of a short-circuit occurring on one of the high-tension lines, one bank of transformers at Grace and one at Oneida would be cut off on overload; and the transformer bank at the terminal station would be cut off on reverse energy. All generators would still be in service, and all the load would be maintained; so that, with the exception of a momentary dip

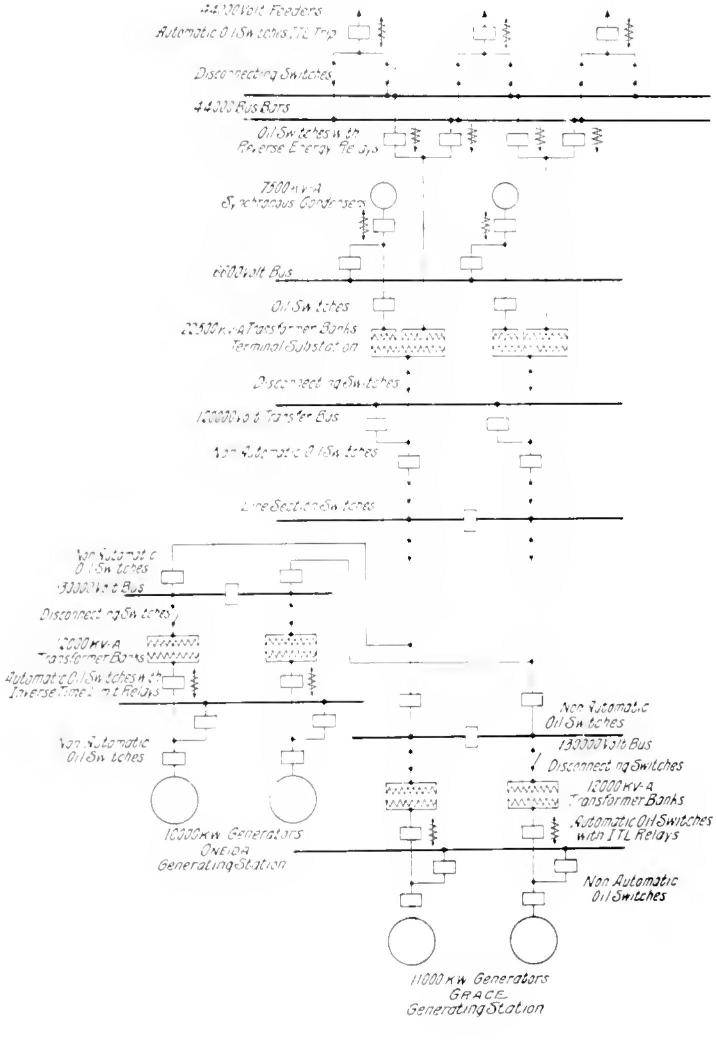

Fig. 1. Proposed Scheme of Connections, Initial Development. Utah Light & Power Company

in voltage, there should be no disturbance that would affect the power supply. If the stations were fully loaded at the time a short occurred, the remaining transformers would have to carry 100 per cent overload until the high-tension line switches at the generating stations could be tripped, the bus section switch closed, the line switch opened at the terminal station, and the bus transfer switch closed, when the only part of the system to be overloaded would be the line. Transformers will easily carry double load for five or ten minutes under these conditions without injury from overheating; and this should be ample for doing the necessary switching for paralleling the banks on the high-tension side.

If a short-circuit occurs on a line when the full generating capacity is not required to carry the load, one generator at either Grace or Oneida will be cut out, together with its transformer bank, and the line tested out to locate the fault. Should the short be permanent the line will be sectionalized by means of the switches placed approximately midway of the line for this purpose, and service continued with three-fourths of the line in commission until repairs can be made.

The 45,000-volt switches on the individual feeders will all be automatic, with inverse time-limit trip; so that a short on any feeder should clear itself without putting out the rest of the system.

In order to provide voltage for the synchronous condensers at the terminal station, the transformers will be built with a third winding for 6600 volts. The transformers will normally be paralleled on this winding, and the synchronous condensers operated in parallel from the common bus supplied from this winding.

In case of a short on the high-tension line the 6600-volt transformer switch will be tripped from the reverse energy relays on the 45,000-volt switch, leaving both synchronous condensers working on the other transformer bank trying to hold voltage under the overload conditions. This method of operation is a distinct advantage, as the maximum condenser capacity will be available when most needed.

When the future generators are installed at Grace two more transformer banks will be put in, and two banks at this station will be operated as part of each line. Oneida will be developed in the same way, two more duplicate lines built, and two duplicate transformer banks installed at the terminal unless load develops in some other direction, in which case only one line will come to the terminal. Whether two, three or four lines come into the terminal station, the transformer banks will be considered part of the line; and will be normally switched automatically from the low-tension side in case of trouble with the line, and the other lines overloaded enough to carry the share of the disabled line. Additional synchronous condensers will be installed at the time the other lines and transformer banks are put in.

The regulation of the complete system will be accomplished automatically by means of voltage regulators in each of the generating stations and on the synchronous condensers. Constant voltage will be held on the 44,000-volt busbars at the terminal, and constant voltage throughout practically the full range of load at both generating stations. The power-factor at the generating stations will be high at all times when the synchronous condensers are operating; but, should the generating stations for any reason be required to carry any great amount of the wattless current of the system, this wattless current will be supplied by Oneida in preference to Grace. The distribution will be made by adjusting the regulating rheostats on the individual regulators. By slightly raising the busbar voltage at Oneida or lowering it at Grace, any desired division of wattless current may be obtained.

It is planned to make Oneida take the load fluctuations as well as carry the greater part of the wattless current, as there are some water-storage facilities at this point. Grace will have very little pondage, and will take the full flow of the river operating at a practically constant load. The flow of the river will be regulated from the storage reservoir at Bear Lake.

In order to operate the two stations in this way with all waterwheel governors working, it will be necessary to change their characteristics somewhat so as to give the machines at Grace less permanent drop under load than those at Oneida. It will be possible to make this adjustment such that Grace will be operating at practically full load, while Oneida has very little load. A heavy load coming on suddenly would open up the gates at both stations; but the greater part of the load would come on Oneida, as Grace would be operating at nearly full gate. If Grace is operating at full gate all the fluctuations will come on Oneida, so long as the minimum load corresponds to that required for full gate opening at Grace. The speed regulation under these conditions would not be as good as though both stations were operating on governors with similar characteristics; but the regulation would be better than if Oneida were carrying the same load and had the same fluctuations when running with a separate load of its own and not tied in with the system, since the flywheel effect of the Grace machines lessens the work for the Oneida governors.

It will probably not be possible to get the exact division of load desired throughout the full range with one adjustment of governors, but it can be closely approximated; and, with occasional hand adjustment, better speed regulation will be obtained than by operating Grace without governors, and depending on a fixed gate opening to determine the load.

The problem of economically operating large power systems can be settled only by experience; but there are certain fundamental principles involved that should be borne in mind in endeavoring to determine on a scheme of operation.

CIRCUIT CONNECTIONS IN HIGH-VOLTAGE SYSTEMS

By R. E. Argersinger

Power and Mining Engineering Department, General Electric Company

As pointed out by Dr. Steinmetz in his article in our June, 1912, issue, the coils of high-voltage transformers possess considerable electrostatic capacity and are therefore subject to dangerous internal surges, and since switching between transformers and line is conducive to high potential disturbances, this practice is to be discouraged. The present article recommends that all generators be paralleled on a common bus, properly sectionalized by disconnecting switches, and, in the larger stations, by the insertion of current-limiting reactances. By paralleling the transformer banks on this bus and considering each bank as a portion of the transmission line, many disadvantages are obviated: the dangers of high-voltage switching under load are done away with, the number of oil switches can be greatly reduced, the most economical transformers become applicable, while trouble on one of two or more parallel lines is confined to the circuit in which it originates. At the substation, it is also recommended that all lines be paralleled on the low tension bus. This arrangement involves the necessity of connecting all feeders to the common bus; but this is in keeping with the best practice.—Editor.

There are certain general principles which should be followed in laying out the connections of a transmission system in order to decrease the service interruptions and to reduce the disastrous effects of trouble in the high-voltage circuits.

Many articles have been written, pointing out the danger to station apparatus from switching, grounds, lightning discharges, etc., on the lines to which such apparatus is connected, particularly where its inductive capacity is appreciable. Improved methods of insulation and protection against lightning are serving to minimize the troubles resulting directly from abnormal line voltages; but so long as switching operations are carried on in the high-voltage circuits, high-frequency surges will be set up which are of very real danger to apparatus. More or less switching must be done, however, to secure efficient operation; and it is the purpose of this article to briefly point out some general principles which should be followed in laying out the connections of a transmission system, in order to secure the maximum reliability of service and reduce the disastrous effects of troubles in the high tension circuits.

In the first place, the source of power must be continuous and uniform. All generators should be operated in parallel on a common bus. This permits operating machines at their maximum efficiency, and renders the service independent of trouble in any particular machine. The bus should be carefully insulated and enclosed to avoid the origination of trouble on itself; and some form of discharger should be connected to it, to prevent the possibility of an abnormal electrostatic voltage to ground. Protection may also be secured by grounding the generator neutrals. The connection from generator to bus should be through non-automatic switches, so that short-circuits on the system will not disconnect the machines; but alarm relays should be provided which will indicate to the operator an abnormal flow of current due to short-circuits or grounds in the generator windings.

The generators themselves should be designed with high inherent reactance in order to limit the flow of current on short-circuit and the resulting strains on the system. High generator reactance in general will also mean that machines will operate better in parallel; and, if the inherent voltage regulation is not sufficiently close, automatic regulators should be provided to control the bus voltage. There is little advantage in attempting to over-compound the station voltage in general transmission work, and better results can be obtained by the use of synchronous condensers connected to substation busses. By this means the voltage can be kept constant at both main and substations for all conditions of load, and the line efficiency increased.

Connections from generators to lines should be so arranged that a line, with a generator or generators of sufficient capacity to supply the line charging current, can be isolated from the rest of the system for testing purposes. This may be accomplished by means of disconnecting switches in the bus; and can be nicely arranged by using a "ring" bus, which allows the segregation of any bus section with its connected line and generators, to be isolated from the system without disturbing the parallel operation of the remaining units (see Fig. 1). Except possibly in very large stations, the use of a double bus is usually unwarranted, the single bus or ring bus giving, as a rule, sufficient flexibility.

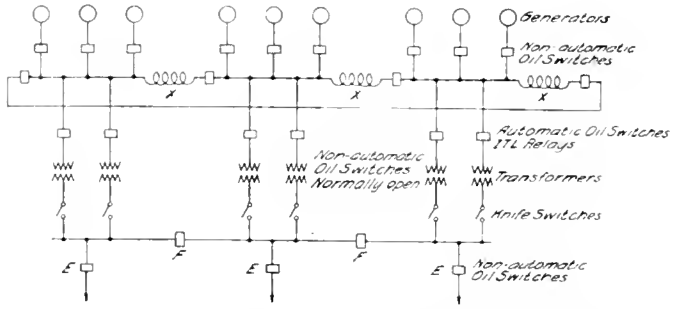

Fig. 1. An arrangement for paralleling high-tension transformers on the low tension side. The ring bus is sectionalized by bus-section switches, which permit of isolating any section without disturbing the operation of the remaining units. Current limiting reactances are also inserted to prevent excessive rushes of current at times of short circuit

A large number of machines paralleled on a common bus means tremendous current rushes during short-circuits; and current-limiting reactances should, therefore, be inserted in the bus, as shown at X Fig. 1, where under normal conditions they will not affect the voltage regulation of the station. * Ordinarily it will be found convenient to place these so as to divide the bus in 30,000 to 50,000 kw. sections. Bus section switches adjacent to the reactances will usually be of advantage. These switches may be automatic, with a time element somewhat longer than the low-tension transformer switches, so that, in case of failure of the latter switch to open the circuit, the adjacent section switches will operate and segregate the troubled section. It may be of advantage to locate the current transformers operating the trip coils of these switches in the circuit supplying the power transformers, rather than to place them in the bus itself.

Considering now the high-tension lines, we assume that there will always be at least two circuits in parallel from generators to load, a condition which should exist if any stress is to be laid on continuity of service. In order to avoid communicating trouble from one circuit to another, they should not be tied together on the high side of the transformers. Where they are so united, the result of any line disturbance, be it a high-voltage or a high-frequency surge, is impressed directly on all lines, limited only by the damping effect of the line itself; and is further aggravated by the fact that the whole transmission system discharges itself as a condenser directly into the fault. On the other hand, if lines are paralleled only on the low side, the interposition of the transformers adds materially to the damping effect, and the disturbance is limited to the damaged line.

Further, if transformer banks are paralleled on the high-tension side, their equivalent reactance in series with a fault in a given line is only one nth the reactance which would be effective were one bank only in series with the line (taking n to be the number of banks paralleled), the current fed to the fault will be correspondingly greater, and the strain on the apparatus increased. Moreover, lightning arresters connected to the high-tension circuits will be subjected to a much larger flow of dynamic current following a discharge, and consequently the possibility of their failure will be much greater.

On the other hand, if a transformer bank is made equivalent to the kilowatt capacity of one line circuit and paralleled only on the low-tension side, as shown in Fig. 2, each bank can be regarded as part of the line, and line switching can be done on the low-tension side; in other words, switches at *A* and *B* can be made automatic and arranged to open in case of line or transformer trouble. The disadvantages pointed out above immediately disappear and the maximum damping effect is secured. Various articles have been published by Steinmetz, Faccioli and others,†

*See page 365, "Power-limiting Reactances in Large Power Stations," by C. M. Davis.

†Proceedings of A.I.E.E. and N.E.L.A., and from time to time in the REVIEW. See June, 1912, pages 341 and 355.

showing the high voltages set up in transformers of considerable distributed capacity by switching in adjacent high-voltage circuits. These results have been demonstrated in tests on such transmission systems as those of the Central Colorado Power Company, the Sierra and San Francisco Power Company, the Great Western Power Company and others. These transient voltages from switching rise to many times the normal value and may materially affect the life of the transformer. They become apparent in transformers with primary windings designed for 50,000 volts and over, since in such designs the electrostatic capacity becomes considerable. Their effects can be obviated by transferring all switching to the low-tension circuits, as indicated above. This is of vital importance. *There is no doubt that many apparatus troubles, especially in transformers, are simply the culminations of a long series of slight injuries from high-voltage switching, which have gradually weakened the insulation until some comparatively slight abnormal condition has caused the final breakdown.* There are also a number of incidental advantages which

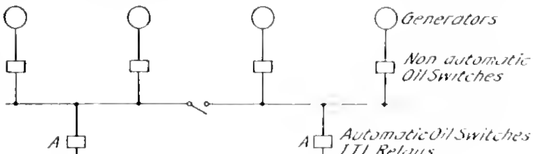

Fig. 2. An arrangement for paralleling high tension transformers on the low tension side. The banks of transformers are equal in capacity to that of the line and may be considered as part of the line

result from this scheme of treating the transformer bank as a unit with the line, rather than the generators, as has been heretofore quite generally the practice. The

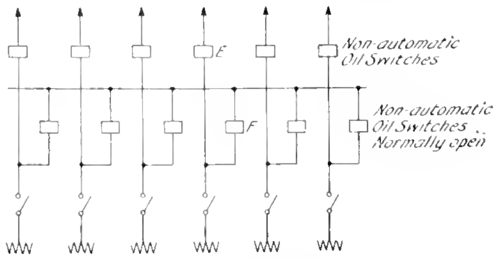

Fig. 3. Connections for six transmission lines, instead of three as shown in Fig. 1

number of high-tension circuits will as a rule be fewer and the number of high-voltage oil-switches materially less. Since these switches are large and expensive, the apparatus cost will be reduced and that of the building also, since the space for the high-tension equipment may be cut down.

Generators for high-voltage power developments usually range in size from 5000 to 15,000 kw. while the line capacity will be from say 15,000 to 40,000 kw. With single-phase transformers banked in units with generators, the transformers will range in size from 1666 to 5000 kw., while if banked in units with the line the size would be from 5000 to 13,333 kw. The most economical size for transformers of 100,000 volts and over will be from 6000 to 10,000 kw. Banking them with generators is, therefore, expensive as regards cost of apparatus; while it may also increase to some extent the building costs.

If the line capacity is greater than 25,000 kw. it will usually be desirable to connect two banks in parallel to a line as shown in Fig. 1. In this way the transformer can ordinarily be made in sizes from 4500 to 9000 kw., which works out very economically.

Assuming that all three lines in Fig. 1 are in parallel to the same substation, the connections in the generating and substations would be practically the same, the low-tension substation transformer switches being provided with reverse energy relays, instead of the inverse time-limit overload type, as used in the generating stations.

If a total of six lines were used, the high tension connections should then be made as in Fig. 3.

In case of line trouble opening automatically the low-tension switches, such an arrangement involves overloading the line or lines remaining in service to the extent of the load carried on the line cut out, and consequently the transformers connected thereto. In the worst case, i.e., of two lines with two banks of transformers (Fig. 2),

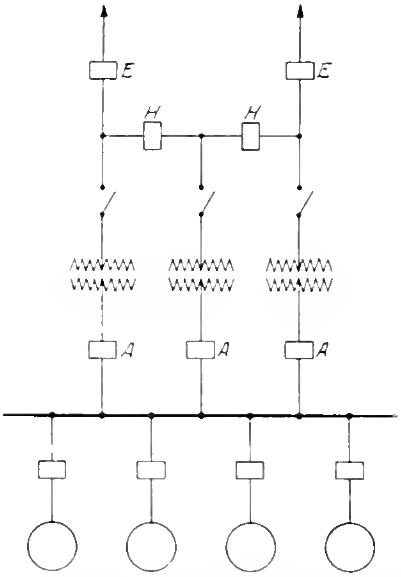

Fig. 4. Connections for three banks of transformers feeding two transmission lines. Transformers paralleled on low tension and high tension sides

the overload will amount to 100 per cent; and as transformers will carry such overloads only for short periods, provision must be made for separating the transformers from the damaged line and connecting them to the unaffected circuit. This may be done by switches as shown at E and F. These should be non-automatic, and normally the system should be operated with the switches at F open.

In switching a transformer in and out of circuit, it should be energized or de-energized only on the low-tension side. For instance, to cut in a line with its transformers, the high-tension switches in both main and substation should be closed first; the low-tension transformer switch in the main station may then be closed and the line so energized without dangerous disturbances, after which the low-tension substation switches may be closed and the load picked up.

If transformers are, under some unusual condition, to be paralleled on both high and low-tension sides, the low-tension switch should be closed first, assuming that the low-tension bus is energized; and similarly, in cutting out the transformer, the low-tension switch should be opened last. In case it becomes necessary to open a high-tension switch in a loaded line, the circuit should be paralleled with another if possible before opening the switch.

If an arrangement involving three banks of transformers feeding two outgoing lines cannot be avoided, connections as shown in Fig. 4 should be used. Switches at E should be non-automatic, but those at A and H should be automatic, instantaneous relays being used at H and inverse time limit relays at A. Substation connections should be the same, except that switches corresponding to A should have reverse energy relays. With this equipment a line short would cause switches at H in the main and the substation to open first, and since no transformer is deenergized and no load circuit actually interrupted, the disturbance will be comparatively small. Switches at A in the short-circuited line will then open; the substation by reverse energy and the main station switch by overload. With a short in any transformer, selective operation will be obtained, since the switches at H will open first.

In general, the substation transformer connections should be treated exactly like those of the generating station and the busses arranged in the same way. Ordinarily, however, bus reactances will not be required in the low-tension bus because of the reactance of the transmission lines. If the load consists largely of synchronous apparatus, such reactances may be considered, however, on account of the pumping back effect of the synchronous machines under short-circuit.

Paralleling all lines to the substation low-tension bus involves taking all of the load feeders off the same common bus. Systems have sometimes been laid out on the assumption that the load requiring particularly good service should have separate supply from the power station. Present tendencies are against such practice. A change of load or other disturbance will cause less change in supply voltage if power is drawn from a common substation bus than if the supply circuit is segregated back to the power station, and a bus fed over a number of lines is not likely to lose its power supply. It is generally recognized that a system fed from a number of power stations gives better service than a line fed from one station. In the same way a bus supplied from several circuits will give the more reliable service. Better load and voltage curves can also be secured by having all feeders fed from a common bus, due to the load diversity factor. Some form of voltage control by synchronous condensers, or motors acting partly as such, is also coming more and more into use. On long lines such regulation is almost a necessity, owing to the difficulty of automatically varying the generating station voltage sufficiently to compensate for the drop in the line when loaded, and for the voltage boost caused by the charging current when lightly loaded. The use of the synchronous condenser operated at either lagging or leading power-factors allows the substation voltage to be kept constant, entirely independent of that of the generating station, and increases the line efficiency.

In laying out a transmission system the following general principles should, therefore, be kept in mind:

(1) Operate all generators in parallel on low-tension bus.

(2) Operate high-tension circuits separately.

(3) Operate load feeders in parallel from a low-tension bus.

(4) Treat transformer banks as part of the line, and confine load switching to low-tension circuits.

It will not in all cases be practicable to carry these out in all details; but if the system is laid out in this way a great deal of high-tension switching can be eliminated, with a very real decrease in the possibilities of damage to apparatus.

THE USE OF POWER LIMITING REACTANCES IN LARGE POWER STATIONS

By Cassius M. Davis

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In most of the articles in this issue dealing with the operation of power systems, reference is made to the power limiting reactance coil, which has by now assumed an important position in the station equipment. This article shows how to determine the size of coil for given requirements, and deals with the factors governing its use and location for generators, busbars, tie-lines and feeders. The author explains the effect of the busbar-sectionalizing reactance in absorbing the excessive power resulting from a short-circuit; and illustrates the normal operation of a system with a busbar reactance in each section of its ring bus, by citing a hypothetical case, and tracing out with diagrams the load distribution amongst the various generators connected to the bus.—Editor.

Power limiting reactances have been described, and the general problem of protection against short-circuits by means of them has been discussed, in previous articles in the Review.* It is the purpose of the present article to outline the method of determining the size of reactances, current carrying capacity and their general application to generating stations.

Method of Rating

The rating of a power limiting reactance is given in terms of the reactive voltage drop across it at a given current and frequency, and this drop is expressed in per cent of the Y voltage of the circuit in which it is connected. Thus, on a 6600-volt (3810 volts Y) circuit, a 6 per cent reactance would have a reactive voltage drop of $(0.06 \times 3810) =$ 228 volts at some given current and normal frequency. The given current is taken as the rated full load current of the apparatus to which it is connected. This is not necessarily the current which the reactance is designed to carry, since this depends upon the amount of energy which it is desirable to transfer through the reactance.

In the case of bus sectionalizing reactances the basis of rating is on the full load current of one of the generators connected to the bus; and where the generators are of different ratings the basis should be made on the full load current of a generator of average rating.

Determination of Size

The size of a reactance required to limit the short-circuit current can be found by expressing the short-circuit current in terms of the full load current of one generator or one transformer, etc. Then 100 divided by this number is the per cent reactance required. For example, to limit the short-circuit current of a generator to 12.5 times its normal current a total reactance of $100/12.5 = 8$ per cent is required. If the generator itself has an inherent reactance of 2 per cent, a 6 per cent external reactance is required in each lead of the generator to make up a total of 8 per cent. The size may be determined also by remembering that, under short-circuit, the total voltage of the circuit is consumed by the reactance; and, if the short-circuit current is to be limited to 12.5 times normal current, the total voltage, or 100 per cent, is consumed under this condition. Hence, under normal load current, the voltage consumed by the reactance is 1/12.5 of 100 per cent, or 8 per cent.

The amount of reactance required in a circuit depends upon at least two things.

*C. P. Steinmetz, G. E. Review, Sept., 1911. E. D. Eby, G. E. Review, Dec., 1912.

First, it must be sufficient to protect apparatus from destruction; and, second, it must be sufficient to maintain continuity of service. In the case of a short-circuit the weakest link in the circuit must be protected. This may be the generator, the transformer or

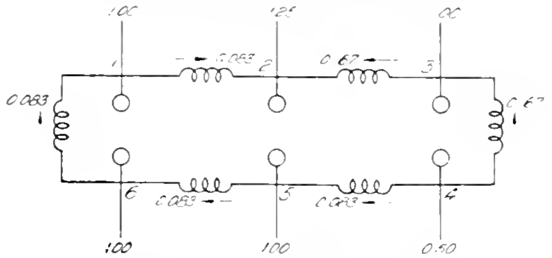


Fig. 1. Illustrating the Use of Bus Sectionalizing Reactances. Total Load 5.75 g. Number of Generators Connected, 6

the switch; and that part of the system which is involved should be as small as possible. As a guide in determining the amount of reactance necessary the following figures may be used: For generator circuits about 10 per cent; and for bus sections, tie lines and other circuits separating large amounts of power, about 25 per cent.

Generator Reactances

Generator reactances should be placed in the line leads and as close to the generator as possible. They should not be placed in the neutral leads for two reasons: *First*, the fact that reactances in the neutral are at ground potential does not reduce the insulation strain which they may be subjected to, since at short-circuit the total voltage of the circuit is consumed by the reactance and it must therefore be insulated accordingly; and, *second*, a short-circuit within the machine itself means a short-circuit on the bus, with the consequent increased damage.

Bus Sectionalizing Reactances

When a bus becomes so large that, for continuity of service, etc., it is necessary to divide it into several sections, these sections may be separated by reactances. This permits any section to draw part of its load from adjacent sections; and has the advantage that, in the event of a short-circuit on the bus, or on a feeder connected to the bus, the momentary short-circuit current is limited to that amount which one bus section can furnish *plus* only a small amount from the adjacent sections. The voltage of the section upon which the short-circuit takes place falls to zero, and thus the reactances connecting the two adjacent sections each consume the total voltage. Suppose they have a reactance of 25 per cent each. Then the total voltage (100 per cent) is consumed when four times the normal full load current flows over them; and hence both adjacent sections supply eight times normal full load current of one machine to the short-circuited bus section. If each section had three generators and each generator had a short-circuit current of eight times normal full load current, then the current supplied from the two adjacent sections would be the equivalent of the short-circuit current of one machine, and the total short-circuit current would be that due to four alternators.

In order to see how a system might be operated under normal running conditions, consider a generating station having eighteen machines of equal output connected to a six-section ring bus, three units per bus section. Assume that during a certain portion of the day the total output of the station equals 5.75 times the full load of one generator, and call this value 5.75 *g*. Fig. 1 shows an assumed distribution of load. Bus section 2 is overloaded by 0.25 *g*. while section 4 has 0.50 *g*. to spare. The overload on section 2 is drawn from both adjacent sections; but, as the generators of each of these sections are under full load, the energy is drawn from those next adjacent, and so on until the next under-loaded section is reached. Between sections 2 and 4 there are two reactances to the right and four to the left. Therefore, whatever load is supplied by section 4 to section 2 is divided inversely as the reactances in series. Thus of the 0.25 *g*. additional required by section 2,

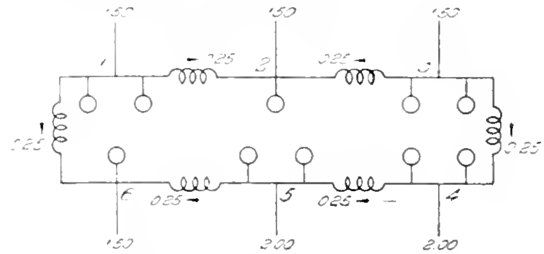


Fig. 2. Illustrating the Use of Bus Sectionalizing Reactances. Total Load 10.00 g. Number of Generators, 10

$\left(\frac{4}{6}\times 0.25g.\right)=0.167$ *g*. comes from the right and $\left(\frac{2}{6}\times 0.25\ g.\right)=0.083$ *g*. comes from the left. These values are indicated at the arrow heads in the figure. The normal operation under this condition is full load on each generator, except that on section 4, which is running at three quarters load.

In Fig. 2 the load is assumed to have increased to the full output of ten generators, and to be distributed as shown. If the generators are connected as indicated, the amount of energy transferred from one section to another may be obtained as follows. Beginning with section 6, it will draw a total of 0.50 g. from both directions. Whatever is drawn from section 5 overloads this section, so that it draws from section 4; which is in turn overloaded and draws from section 3. Passing around the circuit in the opposite direction, section 6 will draw from section 1 that amount of energy which is required, together with that from section 3, to make a total of 0.50 g. In this case, since the overload of section 6 is supplied from both sections 1 and 3, it draws 0.25 g. from each. The overload on section 2 is supplied equally by sections 1 and 3. The energy transferred is shown at the arrow heads.

When the load further increases another condition may arise such as shown in Fig. 3. Here section 6 is overloaded by 0.50 g. while section 3 is underloaded. The loads on the other sections are just equal to the connected generator capacities. Since there are an equal number of reactances between sections 3 and 6, either way around the ring, the energy supplied to section 6 will be drawn equally from both directions as indicated by the arrows. In this case all the generators are running under full load except one on section 3 which is under three-quarters load.

Bus sectionalizing reactances should have 20 to 30 per cent reactance; and their current-carrying capacity should be sufficient to

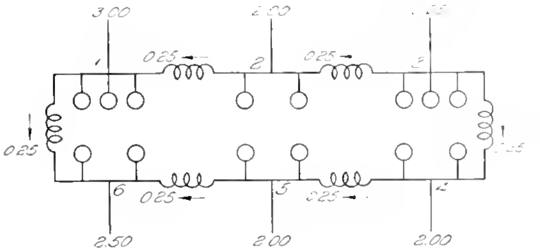
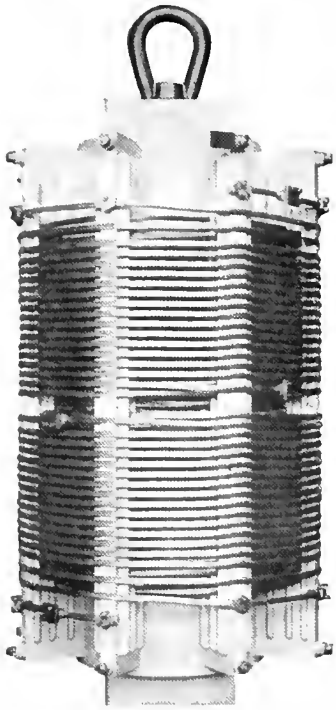


Fig. 3. Total Load 13.75 g. Number of Generators, 14

transfer to one bus section, from both adjacent sections, the output of one of the generators. The number of sections into which a bus should be divided depends largely upon the individual system, and the conditions under which it is expected to operate. As a rough guide it may be said that the largest oil-switches can be expected to safely open approximately 500,000 kv-a. under the usual conditions of short-circuit; and hence a bus should be divided into sections of such size



Reactance with 25 per cent and 50 per cent Taps, Arranged for Bar Connections

that the output of short-circuits which are likely to occur should not exceed the above approximate figure of 500,000 kv-a. Thus a system of 80,000 kw. normal output, which under short-circuit would give ten times normal full load current, or 800,000 kv-a., should be divided into at least two sections.

The value one-half million kilovolt-amperes is expected to serve as a guide in determining the size of bus sections, while the actual short-circuit kv-a. which may be permissible on a single bus section is a matter of judgment. With alternators having a slowly decaying current characteristic, such as waterwheel units, a value less than one-half million kv-a. should be used so that a switch would not have to open an excessive current. In the case of alternators which have a rapidly dying-out short-circuit characteristic, such as steam turbo-generators, this value may be used or even exceeded without causing the switch any great distress.

Tie Line Reactances

Reactances in tie lines between stations should be considered, in a way, as bus sectionalizing reactances; but they may have a greater current-carrying capacity, since it is usually desirable to transfer a greater amount of energy from one station to another than from one bus section to another. Further the tie line reactance should be divided into two parts, one-half being placed at each end of the line. The amount of energy which can be transferred between stations is greatly influenced by the length of the tie line. In long lines the reactances at each end may have less to do with the amount of energy which can be transferred than the resistance.

Feeder Reactances

Reactances may be placed in feeder circuits, in which case the same considerations which govern generator reactances apply; except that the normal rated current may be referred to the load the feeder is designed to carry, rather than to the generator load.

Current-Carrying Capacity

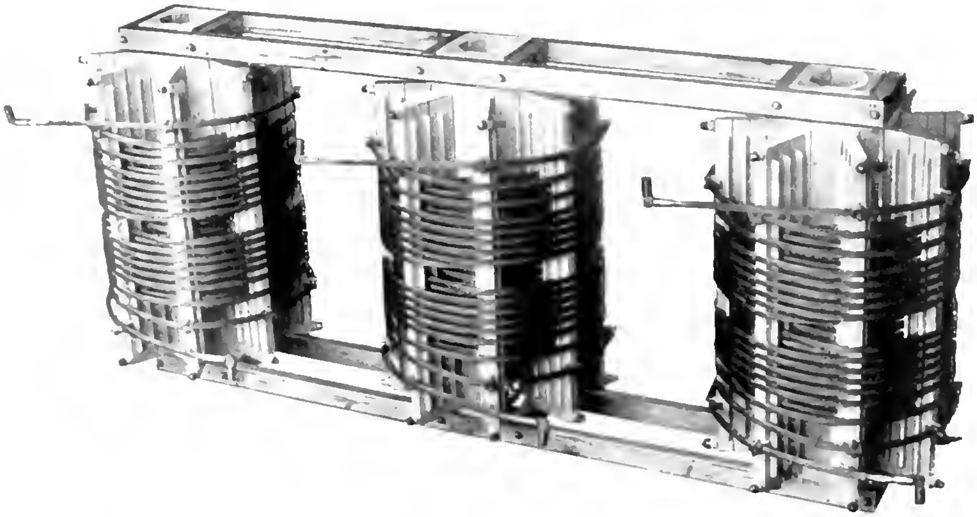
Generator, transformer and feeder reactances should have the same current-carrying capacity as the apparatus to which they are connected. Bus and tie line reactances may be made for quite different currents.

Theoretically, if the current-carrying capacity of each bus sectionalizing reactance be equal to one-fourth of the full load current of one generator, the most efficient condition of operation could be maintained. However, to give a little more flexibility of operation as well as a liberal overload capacity of the reactances, the current-carrying capacity should be based on one-half the full load current of one generator.

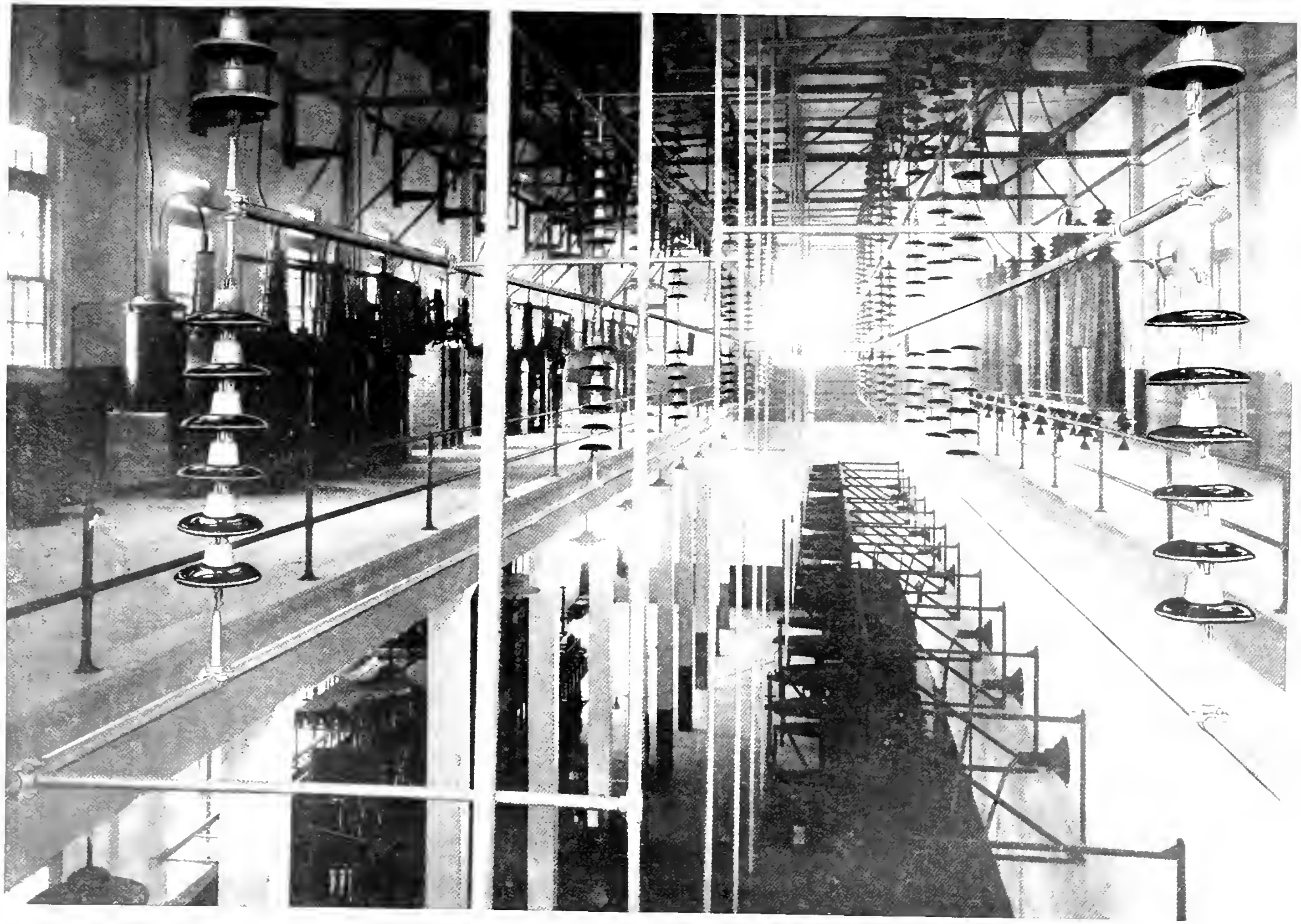
Tie line reactances should have as large a current-carrying capacity as practicable in order to transfer as much power as possible between stations.

Phase Displacement between Bus Sections

Thirty per cent reactances between bus sections give a phase displacement of 8½ degrees under one-half full load current of one generator (full load on the reactance). Two sections can be safely maintained in parallel at twice this angle, and they probably would not fall out of step until the displacement was three or four times this angle.



Bank of 6 per cent reactances for Three-Phase 50-Cycle, 15,000 Kv-a., 11,000-Volt, Turbo-Generator, Showing Method of Mounting and Bracing



Many of our articles this month treat of the theory underlying the practice of station and substation layout, and deal with the principles governing such matters as the design of bus structures, the automatic feature in switching, etc., at both the generating and receiving end. This cut is an illustration of a high-tension bus structure; and, although the interior shown is by no means the most recent which we could obtain, it may be carefully noted by the student of these matters as representing a thoroughly approved and modern type of construction. It shows the Butte 100,000-volt substation of the Great Falls Power Company, a brick building 150 ft. long by 50 ft. wide by 50 ft. high. The four banks of single-phase transformers rated at 3600 kw. per bank are connected in delta on both the high- and low-tension sides, and step the voltage down from 102,000 to 2500. The transformers are installed in fire-proof compartments, and on the gallery above are located the electrolytic lightning arresters. On the opposite gallery are the 100,000-volt line switches. The most unique feature is the 100,000-volt bus construction. The busses themselves are made of $1\frac{1}{2}$ in. iron pipe suspended by standard line insulators from the roof trusses of the building. The connections to the lines are also of iron pipe, making the bus structure as a whole quite rigid, and well adapted to the use of suspension insulators.

THE GROUNDING OF TRANSMISSION LINES

By Charles P. Steinmetz

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The argument against grounding a transmission line is the argument which places continuity and reliability above every other consideration even at an increased risk on the line insulators. Against the isolated system is the certainty of greatly increased risk to the undamaged lines or feeders, even with a maintained service, when an accidental ground occurs. This increased risk is not always to be justified. Which system is preferable depends on the relative value of continuity, and the relative importance of the parts of the system which will be shut down by an accidental ground if the system is already grounded. Dr. Steinmetz considers a few typical cases to illustrate his argument; and also takes care of the remaining, though secondary, considerations which govern the choice of a system—grounded or isolated.—Editor.

Grounding of an electric circuit was formerly considered safe and permissible only at low voltages, and with the advent of alternating current distribution, at thousands of volts, careful insulation of the circuit from ground was considered essential for safe and reliable operation.

When, however, three-phase circuits climbed up to higher and higher transmission voltages, and 20,000, 30,000 and 40,000-volt transmission was attempted, the grounding of the neutral point of the three-phase circuit was tried; and, as it gave, or seemed to give, some advantages, while the disadvantages incident to it at that time did not appear serious, the use of the grounded transmission circuit became widespread.

The rapid introduction of grounded circuits was further fostered by the misconception that, in a grounded circuit, the strain on the line insulators is less than in an isolated circuit, because in the grounded circuit the neutral is fixed, and the line insulators, therefore, can receive only the Y voltage, which is 57 per cent of the delta or line voltage. As the line insulator was, at that time, the weakest link in the system, this belief in its greater safety regarding insulation strain favored grounding in the minds of many engineers. Obviously this is a mistake, as in a transmission line or cable system under normal conditions of operation the neutral is at ground potential, whether it is grounded or not. In the latter case it is held at ground potential by the capacity of the circuit, as long as none of the lines grounds; and when one line grounds, the grounded circuit goes out of service by short-circuit, and the isolated circuit maintains service at an increased strain on the line insulator.

With the development of the suspension insulator the line insulation ceased to be the weakest link; and with the increasing demand for continuity and reliability of service, the principle of maintaining service under all conditions—which had made the Edison stations the strongest central station organizations of the country—also found more and more acceptance in transmission practice. At the same time, with the increasing power of electric systems, the mechanical and electrical strains incident to the short-circuit occurring whenever a line grounded in a grounded system, became increasingly dangerous.

It was, therefore, natural that the isolated system, which is less liable to interruption by grounds on the lines, has been more used of recent years, until today many of the highest voltage long-distance transmissions are employing the isolated system.

The question of grounding or not grounding the neutral of the transmission circuit is separate from the question of the transformer connections, whether delta or Y. While usually in isolated systems the delta connection, and frequently in grounded systems the Y connection, of transformers is employed, the Y connection is not infrequently met in isolated systems, where conditions make it preferable—as with small transformer units; while, at the same time, the delta connection is often employed in grounded systems as safer for the apparatus, with either a separate grounding device, or with one transformer station connected in Y and used for grounding the system.

Comparing the operation of a system with grounded neutral, and the operation as an isolated system, the main distinction is:

In an isolated system a ground on one phase does not interfere with the operation of the system, but somewhat increases the risk on lines and apparatus by raising the voltage against ground of the other two phases from the Y to the delta voltage, and thereby reducing their safety factor of insulation from about 4 to 2.

In a grounded system, a ground on one phase shuts down the circuit on which the ground occurs, by producing a short-circuit and thereby opening the circuit-breakers.

If the system is grounded without any resistance in the ground connection, a ground on one phase is a dead short-circuit until opened by the circuit-breakers, and thereby involves some danger to apparatus by excessive current strains—destruction by the mechanical forces of magnetic fields. The seriousness of this depends on the power available in the system, and on the distance of the grounded phase from the neutral ground.

If the system is grounded through a resistance in the neutral, a ground in one phase increases the voltage of the other two phases against ground until the circuit-breakers open, and thereby involves some temporary increased insulation strains, similar to those of the isolated system.

The relation between isolated and grounded systems is thus that of continuity and reliability of service even at an increased risk, against avoidance of increased risk by shutting down. Which system is preferable depends on the value of continuity and reliability of service, and the importance of the part of the circuit which is shut down by a grounded phase in the grounded system. If the entire system, or a large part of it, is shut down by a grounded phase in a grounded system, and continuity of service is of any value, it would be bad engineering to ground the neutral of the system. Inversely, if the circuit which would be shut down by a grounded phase in a grounded system is only a very small part of the system, and its shut-down involves no serious interruption of service, it would be a mistake to expose the entire system to the increased voltage strain which would result from a grounded phase in an isolated system. Grounding the neutral would therefore be advisable in this case.

For instance: a single 100,000-volt transmission line of 150 miles length delivers the power of a water-course at a big city. If the neutral is grounded, a flash over an insulator would shut down the entire system. In this case therefore grounding the neutral is wrong; and the system should be operated so that, in case of a ground on the line, the service can be continued until the ground is found and eliminated, or the load of the line taken care of otherwise, and a shut-down and interruption of service avoided. The same would be the case if two parallel transmission lines were installed. With a grounded neutral, the short-circuit of one line resulting from a grounded phase would probably shut down both lines, but the undamaged line would be quickly started again and service resumed after an interruption, with half of the line capacity lost. If the system were isolated and a grounded phase occurred on one line, both lines would continue in service until, during time of light load, the damaged line could be disconnected and the fault repaired.

Another instance: a high-power generating system of a large city transmits its power over hundreds of high-potential feeder cables to numerous substations. Owing to the importance of continuity of service, several feeders run to every station, from two in smaller and less important stations, to four or six in important substations. The loss of a feeder by the opening of its circuit-breakers would not cripple the system, since one or more feeders would still supply its substation. In this case it would be preferable to ground the neutral and thereby promptly disconnect a disabled feeder, rather than to expose the hundreds of other feeders to an increased voltage strain for the purpose of keeping the damaged feeder in operation.

In long-distance transmission systems, a transmission line is usually such a large part of the system that it would, in general, be preferable to keep it in operation even if grounded, and increase the insulation strain on the system rather than lose a large part of the system by shut-down. An isolated system is therefore usually preferable in long-distance transmissions, and grounding the neutral is not good engineering. Inversely in high power underground cable systems, a feeder cable is usually such a small part of the entire system that it is preferable to lose it rather than to increase the risk of break-downs in the entire system; and grounding the neutral would, therefore, be preferable.

Thus, while individual transmission lines or groups of lines are more advantageously operated on the isolated system, yet when many such systems are joined together in an extended network the question of providing a ground in the neutral may arise; and in this case a separate grounding device is preferable as giving more perfect control of the ground and its resistance.

While the main distinction between the isolated and the grounded system is that of continuing operating at increased risk to the apparatus, against shutting-down and avoiding any risk, there are a number of secondary features which require consideration.

In case of a flash over an insulator in an isolated system, the current in the arc is limited to the capacity current of the system, as the return of the arc current is over the electrostatic capacity of the other phases. Such an arc tends to be oscillatory of high frequency; and an arcing ground on an isolated system is therefore liable to produce high frequency and thereby endanger apparatus. This danger is specially great in medium voltage systems, 30,000 or 40,000 volts, as the capacity is sufficiently large to maintain an arc, but still so small as to give a very high frequency to the arc oscillation. This danger of high-frequency disturbances due to an arcing ground is materially reduced in very high voltage systems, in which the much higher line capacity reduces the oscillation frequency below those frequencies which are specially liable to cause resonance and thereby damage in apparatus. In isolated systems, especially at medium voltages, protection against arcing grounds is therefore desirable. This is afforded by the arcing ground suppressor, which operates by putting a permanent ground on the arcing phase, thereby extinguishing the arc.* In the grounded system, the arc following the flash over an insulator is a short-circuiting arc, of much higher power, and much less liable to become oscillatory. In the case where it becomes oscillatory it is of far greater destructiveness, owing to its practically unlimited power; but, as this occurs only under exceptional conditions, it does not in general require serious consideration.

The arc following a flash over an insulator, if it continues, destroys the insulator, and so causes a permanent damage of the line. In an isolated system the arc over an insulator, if promptly suppressed by the arcing ground protector, is, owing to its lower power, little liable to damage the insulator; while the high-power arc of the grounded system is more liable to destroy the insulator even in the short time which elapses before the circuit-breakers open and cut off the line. Inversely, however, if no arcing ground protection is given in the isolated system, an arc over an insulator may hold on for a considerable time, and thereby destroy the insulator; while in the grounded system the arc is often interrupted by the circuit-breakers before it has done much damage.

The use of a resistance in the grounded neutral of a system offers the advantages of limiting the current which flows through a ground on one phase, and thereby eliminates the danger of mechanical destruction due to the excessive currents at the dead short-circuit, which would occur with a ground on one phase of a system with the neutral grounded without resistance. Such a grounding resistance, however, abandons the advantage of the dead grounded system that the voltage between lines and ground can never exceed the Y voltage. It is, therefore, not permissible where the apparatus cannot safely stand the delta voltage of the line. This is the case with low-voltage generators feeding a line or cable through step-up auto-transformers, or when connecting transmission lines of different voltages through auto-transformers. Therefore, when using auto-transformers between generators and cables, or between lines of different voltages, the neutral of the system must be grounded without resistance, or, where this is not considered safe, transformers must be used.

The foremost disadvantage of using a resistance in the neutral of a grounded high-potential system is the difficulty of producing and maintaining a perfectly reliable grounding resistance. Normally, the resistance has no voltage and carries no current, but in case of a grounded phase, the resistance carries a large current and receives full Y voltage. It is very difficult to build such a resistance with even moderate reliability. Absolute reliability of the resistance is, however, essential for the safety of the system, as its failure by arcing or flashing over usually results in the production of high frequency and destruction of apparatus.

The grounding of the neutral of a system is usually done in one place only. If the neutral is grounded in several places currents are liable to flow through the ground over the neutrals even under normal operation, and these currents result in high frequency and the destruction of apparatus. Furthermore, with several grounds, serious interference with telephone and even telegraph service may be expected. To some extent even a single ground increases the probability of telephone interference.

As the reliability of the ground is essential for the safety of a grounded system, such a ground must be made so as to be perfectly reliable even with large currents flowing through it. That is, it should be carried back to the waterwheels, penstocks and railway tracks, and other extended masses of metal in contact with the ground and especially with large bodies of water.

*See paper by Professor E. E. F. Creighton, "Protection of Electrical Transmission Lines," Mid-Year Convention A.I.E.E., February, 1911; and "The Arcing Ground Suppressor and Its Applications," by R. H. Marvin, GENERAL ELECTRIC REVIEW, March, 1913.

NOTES ON AUXILIARY STEAM STATIONS FOR HYDRO-ELECTRIC PLANTS

By R. C. Muir

Power and Mining Engineering Department, General Electric Company

Steam stations to be used as auxiliaries to hydro-electric plants are divided by the author into four classes; for emergency breakdown reserve, low water reserve, peak reserve, and continuous operation. The engineering requirements of any one case are rarely to be duplicated elsewhere, but in a broad way the author reviews such features as the location and output of the auxiliary station, and the relative importance of steam consumption and water storage, which have an influence on the reliability and economy of the whole development.—Editor.

Steam power plants held in reserve for, or operated in conjunction with, hydro-electric plants are commonly called auxiliary steam stations. The subject is one which is so general and still the application is so special in each individual case that it is impossible to cover all details in one short article. There are certain fundamental principles involved in the building and operation of all auxiliary steam stations, however, which may be briefly set forth in this paper.

The function of the auxiliary steam station depends principally upon the hydro-electric development, and the load and the nature of the load, and may be any one or a combination of any of the following:

1. To be held as an emergency reserve to take over the load in case of a breakdown in the hydro-electric plant or transmission line.
2. To be held in reserve for periods of low-water or insufficient water supply.
3. To be held in reserve for peak load periods.
4. To be operated continuously in conjunction with the hydro-electric plant.

1. Emergency Reserve

In this case the steam power plant is purely an insurance against interruptions of service; and its adoption or maintenance may be the result of contract requirements of a hydro-electric development and transmission system, where the loss in revenue, due to interruptions, would exceed the cost involved in the installation and operation of the steam auxiliary.

The size of the auxiliary steam station depends upon the nature of the load. The load on any system can usually be divided into two or more classes. With one class, such as the lighting and railway load in the business district of a city, it is practically imperative that there be no interruptions; with the other class, such as industrial load and resident district load interruptions are not considered to be so serious. In case it is desired to provide against interruptions of service in the first class only, the auxiliary steam station must be of sufficient capacity to take care of only this load; but if it is desired to provide against interruptions in both classes the auxiliary steam station must be equal in capacity to the hydro-electric plant.

The location of the steam plant should be at the receiving end of the transmission line, or as near to the point of consumption as is possible to obtain a favorable site as regards cost of real estate, condensing water and shipping facilities. The type and construction of the steam auxiliary station are influenced by the initial cost, the cost of labor and the efficiency of the apparatus.

The initial cost should be kept as low as possible, as the fixed charge is the largest item in the expense involved. In order to keep the initial cost down the site should be low in first cost, and such that the development involved for condensing water intake and discharge will be inexpensive. The construction of the building should be simple. The prime movers should be steam turbines of as large capacity as feasible, and steam boilers should be of the water-tube type of fairly large capacity. Large units will also keep the cost of labor down, and will tend to make a simpler and more easily operated plant. The layout of the apparatus should be given special consideration with respect to the operation of the plant with the fewest possible men.

Efficiency is of the least importance; but with large steam turbine units it is practical to obtain the most efficient unit at practically the same cost as one of poorer efficiency. The more efficient the steam turbine, the less the boiler capacity required. Consequently a plant of high efficiency can be built at practically the same cost as one of lower efficiency.

It is not customary in auxiliary steam plants to have the boilers under steam and in readiness to take over the load immediately in case of an interruption. In some cases it may be desirable to keep part of the boilers under steam, to take over a certain part of the load; and in these cases it is often advisable to keep the steam turbines running light as synchronous condensers, with just sufficient steam entering to make up for the no-load losses. Means should be provided to get the boilers under steam with the least possible delay. In districts where crude oil is usually used for fuel this can be readily accomplished with the oil-fired boiler; while in other districts fuel oil can be used until the coal fires can get under way.

New hydro-electric developments are often subject to interruptions for a short time; but the faults are soon corrected, the operating force becomes familiar with the operation and therefore more efficient, the interruptions become less frequent, and the water power grows in favor with the consumer. In most cases steam plants fortunately precede the hydro-electric plant and can be held in reserve to take care of these interruptions. As the water power grows in favor and the load increases, the steam plant is not usually increased in proportion and consequently is not a complete reserve. Occasionally the consumer has a steam plant which he used up to the time of purchasing energy from the power company. This can be held as a reserve and possibly an exchange agreement effected, whereby the power company can use the customer's steam station during interruptions or periods of low water.

In the opinion of many, the modern hydro-electric plant and transmission system designed and built by competent engineers and contractors is as reliable, or practically so, as the steam power plant. We therefore seldom find a steam auxiliary station held in readiness to take over the entire load in case of an interruption to the hydro-electric plant.

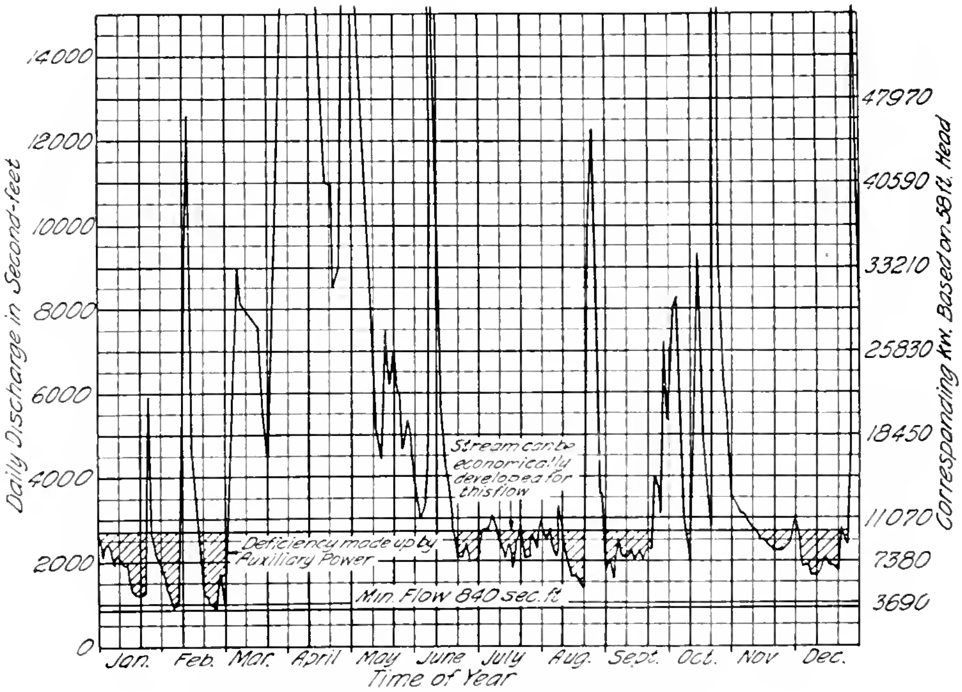


Fig. 1. Daily Stream Flow of the Mohawk River at Dunsbach Ferry for the Year 1904. From U. S. Geological Survey 1905, Report on Stream Measurements

2. Reserve for Periods of Low-Water

The wide variations in stream flow during different times of the year is the most serious problem that confronts the water power concern.

This irregularity in stream flow can be partly met in many cases by water storage. Enough storage capacity can usually be provided in hydro-electric developments to ensure that fluctuations in the 24-hour load can be taken care of, even though the peak load is somewhat in excess of the power corresponding to the minimum stream flow. Of course the average or integrated load over the 24-hour period must be within the energy available from the minimum stream flow. Without water storage the minimum flow determines the maximum power that can be developed the year around. Fig. 1 shows the daily stream flow of the Mohawk River at Dunsbach Ferry during the year 1904, typical of a great many streams. Fig. 2 shows the percentage of the year during which various amounts of power could have been developed from the Mohawk River at Vischer's Ferry and Crescent during the year 1904, had water power plants been installed at these places.

It is customary to develop a water power somewhat beyond the capacity corresponding to minimum stream flow, the deficiency being made up by an auxiliary steam plant. Before a decision is made as to the size of the hydraulic plant the stream flow for many years should be thoroughly investigated. A careful study of curves similar to the above must be made in connection with the daily load or demand curve.

It is usually considered good practice to install a water power plant of such a size that it can be operated at full capacity approximately 60 per cent of the year. The economic development may be somewhat higher than this in some cases, especially where the expense involved in installing additional generating units is small compared with the total investment. The size of the auxiliary steam station is determined by the difference between the demand curve and the stream flow curve, except where storage or pondage is available; then the stream flow as affected by such pondage or storage should be used.

Referring again to Figs. 1 and 2, it will be noted that the capacity of the development, based on minimum stream flow, would be only 3100 kw. With an auxiliary steam plant the stream could b. economically developed for 10,000 kw.; and the load carried by the steam plant would be only 11.5 per cent of the total yearly load. The auxiliary steam plant would have a capacity of 7000 kw. if it were intended to make up the deficiency in water supply only. When, however, the steam plant is so nearly equal to the capacity of the hydraulic plant, it is advisable to make them the same capacity to take care of all emergencies.

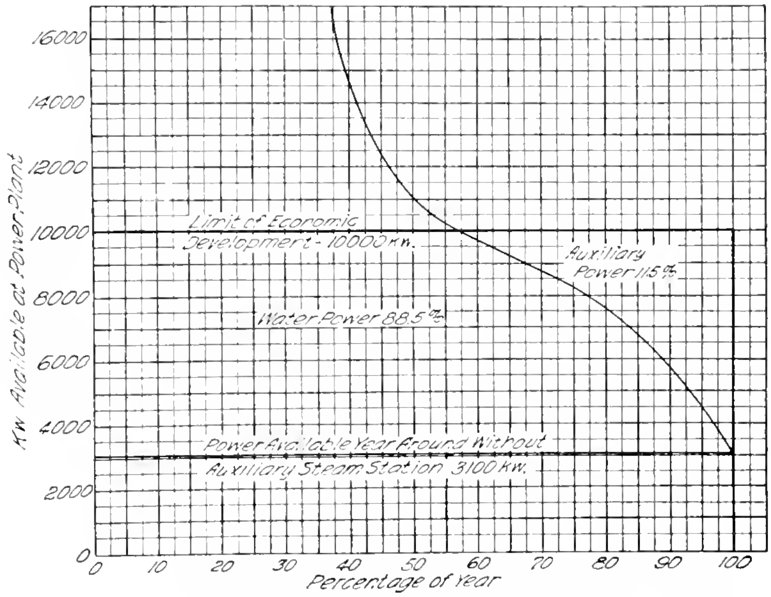


Fig. 2. Total Power Available from Mohawk River at Vischer's Ferry and Crescent for Year 1904. Based on Total Combined Head of 58 Ft. and 75 Per Cent Overall Efficiency of Water Turbines and Electric Generators

The same remarks that are given under "Emergency Stations" regarding location and type of plant apply in this case. Economy is, however, somewhat more important, so that a little more attention should be given to this feature.

The method of operation of a steam auxiliary station in connection with a hydroelectric station deserves careful consideration. Two things are particularly important: economy of operation and peak load. In order to get the best economy out of the steam station it must operate at practically a constant load corresponding to full load on one or more units. In order to get the best economy out of the water power station with the water available during low water periods, the highest water level attainable—in other words the maximum head—must be maintained at all times.

It is impossible to conform to both of these requirements, especially where the minimum stream flow capacity and the steam station capacity combined are not sufficient to carry the peak load. In this case the steam plant can be operated at practically a constant load, using the water power during the peaks and storing water during the balance of the time. With high head plants the head gained by storage is not of importance; so that the steam plant can be operated most economically on constant load, allowing the water power to take the peaks. With low head plants having considerable storage capacity both plants can be operated advantageously during the low-water period. Here again the water power should carry the peaks, and the steam plant operated at constant load over a sufficient part of the day so that the water level will not be materially affected. This method of operation will prove much more economical, both as regards fuel used and labor required, than the method of carrying heavy loads on the steam plant during the peaks, thereby requiring more boilers and machines in service and consequently more fuel and operators.

The term "peaks" is intended to cover heavy load periods of the daily load curve, and not the momentary load fluctuations. Assuming equal governor or speed regulation and equal flywheel effects, these momentary load fluctuations are divided between the stations in proportion to the total capacities of the generators operating in each station. The flywheel effect of the steam turbine is usually the larger and the steam turbine governor is the more sensitive. The steam turbine station will, therefore, ordinarily take more of the momentary fluctuation than its proportionate capacity in operation.

Some fuel can be saved in developments of this kind by carefully observing the rainfall within the drainage area of the stream developed. In case of rainfall within this area the steam plant can be shut down immediately and all the load taken over by the hydraulic plant at the expense of reducing the level of the reservoir. The increased stream flow will again fill the reservoir. Rainfall at the head waters of a large stream would not materially increase the stream flow at the development for some time; and consequently a considerable saving in fuel would thus be effected. During the dry season, water flowing over the dam means fuel wasted; and therefore, if enough reliance could be placed in weather forecasts to anticipate rainfalls, the steam plant could be shut down in time, so that the reservoir level would be reduced sufficiently to take care of the increased flow without wasting any more over the dam than necessary.

3. Reserve for Peak Loads

There are two conditions which make it necessary or advisable to install auxiliary steam stations for peak load reserve:

a. When the water power development is not of sufficient size to carry the peak loads.

b. When electrical energy is being purchased on the maximum-yearly-demand basis, and the load is such that a heavy peak load is experienced only for a short period each year. This applies particularly to lighting or railway companies whose winter peak loads are very heavy and of short duration. In this case it is sometimes cheaper to operate a steam plant during the peak periods than to pay for energy for the entire year on the basis of the peak, which only exists a short time each year.

In either of these cases the steam plant should be located at the receiving end of the line. Its size should be sufficient to take care of the difference between the peak and the size of the water power plant in the first case; and the difference between the peak and the average load demand in the second case.

The steam plant should contain the fewest possible number of units, in order to make it inexpensive as regards first cost and operation. Economy is of practically no importance on account of the short period of operation. The design and care of the station and apparatus should be such that the depreciation during idleness will be a minimum.

4. Continuously Operated Steam Plants

Where the average power demand exceeds the capacity of the hydro-electric plant, the steam auxiliary must be operated continuously. The location of the plant, as with previous cases considered, should be as near the load as consistent with a favorable site. If the load demand is such that the size of the steam plant is necessarily large in comparison with the water power plant, it would be advisable to make it of sufficient size to take care of the entire load in emergency cases. The size of the units should be determined from the load curve, in order that most efficient operation could be carried out. Economy is of importance and requires careful consideration. Both plants should be operated so as to obtain maximum efficiency from each; and the remarks regarding operation under the second case considered, viz., reserve for low-water periods, apply to this case also.

From the foregoing remarks it is evident that each individual water power development presents a different problem, which requires special consideration before the proper auxiliary steam station can be decided upon.

THE APPLICATION OF SWITCHBOARD RELAYS TO THE PROTECTION OF POWER SYSTEMS

Part II

By D. Basch

Switchboard Engineering Department, General Electric Company

The first part of this paper ("Switchboard Relays and Their Application") appeared in our April number, and dealt with the physical construction of the various types of relays and the operating conditions governing their selection, from the standpoint of the time characteristic. The author now proceeds to a third classification of the subject, according to the nature of the disturbances with which commercial relays have to deal. Of six main classes of disturbances he completes a discussion of the first, viz., overload and underload conditions, and comes on to short-circuits. Relay protection for generator and transformer short-circuits is fully treated; and the rest of the paper discusses the requirements of line short-circuit protection. There are so many variables to be met with in the modern network that only certain cases of line shorts can be brought into the scope of the present section of Mr. Basch's paper, and the balance will be left for the next and final installment. Typical systems, with main stations and substations occupying different relative locations, are illustrated in the diagrams; and the text gives a thorough exposition of the relay arrangement best calculated to clear the lines from trouble in the various cases, having regard to the location of the various relays, the general type required, grading of the time element, and so on.—Editor.

It will be remembered that, in the first part of this paper, a classification of alternating current relays was made in accordance with three of their most characteristic features:

(1) According to whether the contact device, when responding to the impulse of the system, makes or breaks contact;

(2) According to the time elapsing between the occurrence of the disturbance and the operation of the contact device; and

(3) According to the nature of the disturbance.

We have dealt with the first two of these sub-divisions, and we will now proceed to consider the selection of relays with regard to the particular disturbances with which they are required to deal.

CLASS 3. CLASSIFICATION OF RELAYS ACCORDING TO NATURE OF DISTURBANCE

3. The various disturbances in an operating system which must be taken care of by commercial relays may be classified as follows:

Overload and underload;
Short-circuit;
Unpremeditated change of direction of flow of energy;
Over-voltage and low-voltage;
Change of phase rotation;
Grounding

The main function of a relay, selected to guard against such trouble as may occur at the point where it is installed, is to operate only on the occurrence of such a disturbance as it has been selected for, and only when this disturbance happens right in the line or circuit under the control of the relay.

Where circuits are connected in series or in multiple, each circuit must be kept immune against trouble in any other circuit, and the trouble must be removed from the system by the relays in the affected line without interfering with or jeopardizing the maintenance of service over the other healthy lines. Mention of this selective action has been made before.

There are instances where interruption of short duration in the operation of the whole system, or of sections of the system, are *not* sufficiently objectionable to justify the expense of installing selective relays all the way through, as in the case of some railway installations, where it may be considered permissible to stall the cars on all the lines or on part of the lines until the trouble has been located and all but the trouble line have been cut in again; but, in general, and especially on power and lighting transmission systems, uninterrupted maintenance of service is the most important matter to be considered, and none but truly selective relays are to be installed.

In judging the merits of any relay, special attention must therefore be paid, first, to the question whether it actually takes care of the particular kind of trouble for which it has been selected; and, secondly, whether it is liable to be affected in its operation by trouble which did not start in its own line, but which passes over it from some other line in trouble, and disappears as soon as the relays in the line in trouble have performed their function. Certain types of relays must be irresponsive to conditions which cause other relays to operate; and it will be evident that it is impossible to design a universal relay which will take care of all kinds of trouble and maintain selective action besides.

Having considered in general the nature of the disturbances with which relays have to deal, according to the third division of our main classification, we will now proceed to treat these matters individually and in greater detail.

OVERLOAD AND UNDERLOAD

A distinction must be made between a transmitted overload and a local overload. An overload created in any circuit will, of course, draw increased current through all the lines between the source of power and the point of overload. The overload of the circuit in which it is created may be called the local overload; and the overload carried by the circuits between the source and the circuit with the local overload may be called the transmitted overload. In best practice protection should be provided only against local overloads.

Overload relays contain only current coils, and the current setting of these relays should be such that they operate when the load current exceeds the maximum long time rating of the circuit. They may be instantaneous or inverse time limit, but rarely definite time limit.

Underload relays have a limited field of application. Their function is to operate when the load current falls below a certain pre-determined figure. They contain current coils only; and are arranged in such a manner that, for all currents above the low load setting, the plunger is held in the coil. When the low limit is reached the plunger is released, and in falling down closes a contact. They are used sometimes in connection with constant current transformer series arc or series incandescent light circuits. One possible source of trouble in the high-tension secondary of such circuits is a break in the leads, which, when falling to the ground, constitute a hazard to life, as the constant current transformer, in its endeavor to maintain constant current against the open-circuit resistance, will raise the potential to its highest limit. In such a case, an underload relay in the primary circuit of the constant current transformer will open up the circuit and disconnect the transformer. Low secondary load will not affect the relay, as on account of the very low power-factor of the transformer at low loads the current in the primary is always kept at a relatively high figure. Underload relays should be instantaneous.

SHORT-CIRCUIT

Generator Short-Circuits

Short-circuits are overloads of very high relative magnitude. Short-circuits in load feeders, i.e., in radial feeders constituting the last link between the distributing system and the commercial revenue load, are to be treated the same as overloads, i.e., with plain overload relays. The condition is somewhat different with circuits that are not apt to develop local overloads, but which must be guarded against accidental shorts.

In the case of generators, a short-circuit will have no detrimental effect on the machine if the operator heeds the unmistakable danger signal given out by alternators in trouble and shuts down in reasonable time. It is not advisable, however, especially in large installations, to deviate the power generated by the unaffected generators from the distributing system into the shorted generator, even for such short time as may be required by the operator to locate and isolate the trouble generator; and it has become quite common practice to install reverse power relays on generator circuits, which are impervious to any distribution overload, but which isolate the generator from the busses as soon as it becomes partially or wholly short-circuited. After the generator has been isolated from

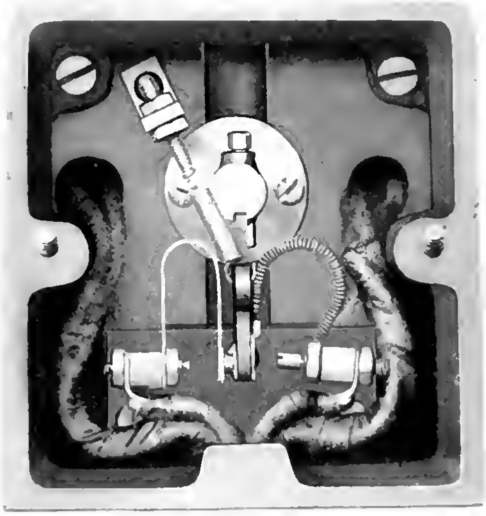


Fig. 5. Reverse power relay for short-circuit protection of generators. Operative on partial or complete short-circuit, but impervious to distribution overloads

the busses it may then be shut down by the operator.

A commercial type of such a reverse power relay is shown in Fig. 5. It is built in single-pole units on the dynamometer principle, with stationary current coils connected to series transformers in the generator circuit, and movable potential coils connected to potential transformers on the busses. Current and potential coils must be arranged to be in phase, so as to limit the effect of power-factor. With correct direction of flow of energy and also at no load, the contact lever operated by the shaft carrying the movable potential coil is held against a dead stop by a spring. When the direction reverses, the potential coil tends to turn 180 deg. and throws the contact lever against a stationary contact, completing the tripping circuit of the corresponding oil switch; and is held there as long as the torque of the moving element is sufficiently strong to overcome the resistance of the spring. It is self-evident that a dynamometrical device is not influenced by any increase of current as long as the direction of flow of energy is correct, simply increasing the force with which the contact lever is held against the stop. Such a relay, of course, must work down to very low potential and power-factor.

Another type of reverse power relay for the protection of generators is based on the

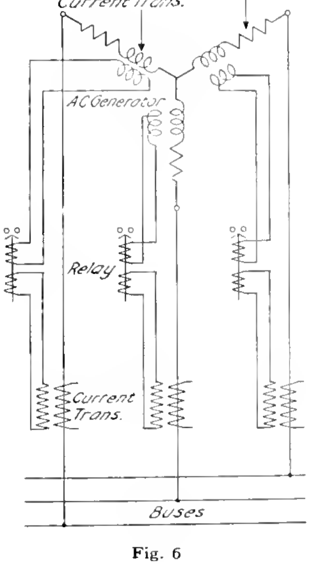


Fig. 6

differential principle (Fig. 6). It consists of two sets of current coils, one of which is connected to series transformers in the generator leads where the windings converge into the machine Y point, and the other one connected to series transformers in the main leads between busses and generator. The corresponding current coils are then connected on common magnetic cores so as to give magnetic balance under normal conditions, and a heavy magnetomotive force when, through a short on the generator or between generator and busses, the direction in the coils in the leads between alternator and bus

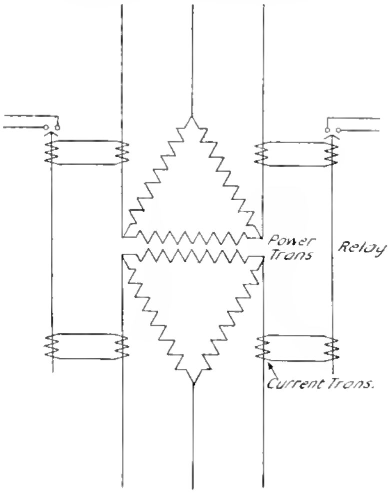


Fig. 7

reverses. This relay is not affected by any distribution overloads, neither is it affected by any conditions of potential or power-factor. Its use, however, necessitates opening up the main windings of the alternator at the Y point.

Transformer Short-Circuits

Power transformer circuits are best protected by means of differential relays similar to the type mentioned for generators. Two sets of coils are connected to series transformers on both sides of the power transformers, each two coils in the same phase being arranged on one common core so as to produce magnetic balance under normal conditions, and a heavy magneto-motive force when, through a short in the transformer, the direction of flow of energy on one side reverses (see Fig. 7).

The same effect may be obtained by using the standard type of reverse power relay, making both the stationary and the movable coils current coils, and connecting one to the primary and the other one to the secondary of the power transformer. The coils must be wound in such a manner that normal conditions in the transformer cause the contact lever of the relay to go against the dead stop. Care should be taken that the phases of the two coils on one core are in line. This will give no difficulty on delta-delta transformers;

but on Y-delta transformers it is necessary to connect the current coils on the delta side on the inside of the delta. On Scott-connected power transformers, three-phase—two-phase, it is impossible to get the same phase relation on more than one phase; and either a

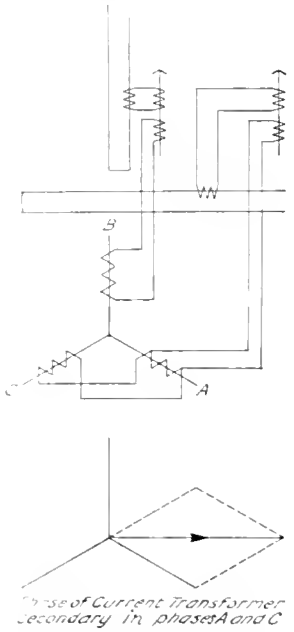


Fig. 8

single-pole relay must be used in the phase where no phase displacement exists between primary and secondary, which gives only incomplete protection; or a special connection as shown in Fig. 8, where, on the three-phase side, by a cross-connection of current transformers in the two phases displaced 30 deg. from the quarter-phase side, a phase alignment is obtained.

In order to obviate the possibility, that, when throwing in the primary of the power transformer with the secondary open, the sudden rush of the magnetizing current might operate the relay, it has been proposed either to make this relay time limit, or to equip it in the primary with some device that will raise the current setting during the first period, such as fuses in parallel with the relay coils, to be removed by hand when the secondary switch is cut in. In the design of the relays described here it has not been found necessary to employ any such means, as the inherent time element of even an instantaneous relay seems to be sufficient to tide the relay over the dangerous period.

Transformer relays should preferably be instantaneous, so as to isolate any trouble on the transformer immediately. Furthermore, an interconnected power system, as a rule, must depend on the proper time sequence of a great many relays; and the introduction of another time element, which must be fitted in and balanced with the rest of the system, is apt to prove annoying in the installation and an added possible source of unreliability in operation.

The use of such differential relays with current transformers on both sides of the power transformer may sometimes be objectionable from a commercial standpoint; and, for competitive reasons, especially on lower voltages where trouble in the power transformer is less liable to happen than on high voltages, plain inverse time limit relays may be used, preferably on the primary side. This relay should be set high enough to respond only to short-circuits and should have multiple contacts so as to open, when operating, the oil-switches in both primary and secondary. The time element feature serves to make the relay selective, in cases where more than one transformer are run in multiple, since, of course, with a short-circuit in a transformer, the relay in the shorted circuit will receive a much heavier share of the short-circuit current than those in the other transformer circuits, and will open up correspondingly faster. A relay in the secondary circuit of the transformer would be cheaper on account of the lower voltage series transformers required for it; but its selective action is not as pronounced as when located in the primary, especially where only two transformer banks are installed.

It should be realized that, when a short-circuit occurs in a power transformer, the destructive effect is generally so rapid that no protective device can save it. The object of the transformer relay is, therefore, less to preserve the transformer than to isolate the trouble and to prevent damage to the other transformers and apparatus in the same system.

Transmission Line Short-Circuits

On transmission lines the problem of protection against short-circuits is rather complex. These lines are the nerve-centers of the whole system, and the distribution of power must be kept up at any cost, without endangering any part of the system. In order to make possible an intelligent and fruitful discussion of this subject it will be necessary to subdivide it as follows:

A. The direction of flow of energy is always the same under normal conditions.

B. The direction of flow of energy may reverse in normal operation, due to changing load conditions, etc., independent and beyond the control of the operator. This is bound to happen, for instance, in transmission lines between two generating stations and in ring distribution systems, where the neutral point of the network shifts from one station to another, according to the disposition of load in the various stations.

C. The direction of flow of energy may be varied intentionally by the operator, but will remain as imposed until he changes it again. This condition occurs, for instance, in a distributing system with a water-power plant at one end and a reserve steam plant at the other with substations between them. With the water-power plant supplying all the power, energy is transmitted from station to station in one direction. When the water-power plant is shut down and the steam plant takes its place, then the direction of feed is reversed.

Besides this subdivision into classes *A*, *B* and *C*, our analysis must also consider whether single transmission lines connect the various stations, or whether two or more lines are employed.

A.a. Direction of energy flow always the same. Single circuit transmission line used.

Fig. 9 shows the simplest arrangement. Trouble on any line will not only disconnect the particular line in trouble, but it will also kill all other lines following the disconnected line in the sequence starting from the source of power. The problem is only to provide relays which will not open up any line oil-switches between source and trouble except the one in the trouble line. Selective time limit relays should be supplied in every line at the outgoing end, with current setting dependent on the actual load carried in normal operation, and equal to about 10 amperes in the secondary of the transformer. The time setting of the different relays should be such that, no matter how high the current drawn through the lines, the difference in time between relays in two adjoining lines would always remain great enough to make up for differences in the mechanical characteristics of relays and oil-switches, and still leave ample margin to maintain proper time sequence between lines. At the same time it should not be too high, so that short-circuits are not allowed to hang on too long. The relatively high current calibration is recommended because the selective relays are supposed to operate only at short-circuits and not on any distribution overloads. The advantage gained is in the reduced volt-ampere load on the current transformers, increasing the permissible meter and instrument load that may be connected to the same transformers.

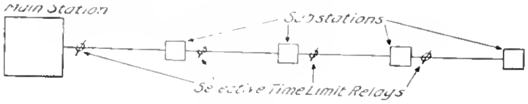


Fig. 9

In order to meet the operating requirements, these selective relays should give time curves which are inverse at their first part and definite time limit after that—as brought out in the previous lines. A simple relay of this description consists of a combination of an inverse time limit and a definite time limit relay, connected in such a way that the inverse time limit relay in the secondary of the line current transformer closes a direct current potential circuit through the definite time limit relay, or, if no direct current is available, throws in circuit an alternating current definite time relay, which in turn, operates the tripping circuit of the oil-switch in the line (see Fig. 10). In this manner the time curves of the two relays are superimposed; and, no matter how heavy the current through the lines, the time difference between relay combinations in two adjoining lines would always be at least the difference in the definite relay setting, even if the inverse time curves should converge.

The inverse time limit relays are provided with so-called pop valves which, for predetermined current values in the line (variable for different line conditions), open up immediately a wide air outlet in the bellows, thus making the inverse time limit relay practically instantaneous, and leaving as the only time component the time element of the definite time relay. The point at which the curve becomes definite can be varied at will by varying the setting of the pop valve. The shape of the curve can also be modified within wide limits by changing the relative setting of the inverse and definite time elements.

Good working characteristics can be obtained by grading the inverse time curves not less than one second apart, and the definite time curves not less than three-quarter second. As brought out previously, in addition to the selective time limit relays, it is recommended to install, in the line nearest the source of power, instantaneous relays which are set high enough to be affected only by such short-circuit values as are inherent to the first line, so as to prevent that extraordinarily heavy short-circuits stay on for too long a time.

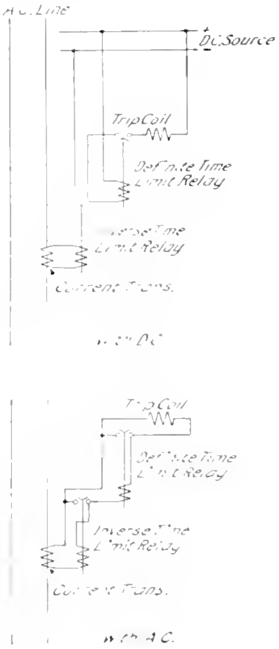


Fig. 10

Some relays with curves similar to those described above have been put on the market, the superiority of which is alleged to be based on the supposition that their setting is absolutely reliable and unvariable, after once made. Without discussing the justification of such claims of absolute and permanent accuracy, it may be well to bring out the point that *commercial operating conditions do not require zero error in relays any more than they must rely on zero error in instruments or any other apparatus of that sort,* so long as there is sure to be sufficient accuracy, even under the most severe conditions, to maintain certain prearranged inter-relations between relays. In the case of the relay described above there is certainly no danger of interference of relays up to the point where the pop valve operates, as with the greatest possible error the inverse time limit curves keep well apart within this range; and, from there on, only the very small error of the definite time relay is to be considered, which is not comparable to that of an inverse time limit relay. On the other hand, with this type the mechanical refinements of an ideally and theoretically accurate device can be and have been dispensed with, resulting in lower cost and greater mechanical simplicity. Where there is a willingness to pay for such a highly and apparently unnecessarily accurate device, it would, of course, be easy enough to furnish a relay that would not vary from the original setting.

A somewhat different and more complicated system of transmission is shown in Fig. 11. If in this arrangement of lines a short-circuit should occur on any one of the lines, it would be necessary to disconnect the line at both ends since energy would be fed into the short from both sides. Selective time limit relays should be installed in the outgoing end, and reverse power relays at the incoming end of the line. Lines *BC* and *CD* do not come within the scope of this subheading, as the direction of power in these two lines is not constant, but variable according to load conditions. They will be discussed under heading *B*. (See p. 381, paragraph 3.)

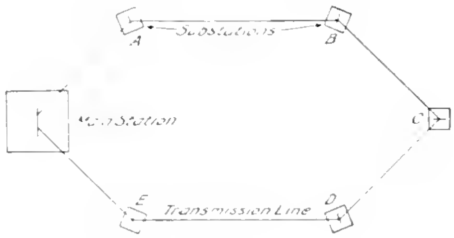


Fig. 11

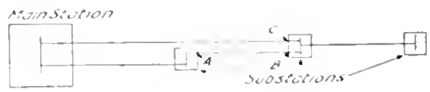


Fig. 12

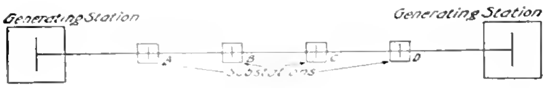
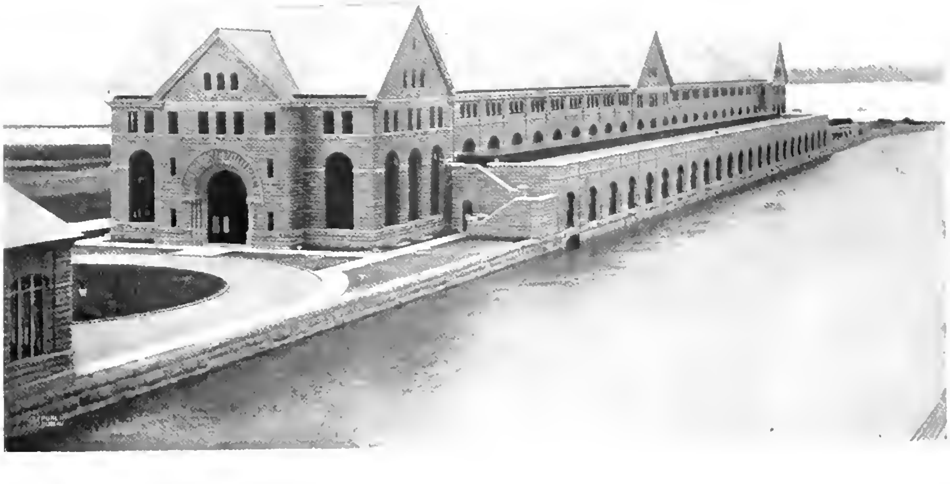


Fig. 13

The operation of the relays is self-evident for lines *AB* and *ED*. A short-circuit, however, in lines between generating station and *A*, and generating station and *B*, produce certain complications. It will be seen that a short, for instance, in the line between generating station and *A* will cause a reversal of direction of power, not only at *A*, but also at *B*, so that plain instantaneous reverse power relays at *A* and *B* would both go out at the same time. It is, therefore, necessary to give the reverse power relay at *B* a slight time element, which will give *A* a chance to go out ahead of *B*. This can be obtained easily and safely by connecting in a definite time element of short duration, so arranged that its coil is energized by the action of the reverse energy relay at *B*, and that the trip coil of the oil switch in turn is energized through the action of the definite time limit relay. If there should be a greater number of lines in series with the same characteristics, the time element should, of course, be graded. Care should be taken that the longest time element of the reverse power relays in series is less than the shortest time element of the selective time limit relays, so as to make sure that the reverse power relays go out ahead of the selective relays. Systems as shown in Fig. 11 have seldom more than very few lines in series, and this condition, therefore, does not impose any hardship.

A similar condition exists in systems arranged as shown in Figs. 12 and 13. In Fig. 12 reverse power relays at *C* and *A* should be instantaneous, and at *B* should have a short time element. In Fig. 13, line *BC* has other characteristics than those to be considered in this paragraph. Reverse power relays at *A* and *D* should be instantaneous, and those at *B* and *C* should have short time elements, which, however, may be of the same magnitude for the two relays.

In the next installment of this paper we will conclude section *A* with a study of the conditions which are met when two or more transmission lines connect the various stations, and take up the remaining relay applications for meeting short circuit conditions on transmission lines. We will then proceed to the other headings of the analysis of relays included under the main classification of "Nature of Disturbance."



VERTICAL SHAFT SINGLE RUNNER HYDRAULIC TURBINES AS APPLIED TO LOW HEADS

By H. Birchard Taylor

Hydraulic Engineer, I. P. Morris Company, Philadelphia, Pa.

In order to compare the performances of any two hydraulic turbines, it is necessary to reduce all factors to a common basis, the quantity best suited for this purpose being represented by the speed of a model runner of unit capacity when operated at its maximum efficiency under unit head. This quantity is known as the "specific speed." The marked increase in the specific speed of hydraulic runners during the last few years has made available low head units of much greater capacity than were formerly practical; and in this development the vertical shaft single runner turbine has come prominently to the front. It is the prime mover in most of the recent large low head hydro-electric developments. Some very interesting data pertaining to tests on the units of the Pennsylvania Water Power Company and the Appalachian Power Company are given. The latter turbines, which are of the single runner vertical shaft type, showed in final test the remarkable efficiency of 93.7 per cent, a gain of 3.02 per cent over the efficiency of the experimental runner at the Holyoke flume, and a better performance by 6 per cent than that given by the McCall Ferry units.—Editor.

Engineers interested in hydro-electric installations have probably noticed during the last few years the increased application of single runner, vertical shaft turbines to low heads, where previously the turbines applied to low heads were either of the vertical shaft multi-runner, or of the horizontal shaft multi-runner type.

The adaptation of the single runner vertical unit to low heads has been made possible by recent progress in the design and development of high-capacity runners. Thus, for a given head and speed it is now possible to secure from a runner a greater output than was possible two or three years ago; or conversely, for a fixed head and capacity it is possible to operate the more recently designed runners at a much higher rotational speed than was the case with runners designed a few years ago. This increase in the capacity of runners has been secured without a sacrifice of maximum efficiency, and with only a small sacrifice in the efficiencies at part loads.

In referring to the capacity of a runner, there is a certain relation between speed, head and power output, which is best expressed by a theoretical characteristic known as "specific speed" (N). This characteristic was first introduced by German engineers. It gives us a means of comparing the relation between the conditions of speed, head and power of a runner in one installation with the same conditions relative to a runner in a totally different installation. This comparison is made after the conditions governing both runners have been reduced to a common base, viz., specific speed.

The specific speed of a runner may be defined as the speed at which any runner will operate when it is reduced to such a size that it will develop one horse power when operating under a head of unity. The numerical value, expressed in the metric system, of the specific speed of any runner may be found by first calculating the speed and power output of the runner under consideration for one metre head, and then mathematically reducing the runner in size until it will deliver one horse power. The speed of this reduced runner, when operating at its point of maximum efficiency, is its rated specific speed.

Considering a given runner in a turbine which delivers a power of HP under h metres head with a speed of RPM, and keeping the diameter d constant, let the head be reduced to one metre. The velocity V of the water passing through it will vary in direct proportion to $\sqrt{h}$; the quantity of water, Q, will vary directly with the velocity; and the power output, HP, will vary directly with $Q \times h$. Since the diameter of the runner is constant, the revolutions per minute, RPM, will vary with the peripheral velocity, or proportionally to $\sqrt{h}$.

Therefore, for a constant diameter of runner

$$^{*}Q \alpha h^{1/2}$$
$$HP \alpha Q \times h \alpha h^{3/2}$$
$$RPM \alpha h^{1/2}$$

Hence, the horse power delivered under one metre head, HP_{1m}, will be $HP_{1m} = \frac{HP}{h^{3/2}}$ (a)

and the speed will be

$$RPM_{1m} = \frac{RPM}{h^{1/2}} \qquad \text{(b)}$$

Now let the head be kept constant and imagine all the dimensions of the runner reduced proportionally. The dimensions will all remain in fixed ratio to the diameter, d, and all areas of passages through the runner will vary in proportion to d^2; the velocities remaining constant on account of the constant head. We therefore have for constant head:

$$Q \alpha d^2$$
$$HP \alpha Q \alpha d^2 d \alpha \sqrt{HP}$$

* To be read: Q varies as $h^{1/2}$

As the peripheral velocity of the runner must also remain constant:

$$RPM \alpha \frac{1}{d} \alpha \frac{1}{\sqrt{HP}} \qquad (c)$$

Hence, the speeds of a set of similar runners, all operating under the same head, will vary inversely as the square roots of their horse powers, and if one runner gives a speed of *RPM* with a power *HP*, it follows that a one horse power turbine will give a speed of

$$RPM_{1HP} = RPM \times \sqrt{HP} \qquad (d)$$

If the constant head be one metre, the speed of the one horse power runner will be

$$RPM_{1HP1m} = N_s = RPM_{1m}\sqrt{HP_{1m}} \text{ from (d)}$$

$$= \frac{RPM}{h^{1/2}} \times \sqrt{\frac{HP}{h^{3/2}}} \text{ from (a) and (b)}$$

or, $\text{specific speed} = N_s = RPM \times \frac{\sqrt{HP}}{h^{5/4}} \qquad (e)$

the quantities being expressed in the metric system.

In transferring this to the foot-pounds system of units, we have $h = 1$ ft., or $\frac{1}{3.28}$ of the metric h given in formula (e).

The English $HP = 0.986 \times$ metric HP.

$$N_s = RPM \times \frac{\sqrt{HP} \times (3.28)^{5/4}}{\sqrt{0.986} \times h^{5/4}}$$

$$N_s = 4.45 \times RPM \times \frac{\sqrt{HP}}{h^{5/4}} \qquad (f)$$

The specific speed as calculated from this formula is the one generally used.

In figuring the N_s of any turbine having more than one runner, the *HP* used in the formula is, of course, the output from each runner.

Formula (f) applies directly to a single runner turbine. In the case of a turbine of the same capacity, having *N* runners of the same specific speed, it is seen that the *RPM* would be $\sqrt{N}$ times the *RPM* of the single runner turbine.

In formula (f) it is readily seen that for a given value of *RPM* and *h*, the *HP* output is proportional to the square of the specific speed; also, that for a given head and *HP*, the *RPM* of a turbine is proportional to the specific speed.

Five years ago a specific speed of 275 was considered to be quite high, while today a specific speed of 400 is secured, together with a higher maximum efficiency than was previously secured with a specific speed of 275.

For comparison, let us consider two extreme cases:

1. Conditions governing the design of the runners in the turbines of the Great Western Power Company. Capacity 18,500 h.p.; head 465 feet; speed 400 r.p.m.
2. Conditions governing the design of the runners in the turbines of the Mississippi River Power Company. Capacity 10,000 h.p.; head 32 feet; speed 57.7 r.p.m.

The runners in the Great Western turbines are of very low specific speed, i.e., 112; while the runners in the Mississippi turbines are of very high specific speed, i.e., 338. Should we install in the Mississippi turbines runners having the same specific speed as the Great Western runners, we would secure for a 10,000 horse power turbine under a head of 32 feet, a speed of only 19.1 revolutions per minute instead of 57.7 revolutions per minute, which is the actual speed of these runners. Such a design would call for a runner having an extreme dimension of approximately 32 feet, which is 1.8 times as large as the extreme dimension of the Mississippi River runners; the points of measurement being different in the two cases, as the shape of a low specific speed runner of the Great Western type is entirely different from the shape of a high specific speed runner of the Mississippi type. The generators would be correspondingly large, which of course would be impractical. With the highest specific speed which could be secured five years ago, the resulting speed for a vertical shaft single runner turbine for low heads was in a great majority of cases such as to make the cost of both the turbine and generator prohibitive. During the last few years, however, with increased specific speed runners, higher speed for the same head and power has been secured, so that the turbine and generator designs have become thoroughly practical and economical. Although it is true that the speed secured in such a turbine is low when compared to the speeds secured with turbines of the same specific speed and having two or more runners, there are many economical advantages secured in the use of a single runner vertical turbine for low heads which more than overbalance the increased cost of the generator.

The following are among the recent prominent low head plants for which the single runner vertical type of turbine has been adopted:

Mississippi River Power Company, Keokuk, Iowa.

Present installation, fifteen 10,000 h.p. units; head 32 feet; speed 57.7 r.p.m.; ultimate installation, thirty units.

Appalachian Power Company, New River, Virginia.

Development No. 2, four 6000 h.p. units; head 49 ft.; 116 r.p.m.

Development No. 4, three 3500 h.p. units; head 34 ft.; 97 r.p.m.

Georgia-Carolina Power Company, Stevens Creek, Georgia.

Present installation, five 3125 h.p. units; head 27 feet; 75 r.p.m.; ultimate installation, ten units.

Alabama Power Company, Lock No. 12, Coosa River, Alabama.

Present installation, four 17,500 h.p. units; head 68 feet; 100 r.p.m.; ultimate installation, six units.

* Cedar Rapids Manufacturing and Power Company, St. Lawrence River, Canada.

Present installation, twelve 10,800 h.p. units; head 30 feet; speed 55.6 r.p.m.; ultimate installation, eighteen units.

Laurentide Company, Limited, Grand Mere, P. Q., Canada,

Present installation, six 20,000 h.p. units; head 76 feet; speed 120 r.p.m.; ultimate installation, ten units.

Had these plants been built five years ago, it would have been impossible to install vertical shaft, single runner units of the same capacity, owing to the low speed and the resultant size of turbines and generators. For the same capacities it would have been necessary to install turbines with more than one runner; or, if single runner vertical shaft turbines were used, the capacity of each would necessarily have been considerably less than that of the turbines actually installed, owing to the excessive dimensions that it would have been necessary to deal with.

In a majority of these plants comparisons of cost were made between vertical shaft, single runner units and both vertical and horizontal shaft multi-runner units. In each case the comparison of total cost (with efficiency, maintenance and cost of operation considered) showed the best investment to be based on the type finally adopted.

Let us assume that in a low head plant under consideration it is practical to install units of any type, and it is desired to make comparisons to determine the advantages of the various types. The principal *disadvantages* which exist in the use of turbines with two or more runners, are as follows:

1st. Two or more sets of gate mechanisms are required.

2nd. Equal gate openings on all runners are difficult to obtain at all degrees of opening, owing to lost motion or torsional deflection in the gate operating shafts.

3rd. One or all of the gate mechanisms are completely submerged and are not accessible until the unit is shut down and the wheel-chamber is drained.

4th. When multi-runner, horizontal shaft type turbines are installed it is frequently necessary for the generator floor to be below high tail-water level.

5th. It is often impossible to place the runners sufficiently far below the head water surface to avoid the formation of vortices and the drawing of air into the turbines. This condition frequently impairs the speed regulation as well as the efficiency.

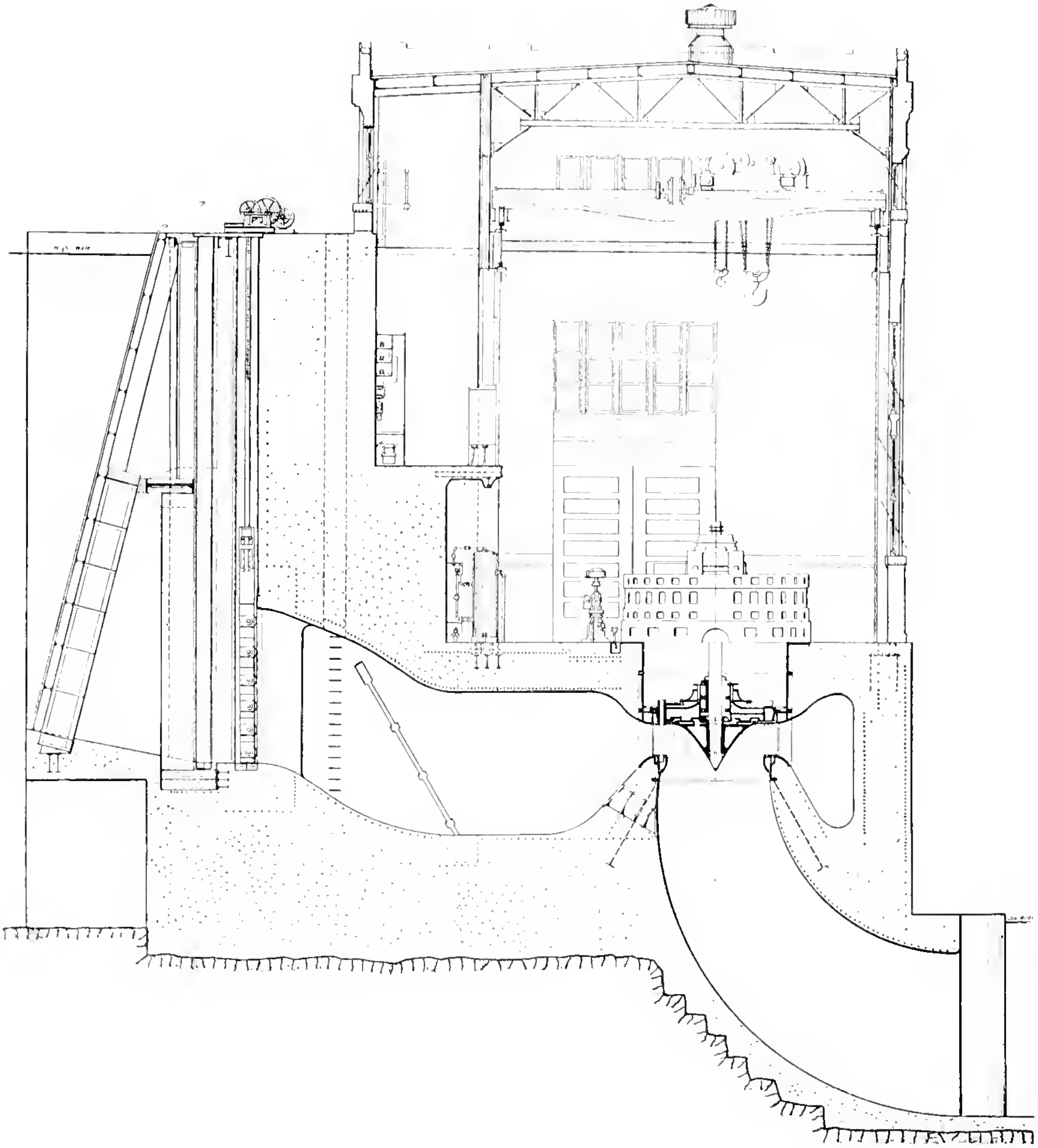
6th In the case of a vertical turbine having more than one runner, the depth and consequently the cost of the sub-structure of the power house is necessarily much greater than in the case of a vertical single runner turbine.

7th. The cost of erection and of dismantling for repairs in the case of the multi-runner units of either the vertical or horizontal type is considerably more than in the case of the vertical single-runner wheel.

8th. In any type of turbine having two or more runners in which the runners discharge against each other into a common draft chest or chests, there is considerable loss in efficiency due to interference of discharge, unless the distance between runners, and therefore the length of the turbine and the cost thereof, is greatly increased. The higher the specific speed, the higher is the discharge velocity from the runner buckets, and as the loss in the draft chest or tube is proportional to the square of the velocity, the loss in efficiency increases with the specific speed. It necessarily follows that in the case of high specific speed wheels, great care must be exercised in properly designing the draft chests and draft tubes. The avoidance of sharp bends in the immediate neighborhood of the runner discharge is an advantage obtainable with the single runner vertical turbine.

In turbines similar to those installed at McCall Ferry, Pennsylvania, which are of the vertical two-runner type, both runners discharge downward into independent draft tubes, which is the best design possible for a turbine of this type. It is necessary in the case of the draft tube below the lower runner to make an extremely sharp turn so as to avoid excessive excavation. There is

* The main units for the Cedar Rapids Manufacturing and Power Company will be the largest in the world, exceeding in dimensions those now being installed by the Mississippi River Power Company at Keokuk.



Section Through Power House No. 2, Appalachian Power Company, Showing
6000 H.P. Hydraulic Turbines and Generators in Place

considerable loss in efficiency in this draft tube, owing to this sudden turn. In the case of the McCall Ferry units, however, the specific speed, and therefore the velocity from the runner buckets, is not very high, and the loss at this point is not excessive.

Among the principal advantages of the single runner unit are the following:

1st. Only one gate operating mechanism is required, and this is located above the head cover of the turbine and is accessible at all times for inspection while the unit is in operation. The only part of the turbine that is submerged is the runner and the guide vanes themselves. Repairs can be made to this mechanism without dismantling the turbine.

2nd. Owing to the fact that only one gate operating mechanism is used, involving a small number of parts, the chance for breakage is reduced to a minimum.

3rd. It is possible to secure in a single runner unit an ideal draft tube of long tapering section, without any obstruction or sudden turn. Therefore with this type of wheel it is possible to use runners of the very highest specific speed, as the draft tube can be designed to convert the velocity at the discharge from the runner buckets into effective head with small degree of loss.

4th. With a single runner vertical unit, it is possible to mold in the concrete a spiral turbine casing similar in design to the cast iron spiral casings used in connection with high head turbines. It would be impractical to prepare spiral casings for vertical or horizontal turbines having two or more runners, for obvious reasons. In a single runner turbine operating in a spiral casing, the water is directed to the runner at uniform velocity around its entire circumference, producing more uniform operation and higher efficiency thereby. In the case of the multi-runner vertical or horizontal wheels, however, it is necessary to set these wheels in open flumes, in which case the water is not guided uniformly to the runner. Consequently, the approaching water is in a more or less turbulent state from eddies and whirls. In order to eliminate excessive loss in efficiency due to these eddies and whirls it is essential to keep the velocities extremely low in the flumes by increasing the dimensions of the flume, and therefore the distance between wheel-centers.

The theory of the flow of water through runners as derived from low specific speed runners is not applicable, without modification, to the design of high specific speed runners, on account of a number of new factors which must be considered. Low speed wheels are such as are usually applied to high head turbines. The runners installed in the various units at Niagara Falls are examples of low and moderate speed types.

Among waterwheel builders it is usually the practice, in high specific speed installations, to test a small model of the proposed runner at the Holyoke flume, in order to determine the performance of any given runner before final installation. From the results of the Holyoke test, the required diameter of the runner for any particular installation can be readily figured. After this diameter is determined, drawings of the model runner may be stepped up by means of a pantagraph in the ratio of the diameters of the large runner to its model. By this means the areas in the large runner are increased in the ratio of the square of the dimensions, and all linear dimensions of the large runner are increased in proportion to the ratio of the diameters.

The usual experimental turbine tested at the Holyoke testing flume consists of a vertical shaft, single runner wheel with a long tapered draft tube. The vertical single runner unit duplicates the Holyoke setting, and consequently it is safe to anticipate securing results in a large unit in place as good as were secured in the model wheel at Holyoke.

In the case of the multi-runner unit, however, in which runners discharge against each other into a common draft chest, the loss in this draft chest may be so great as to produce lower efficiencies in the large unit than were secured in the model runner. For this reason experience has shown that in horizontal or vertical multi-runner units the performance of the large turbines seldom exceeds the efficiency secured in the experimental runner, while in a great majority of cases the results are considerably less.

In the case of the single runner vertical unit, however, where the Holyoke setting is duplicated on a larger scale and where as a matter of fact it is possible to secure a better draft tube than at the Holyoke flume, owing to the fact that the length of the draft tube is restricted by the existing dimensions of the flume, results can be expected in large vertical single runner turbines superior to those secured in the model runners. To illustrate this point, let us compare the turbines of the McCall Ferry and Appalachian plants. The model runner for the last two McCall Ferry units gave a maximum efficiency at Holyoke of 90.62 per cent. Owing to the large size of the McCall Ferry units, it is impossible to measure the water in an efficiency test; so in order to determine the efficiency, a curve was plotted between vane opening and power output. This curve was compared to a curve of the model runner, plotted between vane opening and power output, when stepped up to the conditions of head and speed existing at McCall Ferry. Knowing the efficiency of the Holyoke runner, the efficiency of the large turbines may be approximated by charging any difference in power between the two curves against the efficiency of the large turbine. The efficiency so determined is not altogether correct, because it is unfair to charge all of the difference in power against the efficiency of the large turbine, as the increase in lost head in the large turbine must result in a consumption of water less than that calculated from the Holyoke test. For all practical purposes, however, the above method may be used.

The maximum efficiency of the McCall Ferry units, when calculated in this manner, figures to be approximately 87.5 per cent, or 3.12 per cent less than the maximum efficiency secured in the Holyoke test. The difference may be attributed to the sharp turns in the draft tubes and to the usual losses in the casing of the open flume type.

In the case of the Appalachian wheels, which are vertical single runner units, having concrete spiral casings and ideal draft tubes, very exhaustive efficiency tests were made on two wheels, measuring the water by means of a carefully constructed weir 82 feet across the crest. The average maximum efficiency secured in the two wheels was found to be 93.7 per cent. The model runner for the Appalachian turbines showed at Holyoke a maximum efficiency of 89.68 per cent. Consequently, the large units in place show 4.02 per cent in excess of the maximum efficiency secured in the model wheel. This increase in efficiency is due to the following conditions:

(*a*) The water was brought to the runner in carefully designed spiral wheel-cases, molded in the concrete substructure, while the model runners are tested at Holyoke in an open flume.

(*b*) Ideal draft tubes of long tapering section were prepared in the concrete foundations, while the length of the draft tube used in connection with the Holyoke model was restricted.

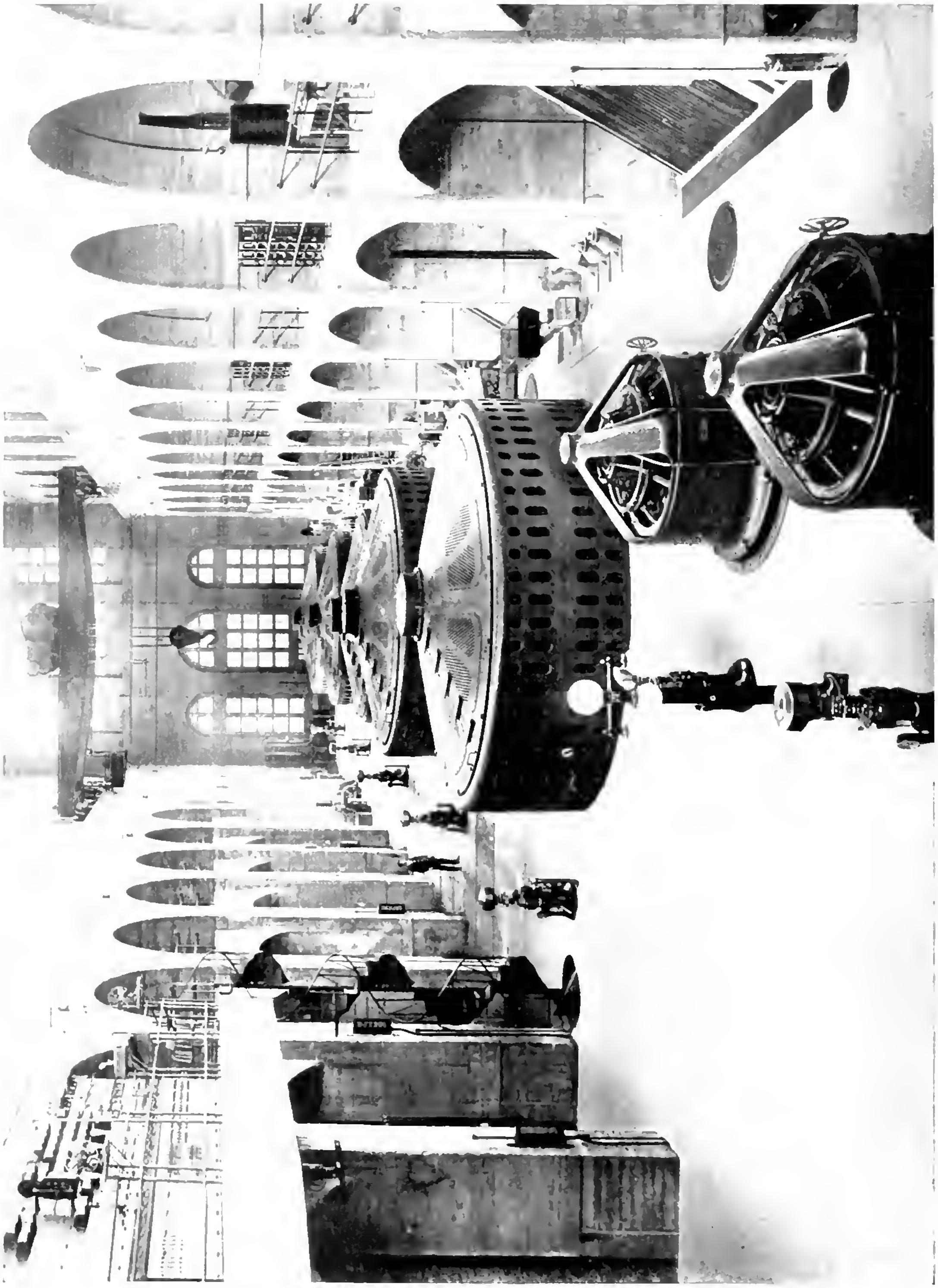
(*c*) The efficiency of a large runner is theoretically higher than a small runner. The diameter of the Appalachian runners is $90\frac{1}{4}$ in., while the diameter of the model runner is $27\frac{3}{8}$ in.

(*d*) The power developed by the model runner was only 115 horse power, as compared to 6000 horse power in the large turbine. The mechanical friction loss in the case of the model is a greater proportion of the total power developed by the runner than in the case of the large turbine.

Comparing the results, therefore, of the McCall Ferry and Appalachian turbines, the experimental runners for both installations showing approximately 90 per cent at Holyoke the single runner vertical units in place give an efficiency of approximately 6 per cent above the maximum efficiency secured at McCall Ferry. It may be assumed that this same difference in efficiency for high specific speed turbines would exist between any vertical single runner turbine of large size, operating in a spiral wheel-casing, and any multi-runner open flume turbine having two or more runners discharging into independent draft tubes; also this difference may be still greater if the comparison were made between a single runner vertical shaft turbine and a multi-runner turbine in which each pair of runners discharges into a common tube

The advantages enumerated in favor of the single runner vertical shaft wheel have made that type of turbine most desirable for low head installations on practically every count which should affect the choice of a hydraulic turbine. It is also to be borne in mind that the recent development of satisfactory thrust bearings for large vertical units has greatly encouraged the use of this type of wheel. There are now three reliable types of thrust bearings suitable for units of the largest sizes. These bearings have passed through the experimental stage and have given very satisfactory results. A few years ago the difficulties of taking care of the thrust safely and economically on large vertical shaft units was often used as an argument against the vertical wheel.

It is safe to predict that in the future the single runner vertical wheel will be used almost exclusively for low heads. Where efficiency is important, 6 per cent capitalized will invariably be found sufficient argument for settling on this type of wheel.



Interior of Holtwood Station of the Pennsylvania Water & Power Company, showing two 400 kw. vertical exciters and three 7500 kv-a. and two 10,000 kv-a. vertical waterwheel generators. The generators operate at 94 r.p.m. and deliver three-phase current at 25 cycles, 11,000 volts. Initial capacity of station 42,500 kv-a.

GENERATORS FOR HYDRO-ELECTRIC POWER STATIONS

By Eric A. Lof

Power and Mining Engineering Department, General Electric Company

The first part of the article shows how the number, speed and capacity of generating units in a hydro-electric station are affected by hydraulic conditions and by the economical rating of the waterwheels. A section on the factors governing choice of voltage and frequency is followed by a discussion of the temperature limits which should be observed and means for specifying them. The author illustrates the correct method to follow in specifying generator efficiency, and indicates the present trend of design in regard to generator regulation. He enumerates the advantages of the Y connection of armature windings, and summarizes the case for isolated *versus* grounded neutrals. The concluding paragraphs illustrate present practice in the mechanical design of large generators for waterwheel drive, attention being directed to the advantages of vertical construction, to ventilation, prevention of corona on high-voltage armature coils, rotor construction, brakes and bearings.
—Editor.

In determining the proper rating and capacity of generators for a water power development, the generator and the waterwheel must of necessity be treated together as a combination. The importance of this is emphasized by the fact that there are in operation, in many stations, units in which the output is unnecessarily limited by an incorrect rating or design of either the generator or waterwheel, the latter being either too small or too large for the generator in question. The generator may, for example, have been designed and rated on the basis of unity power-factor operation, with a wheel having a corresponding capacity; while the actual operating power-factor may be only 0.80, with the result that only part of the waterwheel capacity can be utilized.

Rating of Generators

The rating of a generator is usually determined by its permissible temperature rise caused by the current. This rise necessarily increases with increasing load and also with decreasing power-factor. Thus for a given kv-a. output, the total heat losses are larger for low than for high power-factors, the difference being due to the heat generated by the increased field current which is required to overcome the armature reaction and maintain the given current and terminal voltage.

Alternating current generators are generally designed to operate at normal load and 80 per cent power-factor without exceeding a specified temperature rise; and should such a machine have to be operated with a load having a lower power-factor, its rating will be reduced, when based on the same temperature guarantee. The true operating power-factor should, therefore, be carefully considered in selecting the capacity of the generating units. The power-factor depends not only on the type of apparatus comprising the load, but also on the load factor at which they are operated.

To obtain the total kv-a. capacity of a system, the sum of the energy components and also the sum of the wattless components of the different loads should be calculated, the efficiency, power-factor and load factor being duly considered. The total capacity is then equal, in kv-a., to

$$\sqrt{(\text{Total kw. energy})^2+(\text{Total kv-a. wattless})^2}$$

and the combined power-factor of the load

$$=\frac{\text{Total kw. energy}}{\text{Total kv-a.}}$$

The generator rating should correspond to the point of maximum efficiency of the waterwheel, as the efficiency of the latter usually falls off rapidly above and below this point. The margin between the point of maximum efficiency and the maximum full-load capacity of the wheel—which is that point beyond which the output decreases with an increase in gate opening—depends upon the specific speed of the runner, and is smaller the higher the specific speed, as shown in Fig. 1.* With wheels of high specific speed, which are required with low head developments, it is therefore desirable to operate the wheels normally near their maximum output, leaving only a small margin (about five or six per cent) for regulating purposes. The generator should then preferably be given a maximum or constant continuous rating corresponding to the normal capacity of the wheel.

With high head wheels, as represented by curve *A*, Fig. 1, the efficiency remains comparatively constant over a very large range in power; and for this reason it is not so important that wheels of this type be operated near their full-load output. For the sake of uniformity and standardization, it seems desirable, however, to give all waterwheel-driven generators a constant continuous rating with a certain specified temperature

* "Specific Speed" is defined in Mr. Taylor's article, "Vertical-Shaft Single-Runner Hydraulic Turbines as Applied to Low Heads," on page 384 of this issue.

rise, which rating should not be exceeded except during momentary peaks, and regardless of the rated voltage.

Speed, Number and Capacity of Units

The speed of waterwheel-driven generators is also largely determined by hydraulic conditions, and the characteristics of the type of wheel with which it is to be used. A high specific speed runner means a high actual speed, and a low specific speed runner means a low actual speed in revolutions per minute. For this reason, wheels of low specific speeds must be used with high heads in order to bring the speed of the generator within the range of good electrical and mechanical design.

The variation in the head as caused by floods and dry seasons has also a considerable bearing on the selection of the proper waterwheel unit, as illustrated in Fig. 2. In this case a wheel is assumed to operate normally under a 32-foot head, the speed to be constant for a range of heads from 26 to 38 feet. The curves give the efficiency and power of the wheel when operating at constant speed under these various heads; and it is seen that, as the head goes up to 38 feet, the shape of the curve approaches curve *B* in Fig. 1, which means that the speed of the wheel is lower than the best speed for a 38-foot head. When the head falls to 26 feet the curve approaches more closely to curve *C* in Fig. 1, which, on the other hand, means that the speed of the wheel is higher than the best speed for 26 feet. The curves also clearly show the margin between the point of maximum efficiency and the maximum output of the wheel for the various heads. In the selection of the speed for any installation, therefore, aside from the cost of the units, the efficiencies at partial gate openings have a considerable bearing. Where a unit is likely to operate under a wide range in power, it is advisable to select a wheel with characteristics as represented by curve *A*, giving a high efficiency for a considerable range in power. The frequency of the system must, of course, also be considered when determining the speed.

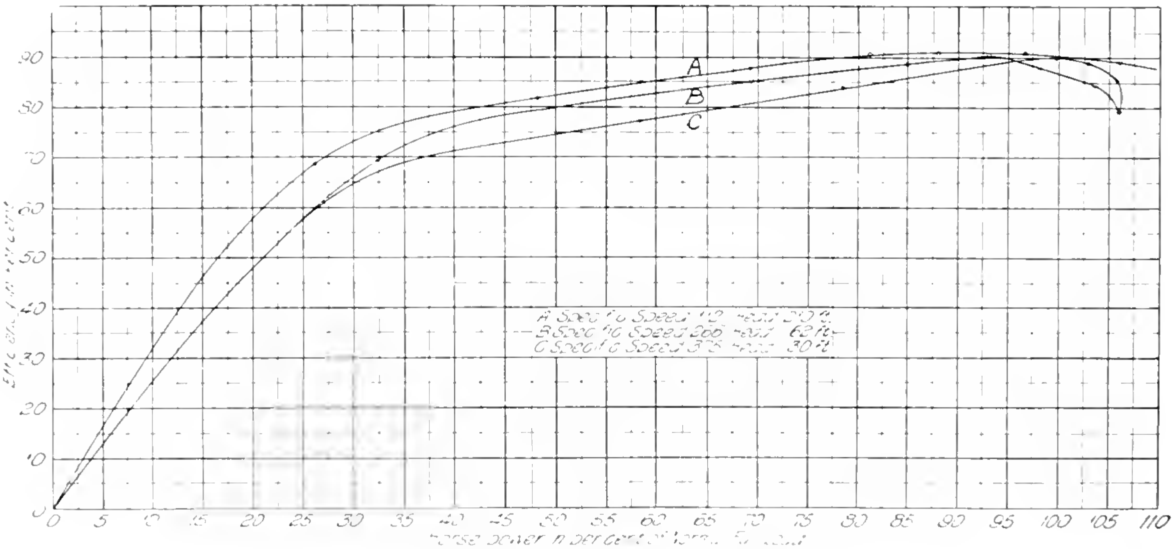


Fig. 1. From a Print Issued by the I. P. Morris Company Showing Performance Curves of Various Turbines Designed and Built for Various Heads and Specific Speeds

The number and capacity of the generating units in a hydro-electric station is, besides hydraulic conditions, governed by the load factor, the nature of the load, the reserve capacity, the reliability and flexibility of the service, etc. The units should be operated at as near full load as possible, and new units should preferably be started as the load increases instead of utilizing overload capacities. Where sudden overloads of considerable magnitude come on the system for short periods, it is, of course, necessary to have wheel capacity sufficient to care for them. Single units are never desirable except for multiple-plant systems, in which case the necessary reserve can be obtained from other stations. For single-plant systems the number of units should preferably not be less than four; but above this the number should be governed by the limit in design, considered both from an engineering and economical standpoint. With a small number of large units the first cost, the maintenance charge and the necessary floor space are reduced, and the efficiency is also usually better than for a larger number of smaller units.

Choice of Voltage and Frequency

The three-phase system is now always used in connection with new developments. The frequency, however, far from being settled, is discussed again with every new installation. It affects the operating characteristics of the circuits and apparatus of the system, and also their cost; and, in order to arrive at the proper value, it becomes necessary to consider the influence which the frequency will have on the different parts of the whole system.* Of greatest importance on systems with long transmission lines is the question of regulation, which may become so poor with a 60-cycle frequency as to entirely prohibit its use.

The frequencies most commonly employed in this country are 25 and 60. In general it may be said that, where lighting load is predominating, 60 cycles should preferably be selected; while, if the load mainly consists of power, 25 cycles is often preferable, especially if the load consists of a large number of synchronous converters. With a large induction motor load it may, on the other hand, be more advantageous to use 60 cycles on account of the greater number of speeds, which are possible with this frequency. The standard generator voltages for all frequencies are 240, 480, 600, 1150, 2300, 4000 and 6600. In addition 11,000 volts is standard for 60 cycles and 13,200 volts for 25 cycles, the generator pressure seldom exceeding this value.

When additions to an existing plant or system are made, the voltage of the new generators is generally determined by that of the old machines, or by some other condition of the installation. In new installations, however, the generator voltage is determined by the nature of the load and the distance of the transmission. Whether the generators are to be wound for a high voltage for direct transmission, or for low voltage and step-up transformers, is to a certain extent decided by the relative cost of the two methods. If economically feasible the latter method with step-up transformers is, however, the most reliable and to be recommended. In other instances the nature of a local load may be such that, by installing high-voltage generators, power for this load may be directly transmitted at the generator voltage; while at the same time step-up transformers may be provided for raising the pressure of the current which is to be transmitted for greater distances.

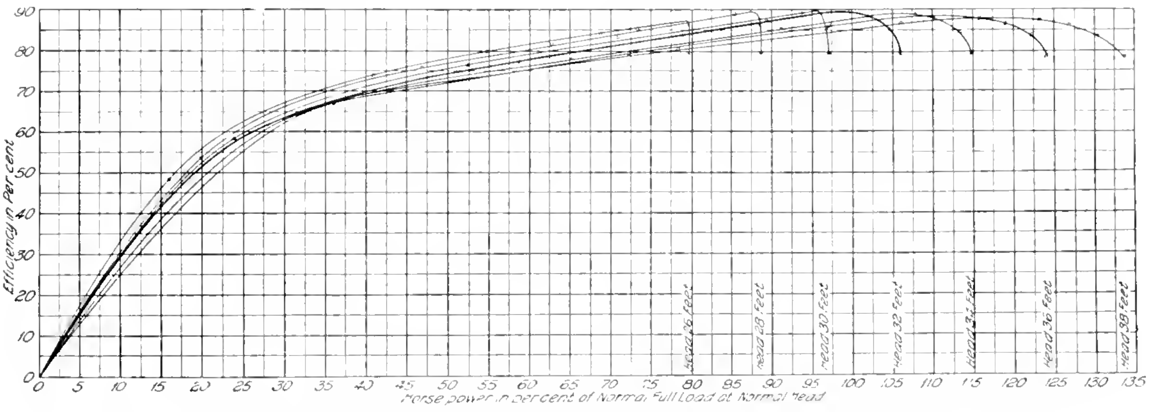


Fig. 2. From a Print Issued by the I. P. Morris Company Relating to a 10,000 Kw. Water Turbine. Turbine is Assumed to Operate Normally Under a Head of 32 ft. Curves Show Efficiency and Power for Constant Speed and Various Heads

Generator Temperatures and Rating

The temperature of a generator, under regular operating conditions, should never be allowed to remain at a point where a deterioration of its insulating material would take place. To prevent this, it has been a

*See A.I.E.E. June, 1912, "Frequency" by D. B. Rushmore.

standard (A.I.E.E.) practice to limit the permissible temperature rise for full continuous rated load, 0.80 power-factor, to 40 deg. C.; and for 25 per cent overload, 0.80 power-factor, for 2 hours, to 55 deg. C., the above rises being based on a room temperature of 25 deg. C. It has, however, previously been shown that it would be more advantageous to give waterwheel-driven generators a constant continuous rating without any but momentary overload capacities; and this practice has successfully been followed in a number of recent developments of considerable magnitude.

The A.I.E.E. Sub-Committee on Rating of Electrical Machinery has also recently* recommended that generators should be rated upon a basis of ultimate temperature, without other limits of capacity being exceeded; and, furthermore, that no overloads be specified except momentary overloads. These should not be less than 150 per cent of the rated current, should be without regard to the rated voltage, and should not exceed sixty seconds.

A maximum ultimate temperature of 90 deg. C. is recommended for machines having the coils insulated with cotton, treated cloth, paper, and similar substances which may fall in this general classification. It is also recommended that the room temperature on which tests are to be based should remain at 25 deg. C., this having been found to be the average temperature of the cooling medium in which generators are operated in practice. It is, however, found that the cooling medium may vary widely in temperature, and may, in poorly ventilated places, and in locations influenced by other conditions, run as high as 40 deg. C., even though the outdoor temperature be lower. For this reason it is recommended that 40 deg. C. be recognized as the upper normal limit of the cooling medium, and that temperatures higher than 40 deg. C. should be accepted as abnormal conditions and require special consideration. With the above stipulations it is, therefore, recommended that a constant continuous rating of alternating current generators should be based on a temperature rise not exceeding 50 deg. C. above that of a 25 deg. C. room temperature. This will then leave a 15 deg. C. margin for variation in the temperature of the cooling medium before the ultimate temperature, which would be injurious to the insulation, is reached.

*"Method of Rating Electrical Apparatus" A.I.E.E., Feb., 1913.

Efficiency and Regulation

The efficiency of a generator is the ratio of the power output to the power input, the difference between these two quantities being equal to the losses. In comparing the guaranteed efficiencies of several makes of generators care should be taken that they are based on the same assumptions. The generator efficiency (the ratio of the output to the input) should always refer to the energy rating at the operating power-factor. In certain instances the efficiencies are based on the apparent kilovolt-ampere rating, but the inconsistency of such a method, whether the losses at unity or at 80 per cent power-factor are used, is apparent from the following.

Assume a generator rated 100 kv-a. and designed to operate at 80 per cent power-factor, the losses at unity and 80 per cent power-factor being 10 and 11 kilowatts respectively. The efficiencies will then be as follows:

Based on 100 kv-a., 100 per cent power-factor:

$$\text{Efficiency} = \frac{100}{100+10} = 91 \text{ per cent.}$$

Based on 100 kv-a., 80 per cent power-factor:

$$\text{Efficiency} = \frac{100}{100+11} = 90 \text{ per cent.}$$

Based on 80 kw., 80 per cent power-factor:

$$\text{Efficiency} = \frac{80}{80+11} = 88 \text{ per cent.}$$

The regulation of an alternating current generator is defined as the rise in terminal voltage which would take place when a full load is thrown off, the speed and field current remaining constant. It is generally expressed in per cent; and is equal to the ratio of the maximum difference of terminal voltage from the rated load value (occurring within the range from rated load to open circuit) to the rated full load terminal voltage.

A close voltage regulation of any transmission system has always been desirable. To design an alternator for a close voltage regulation, however, necessitates that the reactance be of a low value, which is readily obtained with high-speed machines having a comparatively small diameter and few poles. The recent activity in low-head developments has, however, necessitated the use of very slow-speed machines having a large diameter and a very large number of poles. The result of this is a much higher reactance, which in some cases has reached a value as high as 15 per cent and over, this in turn resulting in a rather poor inherent regulation. A poor inherent regulation of the generator, however, does not prevent that a good regulation on the system can be maintained. To accomplish this the automatic voltage regulator has been developed, which will automatically increase the field excitation as the load increases and thus maintain a constant terminal voltage. If desired, it can also be adjusted so as to increase the voltage with the load and compensate for the line drop.

There is, however, one advantage in having generators of a high reactance, in that it reduces the short-circuit current of the machines. This is especially of very great importance in large systems where a considerable amount of power is concentrated in one place, and where the effects of high short-circuit currents would be very destructive, due to the severe mechanical strains which the magnetic fields, set up by these currents, would produce on the apparatus, and furthermore the difficulty of providing satisfactory switching devices to automatically protect the system.

Armature Connections and Grounding of the Neutral

Three-phase generators should have their armature windings connected in star. This is preferable to delta-connection, as it gives a higher voltage with a given number of conductors or a smaller number of conductors is required for a given voltage. With delta-connected generators there is also a danger of triple-frequency currents circulating in the armature winding. These currents are caused by third harmonic e.m.f.'s set up in the armature windings; and, as these e.m.f.'s are in phase, the machine is really running under short-circuit, as far as the triple harmonic current is concerned. This current, however, will consume the third harmonic e.m.f., which will, therefore, not appear in the terminal e.m.f. With low reactance machines the value of the local circulating current may be quite considerable, and the windings should therefore always be Y-connected.

With this connection all third harmonics, though present in the induced e.m.f. for each phase, will be entirely eliminated in the terminal e.m.f., because the third harmonic is in phase at any instant in all three windings, and so cancels out in the e.m.f. wave taken across the line. This also applies to all other harmonics whose frequency is a multiple of three times the fundamental; and hence no triple-frequency currents can flow in the line wires unless the generator neutral is grounded. If this latter condition is the case, the potential difference from line to ground may not be the line voltage divided by $\sqrt{3}$; but, superimposed on this voltage, there may be the triple-frequency e.m.f. and the maximum value of the wave may be greatly increased, thus increasing the insulation strain.

In a balanced three-phase system, third harmonics can therefore only exist in the voltage from line to neutral or Y-voltage; in the current from line to line, or generator delta current; and in the line current only if the generator neutrals are grounded or a return circuit provided.

With two generators operating in parallel, a difference of potential will exist between their neutrals equal to the vector difference between their phase e.m.f.'s. With the neutrals interconnected a local current would flow, limited by the generator impedance at triple frequency; while, if the triple-frequency e.m.f.'s in the two generators were equal and exactly in phase, there could be no neutral potential or current. Owing, however, to the difference in the angular velocity between the machines, different wave forms, different excitation, etc., this condition never exists; and a triple-frequency current, therefore, always flows between the neutrals, if interconnected. This current may be of considerable magnitude with low reactance machines, and, if excessive, precautions must be taken for preventing it. This can be done by grounding only one generator at a time, if the generators are to be grounded, leaving the neutrals of the other machines isolated. Arrangements must then also necessarily be made so that any of the generator neutrals can be grounded.

Whether the generator neutral should be grounded or not depends on the operating conditions.* If an uninterrupted service is the most essential consideration, the system should not be grounded, while if it is more desirable to limit the voltage strains, imposed by grounds, it may be advisable to ground the neutral, thus limiting the stress to the Y-voltage. Grounding may also be advisable where selective action is desired on a number of outgoing feeders, especially underground, so that individual feeders may be disconnected even in the case of grounds.

* This subject of grounding is considered at greater length by Dr. Steinmetz in his article "The Grounding of Transmission Lines" on page 370 of this issue.

In transmission systems with one or two lines the isolated system seems to be the most favored and the apparatus must therefore be designed to withstand the full delta-voltage. If this is not advisable the neutral must be dead-grounded; but in this case the mechanical design of the apparatus must be such that they can safely withstand the strains due to the frequent short-circuits which occur when grounds take place. If the grounding is done to insure selective action of feeders, it may be advisable to ground the generators through a resistance. In this case, however, the voltage strain is not limited to the Y-voltage and this must be given due consideration. The resistance should have a value high enough to limit the neutral current, but still low enough to insure that, if a ground occurs in one phase, it will permit a sufficiently large current to flow in the neutral to open the protective circuit-breakers. Non-inductive resistances are preferable to reactances, since they eliminate the danger of high-frequency oscillations between line and ground through the generator reactance in the path of the third harmonic, by damping the oscillation in resistance. The grounding of the neutral through a reactance may, therefore, be very dangerous, owing to the possibilities of a resonance voltage rise.

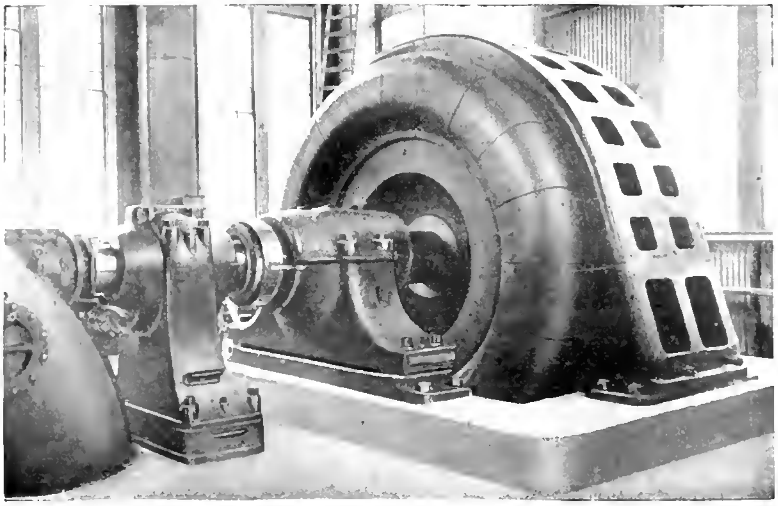


Fig. 3. A 8750 Kw., 6900 Volt Generator, Ventilated Entirely by Air Drawn in Around the Shaft and Expelled Into the Room Again, Through Holes in the Frame Above Base Line. No Openings to the Pit

Wave Shape

In regard to the wave shape standard, the present A.I.E.E. standardizing rules state that a maximum deviation of the generator e.m.f. wave from sinusoidal shape shall not exceed 10 per cent, the deviation to be determined by measurements from an oscillograph record or a wave form taken by a wave meter. There are a number of objections to this rule, such as the discrimination of higher harmonics, the necessity of using an oscillograph or wave meter which may not be available, the difficulty of making accurate measurements from the records, and the amount of work involved in the calculations, etc. Several suggestions for the revision of the above rule were, therefore, made at the recent standardizing meeting of the American Institute of Electrical Engineers.*

Mechanical Features of the Design †

Waterwheel-driven generators may be either of the horizontal or vertical type, the latter being now very extensively used in low-head developments where it becomes desirable to place the generators above the highest flood level. This arrangement requires less excavation, and obviates the necessity for special construction to protect from flood water, which would be necessary with horizontal units. In order to obtain commercial speeds for direct connection to horizontal generators it has been necessary for extreme low-head developments to put a number of runners on the same shaft. Recent improvements in the design of single runner turbines for low-heads resulting in increased speeds, as well as the comparatively low cost of vertical generators operating at from one-third to one-half the speed of horizontal generators, have made the construction of vertical units for extreme low-heads much simpler than horizontal units. The draft-tube excavation required is, of course, much less and involves less expense. For high-head developments with impulse wheels, horizontal units are of course preferable.

With large generating units the question of ventilation becomes of great importance:

* See Proceedings, A.I.E.E., Feb., 1913.

† See also "Notes on the Design of Waterwheel-Driven Generators" by H. G. Reist, GENERAL ELECTRIC REVIEW, June, 1912.

and modern machines are therefore being designed to control the path and utilize the cooling effect of the moving air to the greatest extent. Such a machine is shown in Fig. 3. The frame is provided with ventilating holes only above the base line, no outlets being provided toward the pit. The end-shields are so designed that they enclose the end of the rotor; and all of the air for ventilating the machines is forced by means of fans on the rotor into the end-shields where it is put under pressure, thus ventilating the end windings. The air which passes through the core and windings below the base is forced out of the larger openings in the feet of the armature frame. This will prevent the collection of heated air in the pit, which may again be returned to the field, and so used over and over, and become more and more heated. In certain instances no fans need be provided, the field poles themselves providing the required fan action. Another very noticeable feature of this construction is the quiet running of the machines.

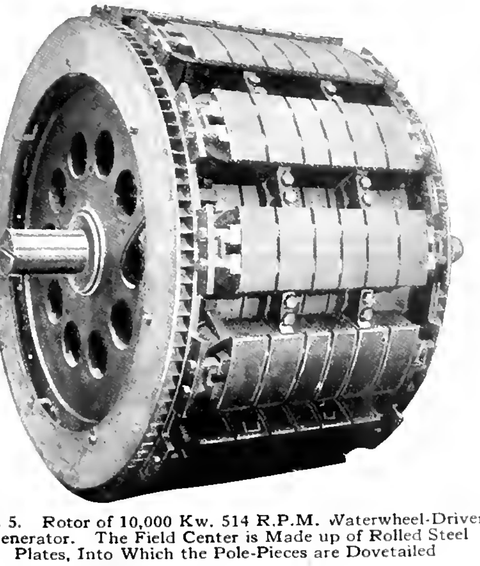


Fig. 5. Rotor of 10,000 Kw. 514 R.P.M. Waterwheel-Driven Generator. The Field Center is Made up of Rolled Steel Plates, Into Which the Pole-Pieces are Dovetailed

Another construction is shown in Fig. 4. A hood is provided in connection with the ventilating end-shields, the intention being to obtain all the air through the pit, ducts

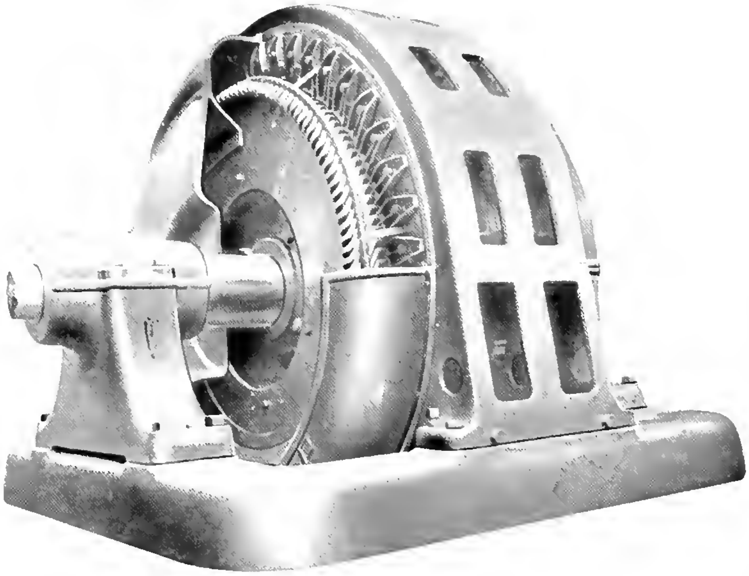


Fig. 4. A 7000 Kw., 11,000 Volt Generator, Ventilated by Air Drawn From the Pit and Expelled Into the Room Through Holes in the Frame

being provided in the floor for conducting the air from the outside. Care must, however, be taken in such a case to see that the air is pure and free from dust, or that dust screens are provided.

The prevention of corona on the armature coils of high-voltage generators must be given careful consideration. In many such machines there has been found a very pronounced corona formation between the coils and the iron. While at first this may not have any harmful effect, the chemical action of the ozone which is thus formed will in time deteriorate the insulation and result in a complete breakdown. It is, therefore, evident that the life of a high-voltage armature coil is just as much dependent on the methods taken to prevent the formation of corona, as upon the ability of the coil to stand up under the usual high-voltage tests. The problem is, however, now thoroughly understood; and this source of trouble can readily be prevented by a careful design and construction.

The revolving parts of waterwheel-driven generators should be designed so as to keep the stresses due to centrifugal force well within the elastic limit of all the material at the runaway speed of the waterwheel. This speed varies with different types of wheels and different conditions of installations; but the general practice is to design the rotors for 100 per cent over-speed, unless otherwise specified by the wheel builders.* This often involves special designs. Ordinarily the revolving field consists of a cast steel ring connected to the hub by means of arms, the pole pieces being dovetailed to the rim. For high speeds this construction is, however, unsuitable, and a design as shown in Fig. 5 has been adopted. The field centers are here constructed of rolled steel plates; and the pole pieces are securely fastened thereto by double or triple dovetails, thus making a very substantial construction. Clamping blocks are also provided between the field coils so as to prevent the winding from bulging out; and the connections between the coils should be securely fastened, to prevent them from working loose due to the strains imposed by the centrifugal force.

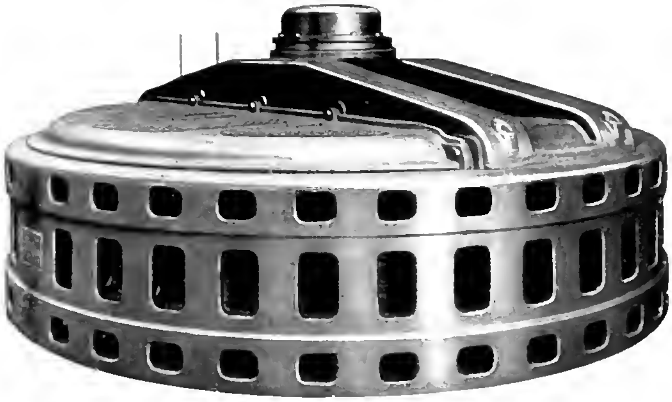


Fig. 6. Large Vertical Generator Showing the Strengthening of the Upper Bearing Bracket, Which in This Case Supports the Total Weight of the Moving Element

In large modern water power installations the units are very often provided with brakes, in order to stop them quickly. Foreign material may obstruct the gates, preventing their closure; so that, unless a brake is provided, it may not be possible to stop the wheel without closing the emergency gates. The brakes are generally applied to the generator rotor, the wooden face bearing directly on the field rim, and the required pressure being obtained by means of the oil pressure which is used for operating the governors.

* See "Runaway Speed of Waterwheels" by D. W. Mead, A.I.E.E., July, 1912

The question of flywheel effect is an important one when selecting waterwheel-driven generators. Modern alternating current generator rotors are as a rule built in the shape of an ordinary flywheel, and usually have a sufficient flywheel effect to obtain satisfactory regulation. When purchasing generators, a comparison of the flywheel effect should, however, always be made, as they are usually built as light and compact as possible. Additional flywheel effect within certain limits can usually be obtained at a small increase in the cost by simply adding more material to the rotor; and it will, as a rule, prove cheaper and more convenient to do this than to add a separate flywheel. There are, however, many cases on record where it was not possible to sufficiently increase the flywheel effect of a standard machine, and where it became more economical to install flywheels.

The bearings of horizontal units are always of the pedestal type arranged for oil-ring lubrication. For the largest machines it is, however, advisable to provide a water cooling system. This consists merely of a number of short tubes extending horizontally through oil-well below the bearing, water being circulated through these tubes, thereby cooling the oil.

Vertical shaft alternators are ordinarily provided with one or two guide bearings, and a short shaft for coupling to the waterwheel. In certain cases a step bearing is furnished by the waterwheel builder, this bearing being located below the generator and designed to support both the waterwheel and generator rotors. In other instances a suspension bearing is provided, this generally being furnished by the generator builder. This bearing is mounted on the upper generator bearing bracket, which, in this case, is strengthened so as to be able to support the weight of the total revolving element, including the water thrust if any. Such a design is shown in the illustration, Fig. 6.

Suspension bearings have mostly been of the roller type, which has given good results in most cases. They require, however, a very careful alignment and their cost is in most cases rather high. With the improvements which have recently been made in the old type oil-immersed plate bearing, and the good results which now are obtained from the same, there is every indication that this type will also come into very general use.

RECENT DEVELOPMENTS IN HIGH-VOLTAGE OIL BREAK SWITCH DESIGN

By E. H. Jacobs

Switchboard Department, General Electric Company

No radically new designs in oil break switches are described in this article, as these devices have for some time been well in advance of the requirements demanded of them by the exacting and severe service of the huge generating systems now in operation. The energies of the designing engineers have been directed towards refinements in the minor details, more particularly to realize a piece of apparatus that would serve with never failing certainty. In this connection, it is of the utmost importance to insure against the possibility of the motor-operated switch making more than the one stroke, opening or closing, that the operating impulse calls for. A description of the operation of the improved mechanism designed to accomplish this end is a part of the article. Other changes consist in the development of contacts and current-carrying parts for very heavy currents, and in the increased flexibility afforded by the greater number of methods of making connections to the switches. Further description refers to the operating mechanism for hand, solenoid, and air-operated switches, and to the arrangements for securing automatic protection against overloads and short circuits.—Editor.

In general, it may be said that the design of high-voltage oil break switches has progressed to such a point that there is but little opportunity or need for any particularly striking or novel changes. The recent tendency has been to refine and perfect the switches in use. This statement, although an accurate one, might be questioned by those who are familiar with the increased demand for high-voltage switches for outdoor service. As a matter of fact, however, the outdoor switches are similar to the indoor type, with some additions necessary to make them waterproof. These features will be brought out later.

The high-voltage oil break switch most extensively used is the so-called motor-operated type. Although generally referred to as motor-operated, this nomenclature is not strictly accurate, as the switch is actually opened and closed by compression springs. Before the initial operation occurs, one set of springs must be compressed either with a wrench by hand, or by the motor, which is a part of the switch equipment. Subsequently the release of the springs throws the switch into contact, or open sufficiently to break the arc, as the case may be, and besides partly compresses the opposite sets of springs for the next operation. Coincident with the energizing of the tripping magnet to release the operating mechanism, the motor receives current and through a gear picks up the motion of the switch and forces it to its ultimate position, with the compression springs fully compressed.

In all switches operated by compression springs it is necessary to provide not only means for releasing the mechanism at any desired time, or under abnormal conditions against which the switch is meant to offer protection, but also to prevent it from making more than one single definite stroke. In the motor-operated switch this is accomplished by a mechanical lock, which has recently been greatly improved. As this device is of such vital importance in the operation of switches of this character, a detail description of it will be given.

The design of the switch is such that the operating crank turns in the same direction for both the opening and closing strokes, making a half revolution each time the switch operates. Therefore the lock must be so designed as to release the operating mechanism when desired and to catch it after the main shaft has traveled 180 degrees. Fig. 1 shows the locking mechanism just at the beginning of a stroke. It is seen that on the main operating shaft (a) there is a cam (b) cast on the locking dog (c) and also that the roller stop (d) has been pulled slightly away from the lower end of the dog, thus releasing the dog and allowing the switch to operate. Attention is also directed to the relative positions of the cam (b) and the end of the lever (e), as well as to the position of the locking latch (f), the locking catch (g), and the motor control switch (h), these having taken the positions shown as a result of throwing current on the control magnet.

The particular feature of this lock is, however, not the method of releasing the switch, but the certainty with which it is stopped at the desired time. This is accomplished as follows: After the switch operating mechanism has traveled a slight distance the current is automatically cut off the tripping magnet by a small switch controlled by a cam on the main operating shaft (not shown in the illustration), the plunger drops back, and the spring (i) pulls the arm back into the locking position. However, if the residual of the tripping magnet is too great to allow the plunger to drop, or if the spring should break, the arm (k) might not return in time to catch the dog. All these points are guarded against. After the main shaft has revolved slightly, the cam (b), Fig. 2, presses against the end of the lever (c) and forces the tripping mechanism to the closed position at approximately half stroke of the switch and holds it in that position until the completion of the stroke. The construction of the lock is such that as soon as the locking latch (f) returns by means of the lever (c) and the cam (b), the main locking dog or roller stop (d) has returned also. Thus it is seen that the locking arm is positively forced back into the locking position by mechanical means, even without the aid of the spring (i). It can therefore readily be seen that, unless the mechanism itself should break, there is no possibility of the switch being able to make more than one definite stroke.

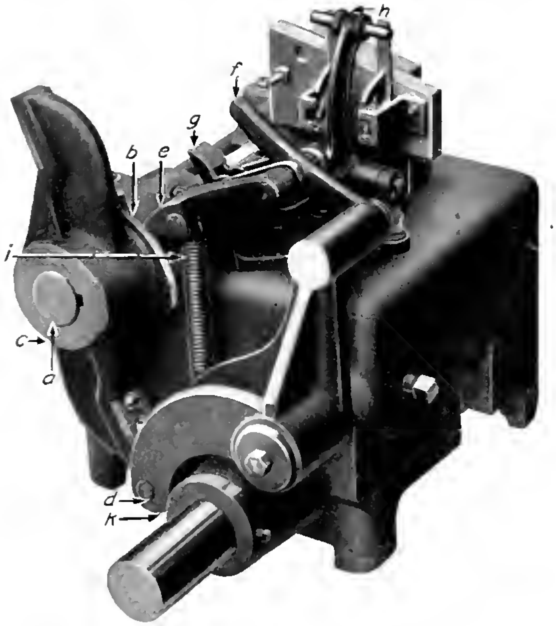


Fig. 1. Locking mechanism for motor-operated oil switch—at beginning of stroke

There is one more point worthy of mention. The locking dog is not obliged to hold the switch against the operating force of the compression springs; it merely has to restrain the switch against the slight tendency of the main operating toggle to buckle, this toggle being "over-center" and taking up most of this force.

There have been some other recent changes in the motor-operated switch. In switches for currents up to and including 300 amperes, a single set of contacts is provided for each oil vessel, which carry the total current while the circuit is closed and rupture the arc when the current is broken. For 500 amperes and upward, however, it has been the custom to use not only the main contacts but another set in each phase, which are similar to a circuit breaker brush and which bridge across the two oil vessels in each phase to carry the running load in conjunction with either the steel oil vessel or copper bars fastened on the outside of the vessel. This construction is used for capacities up to 2000 amperes. In large size stations, however, there is often more current than this to be handled. To meet this condition a new style of contact is employed. Each contact consists of an inverted wedge-shaped copper piece secured to the top of the oil vessel, and a movable set of contact fingers supported from the cross piece on the operating rod by means of steel springs and copper laminations. This arrangement allows from one to four sets of contacts for each oil vessel and provides for operation up to large current values. Some switches have been built with this contact arrangement for service up to 4000 amperes. This contact is especially

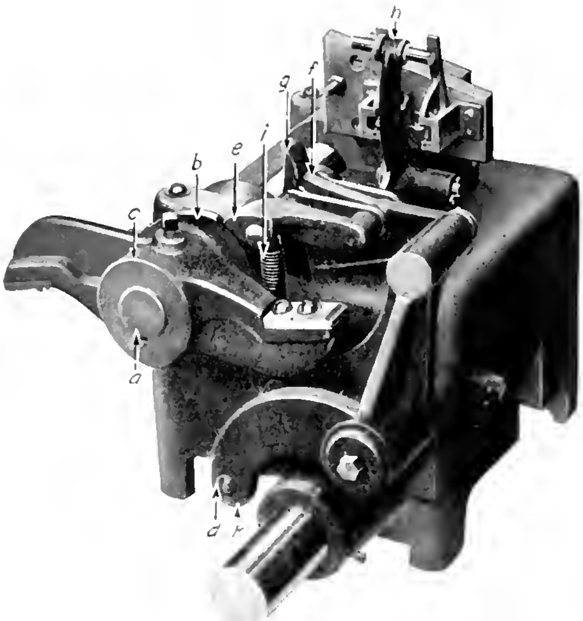


Fig. 2. Locking mechanism—at half stroke

adapted to switches above 2000 amperes, as heavy contact pressure is obtained without placing the cell and mechanism under strain.

The style of contact just described is also occasionally used on switches below 2000 amperes. The determining feature is: When the rupturing capacity of the switch must be greater than can be obtained with the original type switch, i.e., with the one using oil vessels 8 inches in diameter, a switch with 10 inch oil vessels is furnished. In this case there is sufficient space to use the sliding wedge type of contact, which is consequently furnished because this type is in some respects better than the circuit-breaker brush.

Until recently the motor-operated switch was always built with the oil vessels arranged in three sets of two each (Fig. 3). The operating mechanism now permits of the oil vessels being arranged in a continuous row (Fig. 4), which sometimes lends itself better to the design of the station.

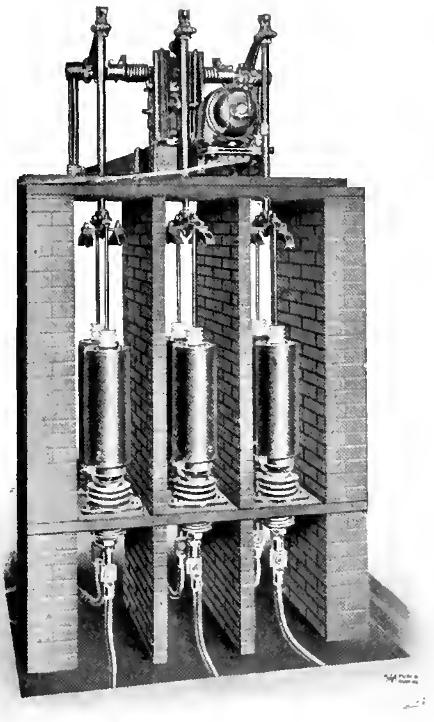


Fig. 3. Motor-Operated Oil Switch with Oil Vessels in Parallel Arrangement

Another improvement is to be found in the method of making the connections, which were heretofore always made at the bottom of the vessel. The switches are now made bottom, back, or combination bottom-and-back connected, which gives great flexibility of arrangement and makes them suitable for all stations using enclosed wiring and isolating switch cells.

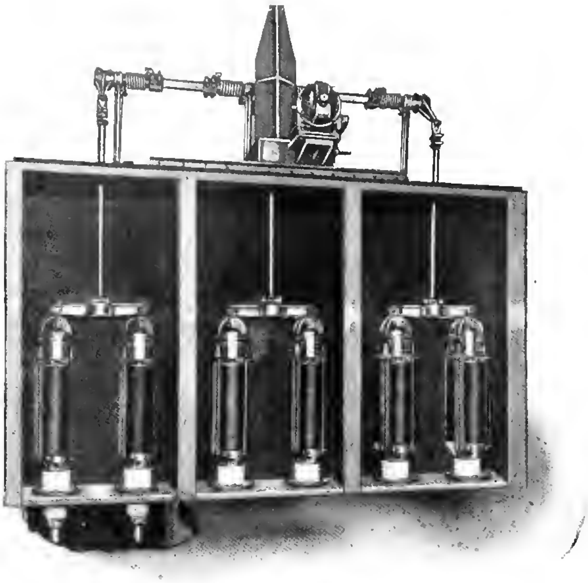


Fig 4. Motor-Operated Oil Switch with Oil Vessels in Tandem

In the bottom-connected switches the current, if above 500 amperes, is carried on copper bars fastened on the outside of and to both top and bottom of the oil vessels. When the switch opens, the bridging connections on top of the oil vessels break contact first, and thus force the current to pass through the cylindrical contact rods upon which the circuit is broken with the assistance of the stationary contacts inside and at the bottom of the oil vessels. In the combination back-and-bottom connected switch, the oil vessels having connections at the bottom have exterior current-carrying bars, while the top-connected vessels have not.

For voltages above 70,000, where open wiring is of more advantage, a different type of switch is used. This switch, as shown in Fig. 5, is top-connected only and does not require cells or isolating compartments. It consists of separate and similar self-contained elements, one in each phase. The insulating bushings and operating mechanism are fastened to the cast iron cover of a heavy boiler iron tank, lapped, riveted and reinforced. This compact construction makes the switches easy to handle and install and reduces to a minimum the floor space occupied.

Each switch stud passes through an insulating bushing, the upper end of the stud being threaded to receive a terminal. To the lower

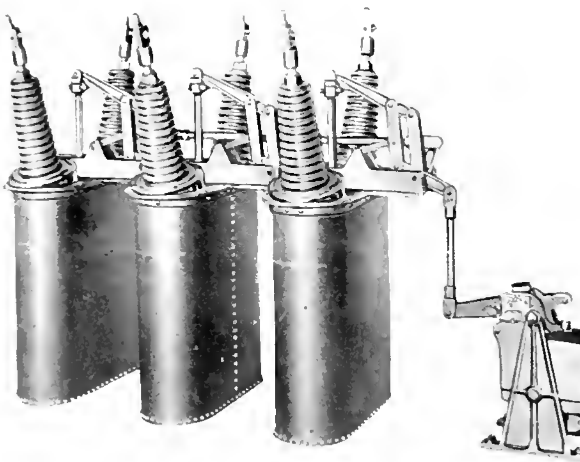


Fig. 5. Solenoid Operated Oil Switch for Use without Isolating Cells or Compartments

end is fastened a contact block and the stationary contacts. In each switch element there are two stationary contacts, between which the circuit is made and broken by a hollow, wedge-shaped, horizontal copper blade. The blade moves in a vertical plane, being drawn up when the switch is closed, and dropped by gravity assisted by springs when the switch opens. Each contact blade is connected to the operating mechanism by a wooden rod, specially treated for the service, which passes through the cover of the switch in a porcelain bushing. The stationary contacts consist of widely flared fingers and extra long arcing tips of drop forged copper fastened to the contact block by flat steel springs, copper laminations and screws. In opening the circuit the final rupture takes place between the extended portion of the stationary contact fingers and the upper extremity of the movable contact blade, at all times protecting the actual contact surfaces from the damaging effect of the arc. The contacts are always kept clean by a distinct rubbing movement which is imparted to the contacts on opening and closing. The contact blades and fingers can be easily replaced when necessary.

Each insulating bushing extends through the switch cover down into the oil and is so clamped to the cover that the gases formed on rupturing the circuit are allowed to escape; the throwing or scattering of oil being virtually nil. The bushings are interchangeable and can easily be removed if necessary. They are mounted at an angle which reduces the necessary size of the oil tank, but still gives proper striking distance in both air and oil. The quantity of oil required is therefore a minimum.

This oil switch can be operated by hand, by a direct current solenoid, or by a diaphragm using compressed air. In each style the switch elements themselves are exactly the same, the only difference being in the method of applying the actuating force to the mechanism.

Hand-Operating Mechanism

The hand mechanism consists of an operating handle mounted on a panel, with bell cranks and connecting rods running to the mechanism on the switch; or the switch can be operated directly where it stands by a handle which can be fitted direct to the mechanism. On all non-automatic mechanisms provision is made for adding overload protection at any time without difficulty. The mechanism for automatic (overload) operation has a free trip feature, so that the switch can not be held closed on overload or short circuit.

Solenoid-Operating Mechanism

The solenoid-operating mechanism is similar to the hand-operated mechanism, except that a direct current two-coil (one for closing, one for opening) solenoid is mounted on the floor directly in front of or to either side of the center of any element.

Air-Operating Mechanism

Where remote control is desired, but where direct current for operating the switch is not conveniently available, air-operated mechanism can be used. The non-automatic mechanism may be a double diaphragm with hand-operated air valves, a double diaphragm with two-way electrically-operated air valves and control switch, or a single diaphragm with electrically-operated air valve for closing and an electric trip coil on the diaphragm for opening.

Automatic Tripping

To automatically protect apparatus under abnormal conditions of overload or short circuit, three methods are commonly employed. A selection depends upon the particular operating conditions, as well as upon the cost of installation. They are as follows:

Current Transformer Method (current transformer trip).

Series Coil Method (series trip).

Series Relay Method (series relay trip).

Current Transformer Trip: Where wattmeters or watthour meters are used on high-voltage circuits current transformers are required, in which case they are also usually used to provide automatic protection.

Hand Mechanism with Current Transformer Trip: With this combination the trip coils are mounted on either the operating lever or the oil switch mechanism. With direct current trip a single direct current coil is used, while with alternating current a similar coil or coils are used.

Solenoid Mechanism with Current Transformer Trip: In this case, circuit-closing alternating current relays are used with the contacts connected in parallel with the opening side of the direct current control switch and the direct current tripping coil of the solenoid mechanism.

Air Mechanism with Current Transformer Trip: With this combination the switches can be tripped either with or without an electrically operated trip coil on the diaphragm mechanism. In the first case, circuit-opening relays are used with the trip coil in the secondary of the current transformers. In the second case a circuit-closing relay is used, the contacts of which are in parallel with the opening side of a hand-operated control switch on the switchboard.

Series Trip: Trip Coil in Series with High Tension Line

This form of trip, instantaneous or time limit, is used with hand-operated switches where a convenient source of low tension current for tripping is not available and where the expense of using high voltage current transformers for tripping only is not justified. It consists of series coils mounted on separate post-type insulators and a ooden rod from each coil which acts directly on the tripping latch of the switch. The oil switches of the type illustrated in Fig. 5 are so arranged that this method of tripping can be added at any time. The inverse time limit coil has a quick acting mechanism, so that both it and the instantaneous coil impart a quick impulse to the tripping latches and make the operation positive. The lever system of the series coil is adjustable for operation in different positions.

Fig. 6. Hand Operated Outdoor Type High Voltage Oil Switch

Series Relay Trip: Relay in Series with High Tension Line

The series relay is similar to the series trip coil just described, except that the wooden rod does not trip the switch directly but operates a small lever switch which closes a low tension circuit through a trip coil, which in turn opens the oil switch.

Series high tension relays are used mostly with solenoid-operated switches, the relay switch being connected to the direct current tripping coil of the solenoid, in parallel with the opening side of the control switch. The series relay may also be used with air-operated oil switches. In this case the relay is so connected that on closing it actuates a low voltage a-c. trip coil on the diaphragm mechanism. However, when considering the probable use of series trip or series relay trip coils the following limitations should be kept in mind.

Owing to the fact that the series coil or relay is of the same potential as the line, it should be used for tripping high potential oil break switches only where the operating conditions will permit of shutting down the line to make changes in calibration or adjustments, or to test the calibration or the operation of the mechanism.

Also, since series trip coils and series relays are mounted separately from the switches which they operate, and are connected to them by long wooden rods, it is not possible to make accurate adjustments not subject to variation. Consequently, it is difficult to obtain good selective action between lines, and for this reason high voltage series trip coils or relays are not recommended for that purpose.

Recently there has been a decided tendency to use switches of the semi-outdoor or full-outdoor variety. The switch for such service is in construction practically similar to the switch just described, except that everything exterior to the cover is enclosed and protected from the weather. For voltages up to 70,000 the bushings consist of a one-piece porcelain with petticoat shaped projections outside the tank, and for higher voltages, of the regular built-up-type bushings with the part outside the cover replaced by porcelain petticoat-shape units, one above the other and cemented together. (See Fig. 6.) The external operating and tripping mechanisms are enclosed in a weatherproof case, and are hand or solenoid-operated. When hand-operated, a handle is connected to the operating mechanism directly at the switch. No panel or other support for the operating handle is necessary. When the switch is solenoid-operated, the solenoid is enclosed in a weatherproof case, as shown.

For automatic overload trip, bushing type current transformers are used, depending upon the number of phases in which it is desired to obtain overload protection. These transformers surround the switch studs and are enclosed in a casing which also constitutes the switch cover. All parts of the switch liable to damage on account of weather conditions are enclosed and are thus weatherproof.

HIGH-VOLTAGE TRANSFORMER LEADS: A COMPARISON OF DESIGNS

By Eugene D. Eby

Transformer Engineering Department, General Electric Company

After enumerating the requirements which a high-voltage transformer lead has to meet, the author treats of the theory upon which the design of all such leads is based, and in which he considers the lead as a special case of armored cable—as a system of two concentric cylinders. He discusses methods which may be followed for improving the effective strength of the dielectric enclosed between these cylinders In dealing with that part of the lead which must be exposed to the air, he shows the advantages of the corrugated edge construction; while he also indicates the desirability of a design which shall project the outer cylinder into the oil inside the transformer, and which will minimize the total height of transformer and lead. In a comparison of the materials used in construction, he discusses the relative merits and demerits of various designs, bringing out the marked superiority of the fluid-dielectric lead on the score of low losses, circulation when under stress, ability for self-healing after rupture, and easy replacement. The latter part of the article deals with the testing of high-voltage leads, discusses procedure, and calls attention to various points which must be watched in the behavior of a lead when undergoing its preliminary test.—Editor.

The function of a transformer lead is twofold: to complete the circuit between the transformer winding and the line; and to insulate this circuit properly from the tank. The importance of this function is not always appreciated. While the first is a simple matter, the second presents not only a difficult, but an extremely important problem; for upon its successful solution depend the safety, reliability, and in fact the very operation of the transformer, and perhaps of the entire system.

Electrically a high-tension lead must withstand all potential stresses, normal and abnormal, to which it may be subjected in operation. At operating potential it should be absolutely free from corona upon any part of its insulating material. Furthermore it must transmit the rated current of the circuit without undue heating in any part. Mechanically, its size and shape must permit its assembly in the cover of the transformer tank, and it must be easily and quickly removable. It should have the smallest size and length consistent with safety, as both of these factors affect the transformer in weight and cost. Its materials should not deteriorate in normal service. If sectionally built and liquid-filled, the joints must be tight, and the liquid permanent. For outdoor service it must be weatherproof, and able to withstand weather conditions of heat or cold, rain or snow, without distress.

Each of these requirements presents its own difficulties, which have been met by different designers and manufacturers in different ways, each more or less satisfactory. It is doubtful if any one design contains all of the most desirable features, although this is the goal for which each designer strives. All designs are more or less of a compromise between ideal theories and practical realities, with results which are always capable of improvement. It is from this viewpoint that the writer wishes to discuss a few of the problems of high-tension lead design.

Electrical Design

In the realm of materials there can be found a great number of insulations which can be used in the construction of high-tension leads. Paper, fiber, treated cloth, wood, porcelain, moulded compounds of great variety, solid and semi-fluid compounds, and insulating oils are among the most common. The approach toward perfection in any design depends upon the judicious use of the dielectrics chosen. In general, the best dielectrics are those least affected by the normal and test potentials, at the same time giving the best distribution of the potential stresses.

Considering the lead as a special case of armored cable, it is seen to be a system of two concentric cylinders, the outer one much larger and shorter than the inner. The general case of concentric cylinders of infinite length, and the potential gradients in uniform and graded dielectrics between them, has been discussed in previous papers* and problems. In the special case of a lead, the lengths of the cylinders must be considered.

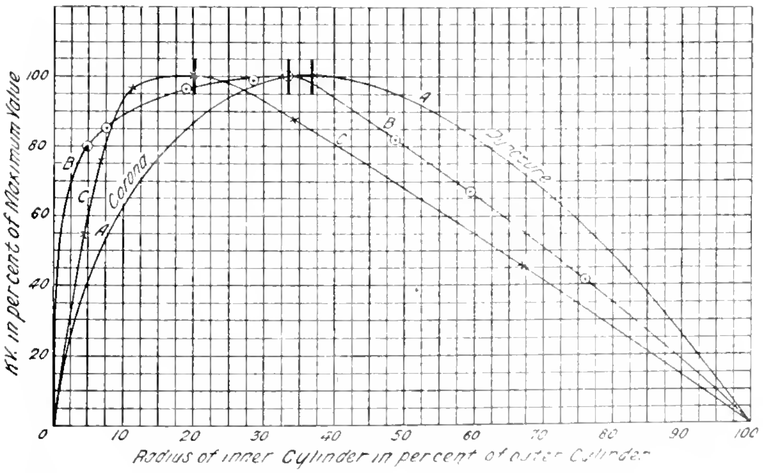


Fig. 1. Curves Illustrating the Effect of Shape of Edges of Outer Cylinder on the Ideal Critical Ratio of Cylinder Diameters

As has been shown for the case of a uniform dielectric between two concentric cylinders, there exists an ideal critical value of the ratio of their diameters, giving a maximum dielectric strength. This calculated ideal ratio is 2.72 to 1. In a lead, the influence of the ends of the cylinders and the shape of the edges affect this ratio, somewhat as shown in the curves of Fig. 1. Curve *B* applies where a large radius of departure is used at the ends of the outer cylinder, and shows a critical maximum strength value of the ratio of about 3 to 1. Curve *C* applies where the radius of departure is small, and shows a critical ratio of 5 to 1. The conditions to which curve *C* applies are those usually found in actual manufacture, and the ratio 5 to 1 is employed by the writer in the design of oil-filled leads. At best, however, these figures are approximate, and vary with the different radii and lengths of cylinders used. The maximum value of the dielectric strength depends also to some degree upon the energy required to start the arc at puncture.

One method of improving the effective strength of dielectrics between concentric cylinders consists in "grading," or arranging two or more dielectrics of different permittivity in such a manner that the maximum stresses upon various layers will be equalized or made proportional to the strengths of the materials. Another method of improving the effective strength consists in dividing the dielectric into a system of condensers by inserting metallic cylinders at intervals. By properly choosing the lengths and diameters of these intermediate cylinders the capacities between adjacent pairs may be made proportional to the strength of the insulation between them; i.e., the potential throughout the system of condensers, which will be distributed inversely as the capacities, will be applied to thicknesses of insulation consistent with the stress.†

* Before the class in High Voltage Engineering, Pittsfield Section A.I.E.E. Season 1912-1913.

†Thus, as in Fig. 2, if 1, 2, represent the metallic cylinders of radius r_1, r_2, with voltages e_1 between conductor and 1, e_2 between 1 and 2, etc. the potential gradients at the surfaces of the conductor, cylinder 1, cylinder 2, ... , will be

$$g = \frac{e_1}{r \log_e \frac{r_1}{r}};\ g_1 = \frac{e_2}{r_1 \log_e \frac{r_2}{r_1}};\ g_2 = \frac{e_3}{r_2 \log_e \frac{r_3}{r_2}};\ . \quad . \quad .$$

Another consideration which lends weight to this configuration is illustrated in Fig. 3. Representing the dielectric flux between conductor and outer cylinder by lines starting

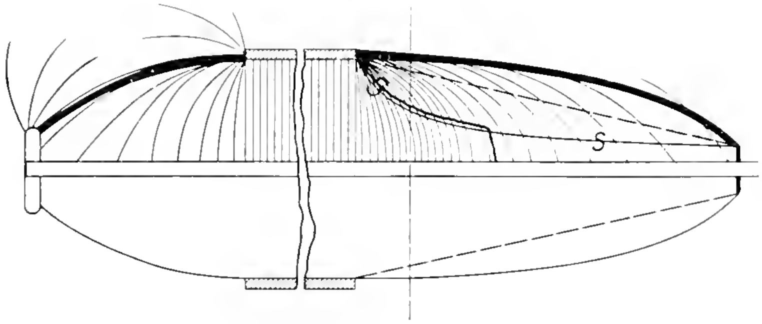


Fig. 3

from the former and ending upon the latter, it is seen that the field within the cylinder is uniform, while at the ends it is condensed by the collection of lines from the ends of the rod. The field becomes less dense as the ends of the rod are approached. The measure of the drop of potential along a unit distance upon a surface in this field is the number of lines cut by a unit area perpendicular to the surface at the point in question. In any plane, perpendicular to the axis of the lead, the field will be found more dense near the rod than at a distance from it. Consequently the surface SS may drop quickly from the cylinder toward the rod, along the path of the field. As the density becomes greater nearer the rod, the surface changes its direction more along the rod, cutting the flux, and avoiding a large drop of potential over that part of the surface. On account of the lower strength of air than that of the dielectric between rod and cylinder, the above consideration can seldom be recognized, owing to the danger of puncturing the narrower portion of the lead, with an arcing-over of the remainder. The heavy line illustrates this kind of failure. Moreover, the unequal distribution of the potential over the distances between the exposed ends of the cylinders necessitates a very

Assuming that the dielectric is uniform, it should be subjected to the same stress in the various sections of the condenser; or

$g = g_1 = g_2 \dots \dots$

By assigning to these gradients safe values of the dielectric strength (perhaps 20 per cent below the rupturing value), and giving numerical values to $r, r_1, r_2, \dots$, the values of $e_1, e_2, e_3, \dots$ follow at once from the equations above. The sum of $e_1, e_2, e_3 \dots (=E)$ is the total voltage which may be applied between conductor and outer cylinder without over-stressing the dielectric at any point.

To produce this distribution of the voltage, the capacities $c_1, c_2, c_3, \dots$, over the sections stressed with $e_1, e_2, e_3, \dots$, must be made inversely proportional to these voltages. That is

$c_1 e_1 = c_2 e_2 = c_3 e_3 = \dots$

The capacity, in c.g.s. electrostatic units, of a cylindrical condenser is

$$C = \frac{k\ L}{2 \log_e \frac{D}{d}}$$

in which k = permittivity of dielectric

L = length of cylinders in cm.

D = outer diameter in cm.

d = inner diameter in cm.

Since, by assumption, the values of $r, r_1, r_2, \dots$ were assigned, the only remaining variable in this equation is L. Therefore the products of capacity and voltage may be written

$$\frac{L_1\ e_1}{\log_e \frac{r_1}{r}} = \frac{L_2\ e_2}{\log_e \frac{r_2}{r_1}} = \frac{L_3\ e_3}{\log_e \frac{r_3}{r_2}} \quad \dots$$

Since $e_1, e_2, e_3, \dots$ have already been calculated, by assigning a length to either the center rod or outer cylinder, the required lengths of $L_1, L_2, L_3, \dots$ may be calculated. The lengths of these metallic cylinders determine the shape of the lead, which for equi-distant cylinders is somewhat as shown in Fig. 2.

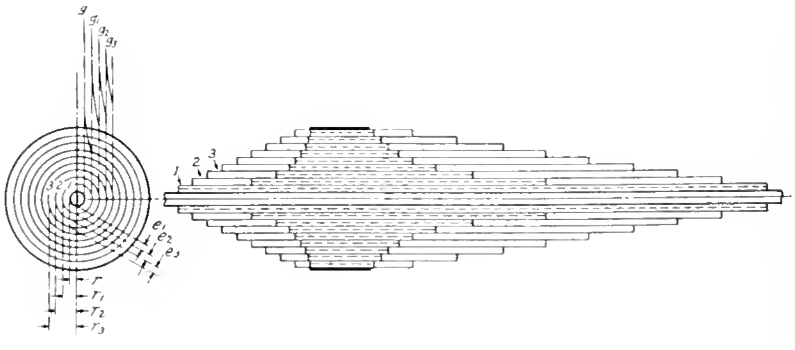


Fig. 2

No consideration is given here to the capacities of the separate cylinders with respect to ground, which tend to reduce the stresses on the outer sections, and increase them on the inner ones.

inefficient length of the lead. Consequently it is customary to make the ends of solid condenser leads conical, diminishing the diameter uniformly from outer cylinder to conductor. This is well illustrated in Fig. 4, showing practically the only lead now manufactured which employs metal cylinders for controlling the voltage distribution. This type of lead is composed of paper rolled to the required thickness, with layers of tinfoil inserted at regular intervals. The design is a compromise between ideal and practical considerations, and does not accomplish the ideal distribution of voltage. On account of the central layers being longer than in the calculated curve of Fig. 2, their capacities are increased, and stresses reduced, while the stresses on the outer and inner layers are correspondingly increased.

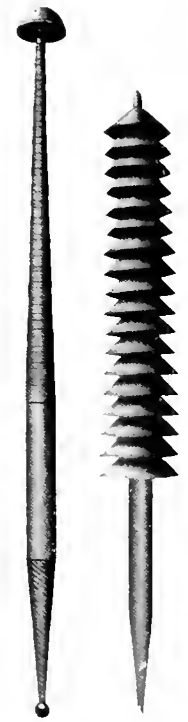


Fig. 4. Solid Condenser Type Leads for (a) Indoor and (b) Outdoor Service

Fig. 5. Oil-filled High-tension Lead of Compound Rings for Indoor Service on 91,500-volt Circuit

The use of metal cylinders, particularly with solid dielectric between them, offers an objection due to the fact that all weak spots in the lead are placed in series. Thus, if one weak point, such as an air bubble, or a defective spot in the dielectric, is located between a certain two cylinders, and another such weakness exists between any other two, the effect is equivalent to placing both opposite each other, since the metal cylinders are surfaces of equal potential. In the case of oil-filled leads, where local defects are less likely to be permanent, on account of constant circulation of the dielectric, the use of metal cylinders offers some advantages.

Fig. 6. Outdoor Type Oil-filled Porcelain High-tension Lead 115,000-volt Circuit

The foregoing considerations have dealt mainly with diameters, or radial thicknesses of the dielectric. The length of that part of a lead exposed to the air depends upon its general shape, and the configuration of its surface. If the surface is smooth or nearly straight as in Fig. 2, the length must be great to prevent creepage, i.e., short-circuiting of part or all of the surface by the condenser current which follows the surface. In this feature lies another serious objection to the condenser type lead with solid dielectric: its length above the transformer is far greater than is found necessary for some other types of leads, such as, for instance, the oil-filled lead. With corrugated surfaces, as in Fig. 5, the length may be made as small as the sparking distance in air will permit. For example, a lead for a 300,000-volt test, with a margin of 20 per cent, should have a length above the transformer cover of 1.20×30 inches (which is the approximate sparking distance between needle points in air), or 36 inches. In order to use as short a lead as this, the corrugations should be so designed that the total distance over the surface will be $2\frac{1}{2}$ or 3 times the straight height of the lead. Furthermore the configuration must be such that the path of the stress from top to grounded cylinder will lie practically wholly through the air, and not over broad surfaces of the dielectric in contact with air. Thus a corrugation with a broad edge might increase the actual surface distance by the specified amount, but would prove ineffective in preventing arc-over. The corrugations should have a narrow outer edge, with a depth about equal to their pitch. For outdoor leads they should have slant enough to drain moisture, but a very decided droop is not necessary. Corrugations of the shape shown in Fig. 6 have been found to be as effective as others with a 45 deg. angle. In general, a moderate number of small corrugations is preferable to a few large ones, which occupy more space, are usually more difficult

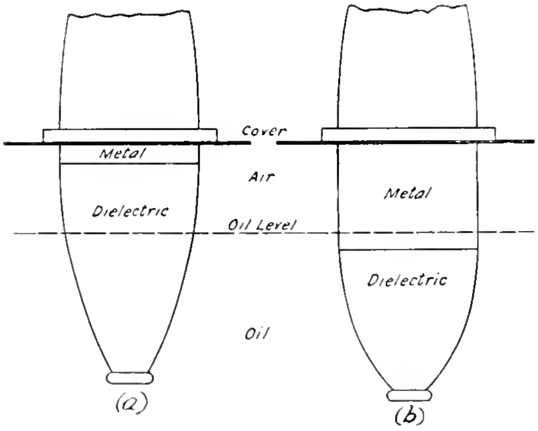


Fig. 7

to manufacture, and give a poorer surface distribution than the more numerous small ones.

The length of that part of the lead within the transformer tank depends mainly upon two things, viz., whether or not the ground ring, or outside metal cylinder, is carried below the surface of the oil with which the tank is filled, and upon the strength of the dielectric. To project the outer cylinder into the oil is very desirable. If, as in Fig. 7, (a), an air space exists between the grounded cylinder and the oil, the stress over the outer surface of the lower end of the lead will be distributed over a path composed partly of oil and partly of air. As the stresses will be divided inversely as the permittivities of the two dielectrics, the oil, with a permittivity of $2\frac{1}{4}$ and a high dielectric strength, will bear less than its proportion of the stress; while the air, with a permittivity of 1 and a low strength, will be over-stressed, producing corona and perhaps effectively short-circuiting that portion of the dielectric in contact with it. The entire stress would then be thrown upon the dielectric submerged in the oil, which might not have been designed for it, and failure would result. On the other hand, if the grounded cylinder is projected into the oil, as in Fig. 4, (b), the entire stress is placed upon the submerged dielectric, which must be designed for it, but which fact removes the undesirable presence of corona in the air about the lead.

The other feature affecting the length of the lower end, viz., the strength of the dielectric, will determine whether ultimate failure will occur through the dielectric, or through the oil in contact with it. The length of the portion under oil vitally affects the cost of the transformer, as this is usually the factor determining the depth of oil above the terminal boards, with a corresponding effect upon the height of the tank. Since the transformer is frequently the tallest piece of apparatus in the station, the length of the leads, both above and below the oil, may affect the height and consequent cost of the building. The desirability of compact leads is therefore evident.

Comparison of Materials

Any comparison of materials used in the construction of leads must of necessity be a study of the designs themselves, as no one design could employ all of the available materials in the same manner. A discussion of a few of the most widely used types, with an investigation of their respective merits and demerits, should prove most useful.*

In general, a comparison of solid, semi-solid, and fluid dielectrics shows marked advantages for the latter. While the possi-

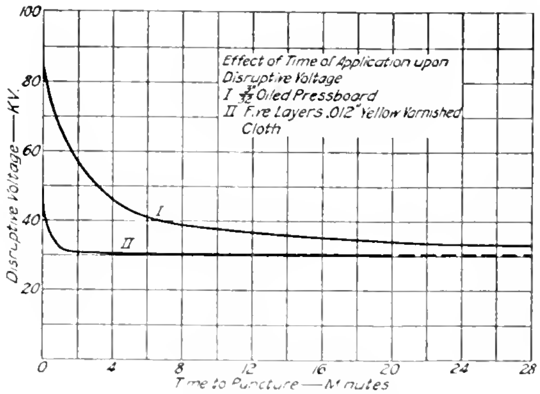


Fig. 8. Effect of Time of Application upon Disruptive Voltage

bility of "grading" is practically eliminated in a fluid dielectric, yet the advantages of low losses, circulation when under stress, self-healing after rupture, and easy replace-

*For a useful comparison of several insulating materials, the reader is referred to an article by Mr. A. B. Hendricks on "The High Tension Testing of Insulating Materials," Proceedings A.I.E.E., February, 1911.

ment, more than recompense for the lack of grading. Losses by dielectric hysteresis,† which produce most of the heating under stress, are greatest in fibrous materials, which have shown losses as great as five watts per cubic inch‡ before injury resulted by charring. A much smaller loss than this will, however, char the material in time. These losses vary as the square of the stress, other conditions remaining constant. With changing temperature they increase faster than the temperature, and may exceed the amount which can be radiated. It is probably true that the majority of failures of fibrous insulation are due to local heating and burning of the material, rather than mechanical rupture. This is well illustrated in the curves of Fig. 8 showing the effect of time on the value of the disruptive voltage applied to $\frac{3}{32}$ in. oil-treated pressboard. This fact of high losses in solid materials of a fibrous character, such as paper, pressboard, cloth, etc., with their accompanying poor conductivity of heat, greatly lessens their desirability for use in closely massed quantities. If subdivided into thin layers with ventilation or circulation of oil between the sheets, they become much more valuable as insulations.

Similar considerations apply, in a less degree, to semi-fluid compounds of high viscosity, when used as a filling for the outer shell of a lead. In such solids as glass and porcelain the losses are negligible. This is also true of fluid dielectrics, such as the mineral oils employed in insulating transformers. One of the great advantages of the latter lies in their circulation under stress, thus continually changing the portion of the dielectric undergoing the greatest strain. The tendency in an oil-filled lead, as in Fig. 9, is for the impurities in the oil to gather along the paths of greatest stress. To prevent this, thin insulating cylinders are inserted in such a manner that the oil is divided into concentric layers. This prevents the congregating of impurities by directing the circulation upward along the conductor, with return paths downward through the outer layers.

Another marked advantage of a fluid dielectric is its self-healing property, i.e., its ability to restore the lead to a high percentage of its initial strength after rupture has occurred. Even when insulating cylinders are used to subdivide the oil-space, which are punctured upon failure of the lead, values averaging from 95 to 100 per cent of the initial rupturing stress have been obtained on second trial. A still further advantage of the fluid dielectric lies in the ease with which it can be removed and replaced without disassembly of the entire lead.

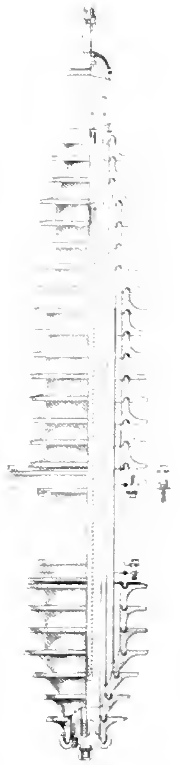


Fig. 9. General Construction of Oil-filled High-tension Lead for Transformers

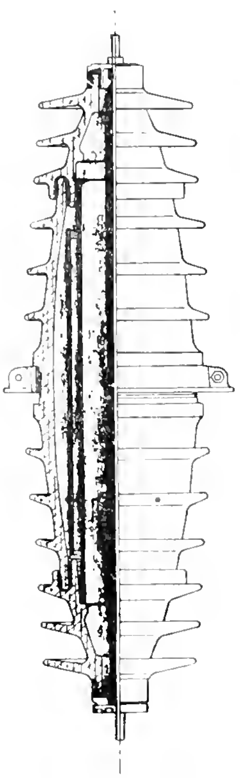


Fig. 10. Compound-filled Porcelain Lead (Foreign Manufacture)

It is understood, of course, that the use of a fluid dielectric necessitates a solid shell or vessel to contain it. This containing vessel may be made of wood, paper, vegetable fiber, mineral compounds, porcelain, earthenware, glass, etc.; but the best materials, as stated earlier, are those least affected by the applied stress, and most stable under operating conditions. For oil-filled leads, mineral compound moulded into rings, and porcelain have been most largely used (see Figs. 5 and 6). The use of oil, or other fluid dielectric, necessitates an oil-tight vessel, which is the chief mechanical difficulty in the manufacture of this type of lead. It is possible to meet this requirement by the use of tongue-and-

†For a brief summary of investigations on this subject, see an article by the author on "Dielectric Hysteresis" in the GENERAL ELECTRIC REVIEW, May, 1911.
‡C. E. Skinner, *Elec. Review*, Vol. 41, 1902 pages 82-87.

groove joints between the moulded rings, filled with a strong insulating cement, as shown in Fig. 9. In the case of a porcelain shell, made in long sections with glazed joints, a most satisfactory lead is obtained.

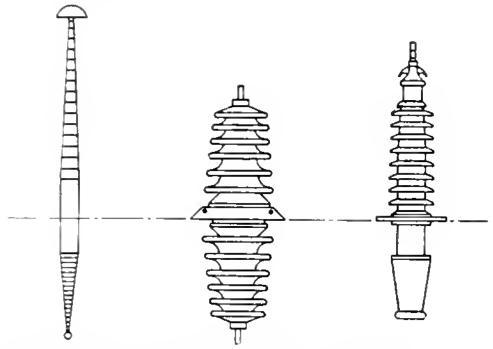


Fig. 11. Comparative Sizes of Three Different Types of High-tension Leads

the relative proportions of these three types. While the condenser lead has the smallest diameter, it does not follow that this is a decided advantage, since the space in the cover of the transformer is seldom so small that either of the other types could not be mounted.

The considerations which have been applied to high voltage leads are applicable, in general, to leads for lower voltages than 50,000 volts. The greater simplicity of solid leads for low voltages, however, eliminates the oil-filled type from this class of service. Such materials as paper, varnished cloth, moulded compounds, and porcelain predominate.

One very desirable feature, used for some time on lower voltage leads, but only recently introduced into leads of all sizes, permits the removal of a lead from the transformer cover

To meet the condition of exposure to the weather in outdoor installations, no other material has been found so adaptable as porcelain, although moulded compound may be used if well protected with weatherproof paint or varnish. Earthenware has a dielectric strength much inferior to either glass or porcelain; and glass is fragile, particularly subject to cracking under expansion and contraction, and expensive in shapes suitable for leads. The successful development of oil-filled porcelain leads for operating voltages as high as 115,000 volts has solved the problem of outdoor leads for the present. Inasmuch as transformer oil contracts upon freezing, no danger to the lead will result from exposure to severe weather when idle.

In Fig. 10 is shown a type of compound-filled, porcelain lead manufactured abroad. This lead is more bulky than either the condenser or oil-filled type; and while its reduction in length over the condenser lead is an advantage, that portion of it beneath the cover is still longer than the corresponding oil-filled lead. Fig. 11 illustrates

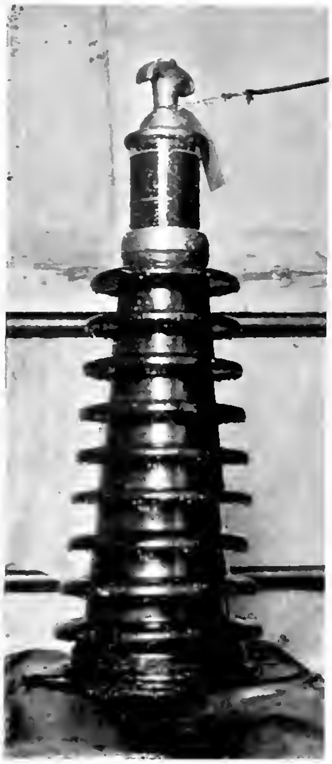


Fig. 12. Oil-filled Porcelain High-Tension Lead Arranged for Rain Test

Fig. 13. Oil-filled Porcelain High-tension Lead, Five Minute Exposure at 200,000 Volts (Dry)

and its replacement, without the necessity of entering the tank to disconnect the lead from the transformer winding. This is accomplished by the use of a pipe extending through the lead, and through which is drawn a flexible cable attached to the terminal of the winding. This cable has at its upper end a terminal which is secured to the top of the lead, and extends beyond it for connection to the external circuit. As the oil above the terminal board in a high-voltage transformer is often so deep that the connection is beyond reach from the cover, it becomes necessary to draw off the oil from the tank before a lead can be removed. The introduction of the pipe and cable feature overcomes this necessity.

The current-carrying capacity of leads is governed by the size of transformer with which they are used. Frequently a transformer is designed with series-multiple connections on the high-tension side, in which event the lead capacity must be based upon the lowest voltage. For purposes of standardization and interchangeability, it is desirable that all leads for a certain voltage should have the maximum current capacity which is likely to be required at that voltage.

Fig. 14. Oil-filled Porcelain High-tension Lead, Five Minute Exposure at 218,000 Volts (Dry)

Fig. 15. Oil-filled Porcelain High-tension Lead, Five Minute Exposure at 180,000 Volts (Rain Test)

Tests and Observations

In the manufacture of leads for commercial or experimental purposes, it is customary to check the calculated design by the application of potential a specified number of times (usually from two to three times) as great as the normal potential of the transformer. This is equivalent to doub' this ratio, four to six times the normal stress upon the lead for single-phase transformers; and $\sqrt{3}$ times this ratio, or $3\frac{1}{2}$ to $5\frac{1}{4}$ times the normal stress for leads in three-phase transformers. Thus a lead for a 100,000 volt, single-phase transformer, whose normal potential above ground is 50,000 volts, in its initial test may be subjected to 300,000 volts, or six times normal. This is taken to represent the factor of safety, and a lead which does not fail or give evidence of undue distress under this test is accepted as satisfactory for assembly and final test with the transformer. It is always considered desirable to apply a higher initial test to the leads alone than they will receive with the transformers.

In the testing of a lead, its lower end is immersed in oil as in operation with the transformer. The ground ring at the center is connected to earth, and the upper end of the conductor to one side of the testing circuit. The other side of the testing circuit is connected to earth, and potential applied

Fig. 16. Oil-filled Porcelain High tension Lead, Five Minute Exposure at 200,000 Volts (Rain Test)

to the lead, usually for a period of one minute, at the specified value. A lead may fail in four ways: (1) by arcing-over its outside surface, which means that the distances from the live parts at the ends to the ground ring at the center are too small, or else the surface distribution of potential is bad; (2) by rupture of the dielectric radially from conductor to ground ring which indicates that the thickness of the dielectric is insufficient, or the voltage gradient too high; (3) by rupture of the dielectric from one end (usually the shorter end) to the ground ring; or a combination of (2) and (3); and (4) by evident distress which may not have resulted in actual rupture.

A lead which withstands its commercial one-minute test without failure in any of these ways is generally considered satisfactory. The fact that failure has not occurred, however, is not proof that the lead has escaped injury. Referring again to Fig. 8 it is seen that the duration of the test may have a very decided bearing upon the value of test voltage required to produce rupture of the dielectric. Thus a test voltage which just fails to produce rupture after one minute may have injured the material to the extent that a 1¼ minute test would prove disastrous, or that the long-continued application of operating voltage may develop weakness and final failure. It is not sufficient, therefore, that a lead shall withstand its specified test; it should be known that this test does not materially affect the structure of the dielectric. In purchasing transformers, some users specify that transformers or leads shall be subjected to long-continued high potential tests. The writer feels that this is not good practice and should be discouraged, for, by the very means employed to prove the safety of the insulation, it may be seriously injured without this fact being discovered. A much better plan, at least in the case of leads where one or two units may be sacrificed without entailing great expense, would be to require long endurance tests on duplicate units until failure resulted, with only brief tests on the units for actual service. Certified reports of these tests would then assure the purchaser that the required safety had been secured in the design, with the further assurance that the apparatus had not been injured by over-testing.

To be satisfactory in a commercial test, a lead should give no evidence of serious distress indicating probable failure in any one of the four ways mentioned. If the testing voltage should be increased past the margin of safety allowed in the design, the preferable method of failure is the arcing-over of the upper portion through the adjoining air. This serves as a safeguard against the application of further stress, and in the best types of leads is not accompanied by damage to the surface of the dielectric.

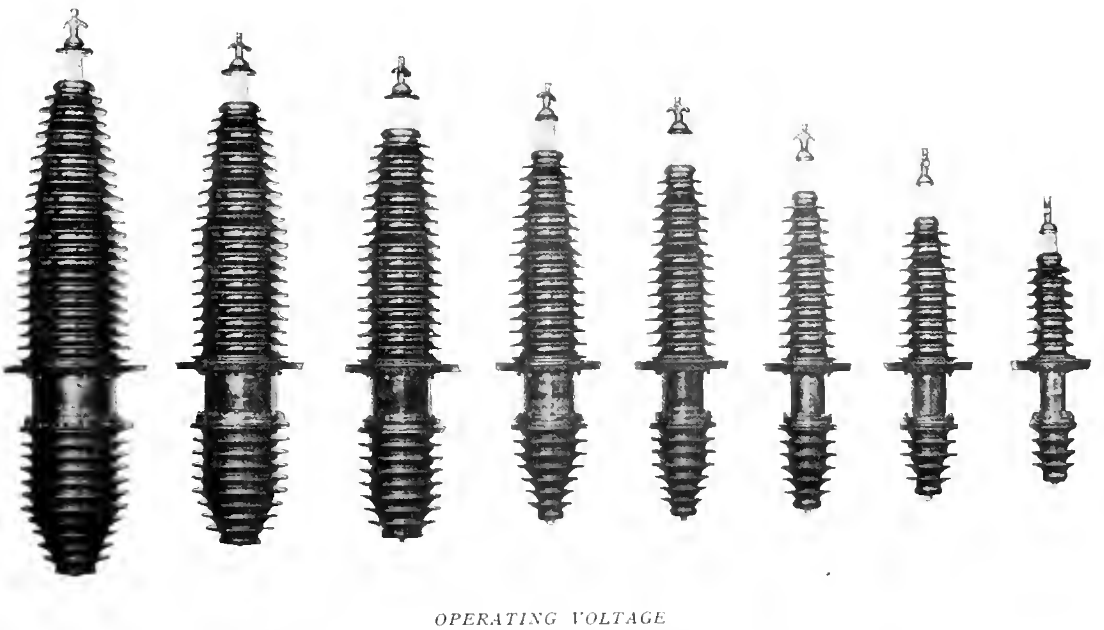
During preliminary test, a lead should be situated in a location which may approximate as nearly as possible its operating location. If the cover of the transformer tank is available, the lead should be mounted in its proper position. With two leads in a cover, located near each other, one has an influence upon the other, and a different value of arc-over voltage may be obtained when testing the two in multiple, than if tested separately. This should be recognized; and if the testing voltage is near the arc-over value, the pair of leads should be tested in multiple, with the same spacing as when assembled with the transformer.

The appearance of corona or streamers of leakage current upon the surface of the dielectric is undesirable, as this represents an over-stressed condition in the air, with consequent heating, which may injure the material. No corona whatever should appear at operating voltage, and as little as possible at test voltage. In Figs. 13, 14, 15, 16 are reproduced some photographs taken to record the corona and arc-over phenomena on an oil-filled porcelain lead. These photographs were taken in a darkened compartment, with five minutes exposure of the plate, and illustrate one highly desirable feature of this type of lead. It will be noted that the test dry at 200,000 volts shows practically no corona upon the surface of the porcelain, while at 218,000 volts arc-over occurs. The same lead arcs over at 200,000 volts under artificial rainfall directed at an angle of 45 deg., while at 180,000 volts it is comparatively dark. That is to say, at 10 per cent below its arc-over voltage this lead is comparatively free from objectionable corona upon its insulating surface.

The relative merits of sharp points and smoothly rounded surfaces are understood well enough to need no special comment. In general, the use of sharp points, angular corners, and thin edges upon the metal parts of leads as well as all high voltage apparatus should be avoided.

At the present time practically all tests on leads are made at 60 cycles. In their recent paper* on testing of line insulators with high frequency, Messrs. Imlay and Thomas have shown the great discrepancy between normal-frequency and high-frequency tests. If leads are to be expected to withstand high-frequency impulses produced by lightning or line disturbances, they should evidently receive high-frequency commercial tests in addition to those of rated frequency; and the time may not be far distant when such tests will be considered indispensable, as an additional safeguard to apparatus and continuity of service.

*"High Frequency Tests of Line Insulators" by Imlay and Thomas. Proceedings A.I.E.E., December, 1912.



OPERATING VOLTAGE

140,000 *127,000* *113,000* *102,000* *90,000* *80,000* *67,000* *50,000*

Fig. 17. Line of Oil-filled High-tension Leads. Made from Moulded Compound Rings

MODERN POWER TRANSFORMERS

By W. S. Moody

Engineer, Transformer Department, General Electric Company

Transformers for almost all of the large power transmission companies are of special construction, and have been designed and built for the particular system on which they are used. This fact has made it necessary for the designing engineer to accumulate accurate data of multifarious kinds in order that precise calculation may be substituted for the "cut-and-try" methods of former days, and the economic manufacture of transformers made possible. Although transformers have been greatly improved as regards construction and operation, the costs have been reduced rather than increased. As a pointer to recent developments, reference is made to the oil-filled leads for outdoor units, and to the modifications in the radiating surfaces of self-cooling transformers for the same service.—Editor.

At one time elementary text-books used to speak of transformers as the simplest form of electrical apparatus. The designer and most users of transformers always knew that making a good transformer was not so simple as the text-books would have one believe. Many of us can remember, however, the days when the "designing" of a transformer was limited to the calculation of core and copper losses, the use of judgment and experience, together with "cut-and-try" methods after tests, being relied upon for all else. While the art of accurately designing all classes of electrical apparatus has greatly progressed during the past few years, it is still permissible in most apparatus to determine important features by test and by "cut-and-try" methods, because such apparatus is usually developed in standard lines of units of varying capacity, in which large numbers of identical units are built. Consequently, two or three trials are permissible before the final designs are settled upon.

In large transformers, and in many cases even in small ones, few duplicate designs are built; and the engineer must, therefore, have such ample general data and make such complete and accurate calculations as to know with certainty what the finished transformer will do. To know exactly what the transformer will do, even under normal conditions of operation, demands extensive knowledge of the materials to be used and their behavior under a wide range of conditions. This, however, is far from sufficient; for it must be known what the apparatus will do under a vast variety of abnormal conditions, such as heavy overload and even short-circuit, lightning and other over-tension strains, high-frequency disturbances, etc., which, collectively, form a far greater variety of conditions than those which most other devices, static or rotating, are subjected to, whether they be electrical or mechanical.

We find, therefore, amongst the various factors which the builder of a large transformer must be able to calculate with exactness, not only the core loss and the copper loss of early days, but such factors as reactance, impedance, mutual induction and self-

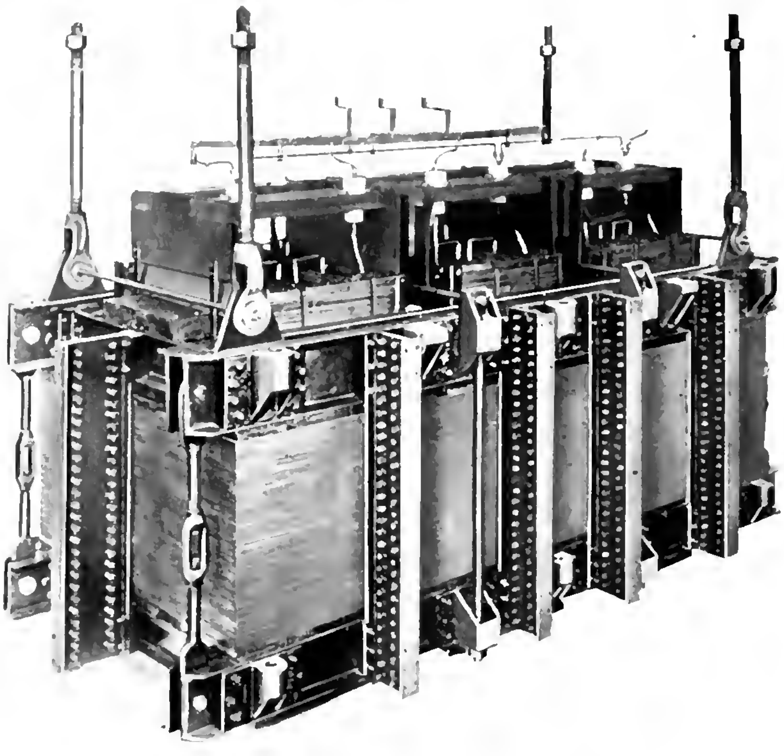


Fig. 1. Large Transformer Showing the Use of Structural Steel

induction; electrostatic capacity of turns and of coils; heat radiation per unit coil surface, core surface, and tank surface; thermal gradient in conductors, insulation, and cooling medium; thermal storage capacity; dielectric gradient; elastic limit of conductors and insulation subjected to mechanical strains, etc. To properly predict the successful operation of a large transformer requires data and experience from which one hundred to one hundred fifty such items as just enumerated can be accurately calculated.

Proper attention to most of these features of transformer design, which were, until a few years ago, given only such general consideration as follows from general experience (such as mechanical strength to withstand overloads and short-circuits, temperature gradients necessary to avoid localized temperature, dielectric gradients necessary to avoid concentration of high-potential strains, arrangement of windings to avoid localization of high-frequency strains, etc.) tends to make designs more expensive. That

Fig. 2. Air Blast Transformer with Steel Plate Base and Cap

great improvement has been made in all these characteristics by the best designers and manufacturers, and yet co .s reduced rather than increased, is due to the great amount of skill and expense devoted to research and design work, and to the vastly increasing volume of manufacture; which in turn is due to the rapid development of electric transmissions which became commercially feasible only with the ability to construct

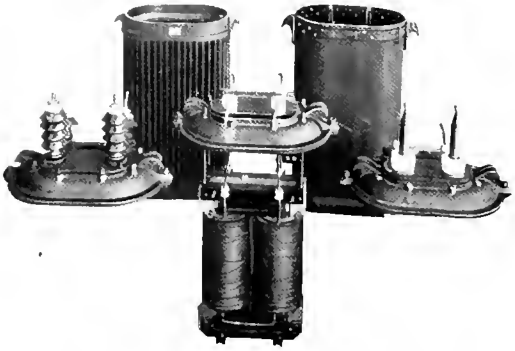


Fig. 3. Same Transformer Interchangeable with Water-cooled, Self-cooled, Indoor and Outdoor Tanks

transformers and lines capable of operating at from 100,000 to 150,000 volts.

Ability to limit the current output of the system which it feeds at time of short-circuit, and successfully to withstand the tremendous mechanical strains that follow the massing of the hundreds of thousands of ampere-turns which result from such short-circuit, is a most important and new requirement for large transformers. Formerly short-circuits were relatively rare and limited in intensity by the reactance of lines and generators. Now with high-speed generators and lines at such high voltage that capacity often neutralizes reactance, and in high-voltage cable transmissions, the transformer must supply nearly all the reactance there is to limit current and energy output. The designer must first build with sufficient reactance to protect the generator, and then so choose his type of winding as to minimize the mechanical strains. Even then forces of hundreds of tons are often unavoidable; and a form of supporting structure for the coils must be adopted that will successfully withstand such forces, and yet act as safe insulation for the voltage and not interfere with the free circulation of the oil or air used as a cooling medium. The problem presents ample opportunity for the exercise of engineering skill of a high order. The present standard construction of such supports has been successfully tested under conditions corresponding to 50,000 kw. generator capacity, short-circuited through a 1000 kw. transformer having only 4 per cent reactance.

The "oil-filled" lead,* first built over ten years ago for a 500,000 volt transformer has recently been greatly improved both electrically and mechanically; and is especially

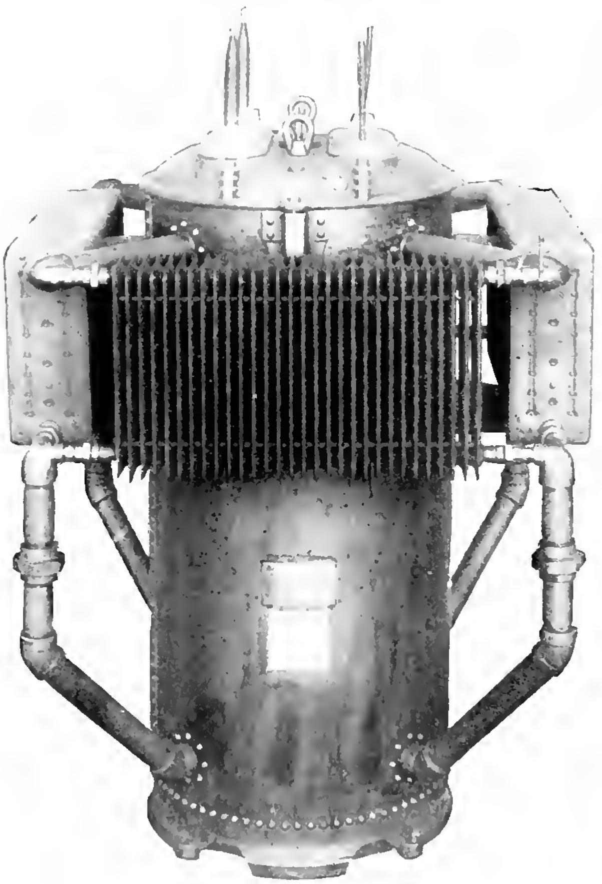


Fig. 4. Oil-cooled Transformer with Radiator Tank

adapted, with slight changes from past practice, to be used on such large transformers as are installed without protection from the weather. This form of lead brings the coil terminals into the air high above the transformer tank, without once coming out of the best-known insulation—oil. That portion of the outer shell of this lead which is in the tank and composed of insulation is entirely oil immersed, so that there is no possibility of any unseen corona discharge, or any discharges from lightning and other high-potential that might ignite the exposed oil surface, or gases above it.

Along with the advance in the electrical features there has been a marked, although not as important, advance in the simplification of mechanical design and reductions in weight and dimensions, by the substitution of rolled structural and sheet steel wherever possible, to the almost complete exclusion of any cast parts. A reduction in weight, due to the use of these lighter mechanical parts, is an important item in connection with the transportation from manufacturer to point of installation. This often is far from a negligible item in the total cost of the transformer installation. More important, however, is the fact that structural steel can be as easily cut to one dimension as to another, so that the designer is bound by no standard patterns, but may design his transformer in whatever size and shape gives the most efficient results.

Among the recent mechanical developments none is more important than the various forms of tanks that have been developed to meet the increasing demand for self-cooled units of large capacity. There has always been a demand for larger self-cooled units than could be supplied at a reasonable cost; but the increased use of outdoor installations, which emphasizes the objections to any artificial cooling, has so increased this demand that the manufacturer who would properly take care of the needs of the user must be prepared to furnish practically any size of transformer in self-cooling tanks. This means that tanks must be built with a radiating surface more than fifteen times that of the surface of a tank which would merely enclose the transformer.

Such tanks are being successfully built in numerous designs, among which may be mentioned thin sheet steel tanks of deeply corrugated and compound corrugated outlines, which give to the tank itself sufficient surface for the dissipation of heat. There are tanks of heavy steel with numerous vertical steel tubes surrounding it and connected to the top and bottom portions of the oil. The latest form is a plain tank with various forms of auxiliary heat radiators, which give a maximum of surface with a minimum of interior oil space. These radiators are connected to the top and bottom of the oil by piping of large cross section (see Fig. 4 for one of such form). Self-cooled transformers having some one of these various forms of cooling surfaces are now available for transformers of almost any size at a cost not seriously higher than that of artificially cooled units.

*See "High-Voltage Transformer Leads: A Comparison of Designs," by E. D. Eby on page 404 of this issue.

SOME MECHANICAL CHARACTERISTICS OF THE MODERN TRANSMISSION LINE

By T. A. Worcester

Power and Mining Engineering Department, General Electric Company

Under the heading "Types of Support" the author discusses the relative advantages and fields of usefulness of wooden poles, concrete poles, steel poles, and steel towers. A section on loads shows how to figure the amount of load which a tower must be designed to withstand, the proportion of the ultimate strength of the conductor which must be taken as the load, and factors of safety for commercial lines. A treatment is given of preferable arrangement of the conductors on the tower; while the paragraphs on insulators take up the mechanical strength of the two types and methods of attaching insulator to tower. In the final section several points affecting the selection of a right-of-way are discussed.—Editor.

In designing any transmission line, the first thing likely to be considered is the size of the conductors and the number of circuits These are determined by the amount and kind of load which it is contemplated to carry, the voltage, the distance, the altitude, the value of lost energy and the character of the country.

The last item is purely mechanical, the influence on the size of conductor being produced perhaps by the necessity of long average spans. The others are electrical; and complete consideration must be given to each before the size of conductor can be settled upon. The final choice will be a compromise between permissible energy loss, voltage regulation, cost of construction and the desirability of reliable and uninterrupted service. In some instances the latter is paramount; and in such cases it is essential to have duplicate circuits, and to suppress any tendency toward a cheap installation with minimum number of circuits and towers. A double circuit, each capable of carrying a major portion of the load, is usually desirable. These two circuits may be placed on the same poles or towers; or, where the greatest reliability is desired, separate structures for each circuit are used. Such an arrangement prevents trouble in one system from communicating to the other. This, while the most expensive arrangement, is by far the safest and has been used in several of our large modern systems.

Types of Support

After the size of conductor is settled upon, the next step is to choose the type of support and insulators and the right of way. These are more or less dependent upon each other, and consideration must be given to all at the same time.

For supports there are available the wooden, concrete or steel pole, or the steel tower. The latter is, of course, the most durable and desirable for a long-distance high-voltage line, but there are many cases in which it is advisable to use one or another

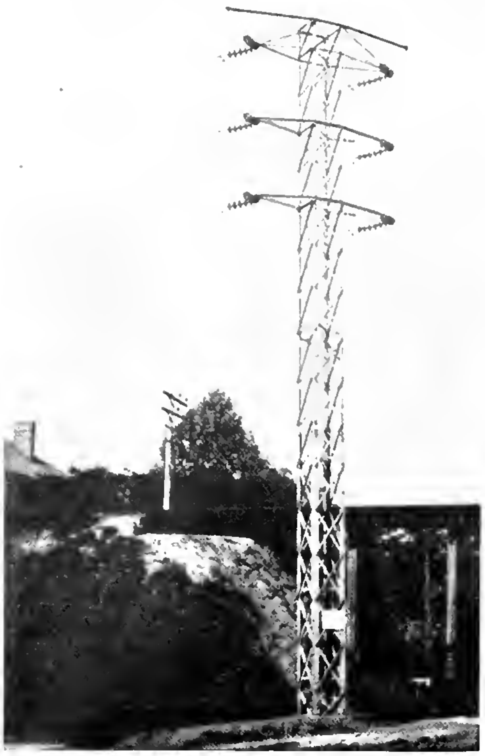


Fig. 1. Latticed Steel Pole at Angle on the Lines of the Central Georgia Power Co.

of the types of poles mentioned. If, for instance, the line is to run through wooded country where pole timber is plentiful, or if it is to be of a more or less temporary character with changes contemplated after five years or so, or if the first cost is of great importance, the wooden pole would be chosen.

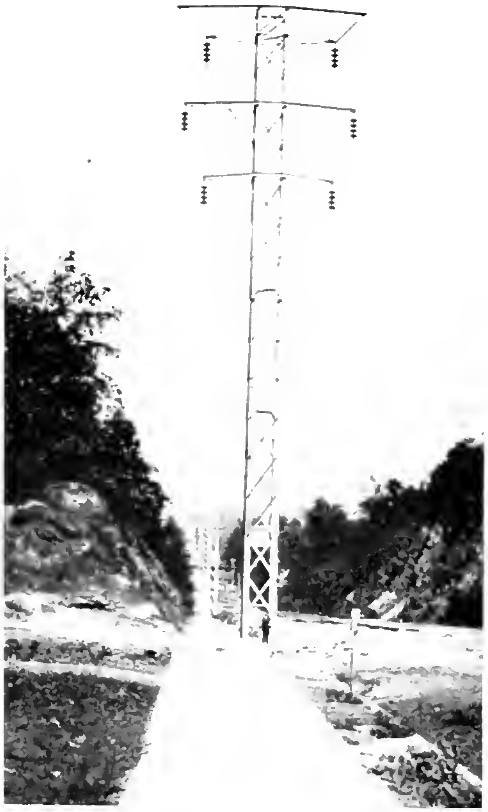


Fig. 2. Latticed Steel Pole on Lines of the Central Georgia Power Co. Note the Staggered Arrangement of Conductors on Each Circuit

Likewise the steel or concrete pole would be used if the line is to be built along a highway, a canal, or a steam railroad, where space is limited and safety and reliability are essential.

Of the various types, the wooden pole is, in the great majority of cases, the cheapest; but it is likewise the least durable. Under the best conditions it cannot be counted on to last longer than twelve years, and where soil and weather conditions are bad, not more than three or four years. When treated with one or another of several approved preservatives the life can be lengthened to 20 years or so. Even though this adds to the first cost of the installation there is not the slightest doubt that treatment will pay, especially since the demand for pole timber is rapidly increasing year by year and the cost is likewise going up in bounds.

Concrete Poles

Concrete poles compare favorably with the wooden pole as to cost, provided the longer life is taken into consideration. While it is true that no concrete poles have been up long enough to determine their actual life, the experience of the past ten years is sufficient to demonstrate that one can expect a life of 40 to 50 years; and the claims of some engineers for even longer life are not at all unreasonable. In order to possess this durability the poles must, of course, be well designed and constructed. This is not

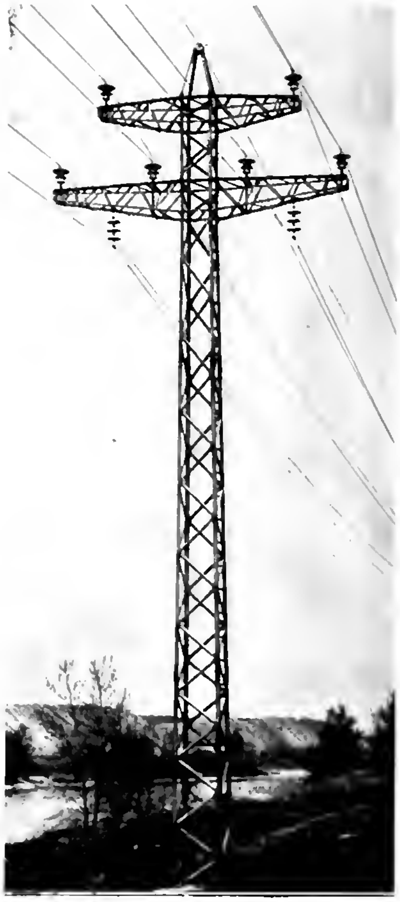


Fig. 3. Latticed Steel Pole on Lines of Sanitary District of Chicago

always the case, many poles after a year or two having shown cracks due to temperature changes. In the great majority of cases, however, the early fears of trouble from this source have not been realized, and the more satisfactory experience is very gratifying. The chief disadvantage of concrete poles is their weight, which makes transportation and erection difficult and costly, and precludes their use for cross country lines where long hauls must be made. When water is available concrete poles can be made at the place of erection, but this is not practicable when water must be hauled.

Steel Poles

The steel pole is more durable and at the same time more costly than any of the other types; but it has a special field where the best construction is desired and the right of way is limited. Examples of the better types of latticed steel pole lines are to be seen adjoining some of the steam railroads over sections of electrified line near large cities. In such installations the matter of reliability is of

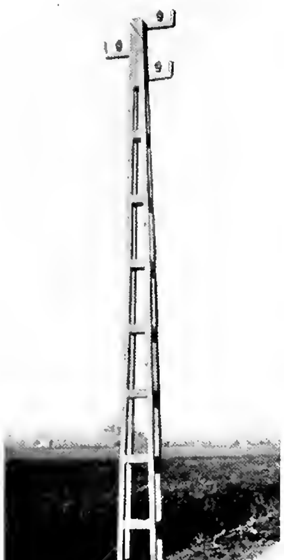


Fig. 4. Concrete Pole for High-Voltage Transmission Line. This Cut Illustrates Foreign Practice

first importance and expense is a secondary consideration. Poles of this type are made of relatively thick metal and are not galvanized, but frequently inspected and painted. They are set in concrete foundations which extend a foot or a foot and a half above the ground level, thus giving mechanical stability and insuring that the steel work will not stand

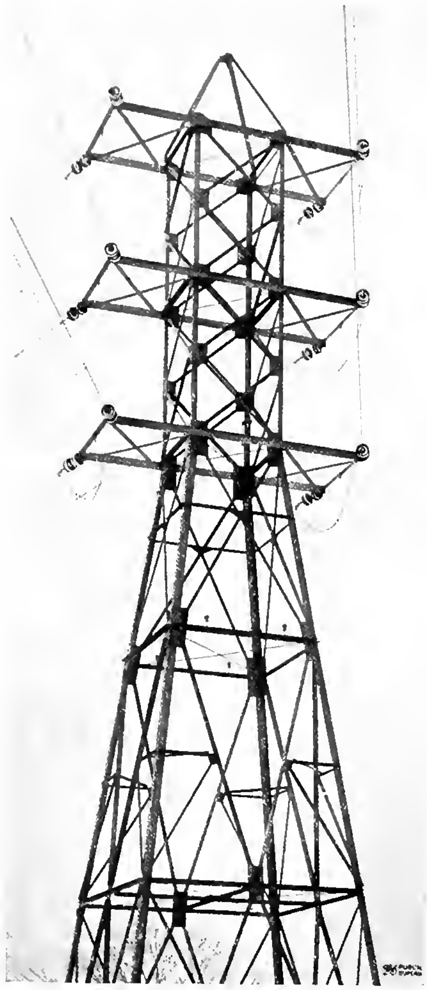


Fig. 5. Strain Angle Tower, 1200-Foot Span, on Lines of Schenectady Power Company

in moist earth which would produce rusting. Such poles, properly cared for, may be said to have almost an indefinitely long life.

Oftentimes steel poles of very much lighter construction are built where less reliable service is needed. These should always be galvanized, and in most cases should be set in concrete foundations. Such poles are useful for light lines in mountainous regions where transportation is difficult and pole timber scarce. Concrete foundations can often be omitted and rock filling depended upon.

Steel Towers

As stated above, the built-up steel tower is the most serviceable and economical for high-voltage long-distance lines. There are

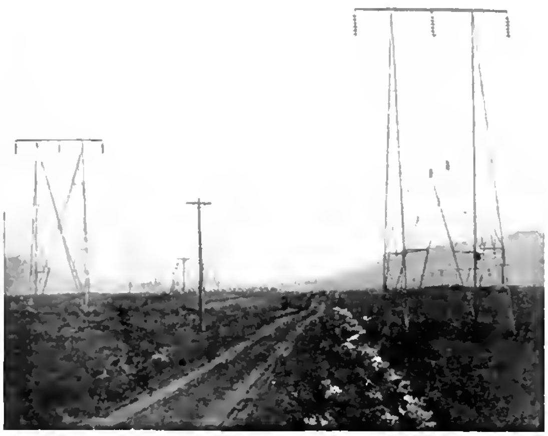


Fig. 6. Double-Circuit Double-Tower Line, Great Falls Power Company

a great many varieties of towers, both from the standpoint of construction, appearance and utility; but, in general, tower lines may be divided into two classes: first, those which contain all rigid towers; and, second, those which contain a few rigid and a majority of flexible structures.

In the first class every tower is rigid in all directions and able to withstand a considerable load in a horizontal plane parallel to the line, as well as at right angles to the line. Usually such a line is built up of a number of light weight and a few heavy structures. The former is able to withstand only a moderate load in the direction of the line, such as would be caused by the breakage of one or two conductors; while the latter are designed to withstand the unbalanced load caused by the breakage of all conductors. The heavier towers are placed at, say, one mile intervals and at angles in the line, and the lighter ones in between, this arrangement limiting the spread of any trouble to the distance between heavy towers.

In the other class of systems, the few heavy towers can withstand the breakage of all conductors just as in the rigid tower line; but the intermediate lighter structures are rigid only in a horizontal direction at right angles to the line, and are flexible parallel to the line. Thus, if a small number of conductors break, the towers will bend slightly, owing to the unbalanced load until equilibrium exists; or in other words, the unbalanced load caused by the breakage of a few wires is cared for by the remaining wires instead of by the towers, as in the rigid system.

The rigid system as described above has the broadest field and is most frequently used. Even in this type of system there is a great variation in practice, and no one set of conditions or style of tower can be taken as standard. In general, the rigid tower is a three- or four-legged structure, made up of light section galvanized steel, with broad base and angle iron ground stubs and feet. Concrete foundations need not be used in all cases, but are advisable where the soil is loose or moist and good rock filling cannot be secured. The foundations are quite an important item and should be given careful attention, since the towers may be amply strong themselves and fail by pulling up of their footings. Many such failures have

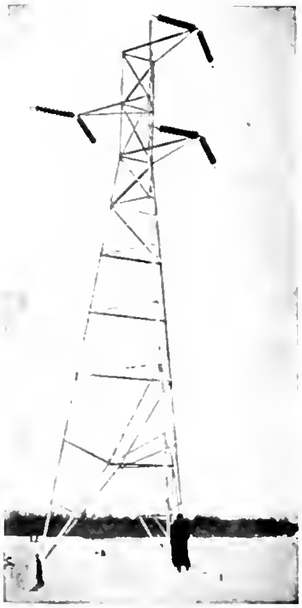


Fig. 7. Strain Angle Tower on Lines of Au Sable Power Company

occurred and are disastrous to the successful operation of a line. Towers should never be placed in filled ground if it is possible to avoid it; and in hilly country special care should be taken to avoid points at which land or snow-slides are likely to occur. Likewise in the neighborhood of rivers which occasionally overflow their banks the foundations should be protected by piling or cribs, otherwise serious difficulty may result.

Loads

There is a great difference of opinion among engineers as to the amount of load which a tower must be designed to withstand. This is due to the uncertainty, first, as to the amount of wind and ice likely to occur, and at what temperature; and, second, as to the number of wires likely to break at any one time.

Space will not permit going into a lengthy discussion of this topic; and it will simply be stated that for most districts throughout the United States where sleet frequently forms on wires, it is about agreed to allow for a combination of one-half inch thickness of ice and 8 lbs. of wind per sq. ft. of projected area of ice-covered wire. The wind acting on this surface is applied to the towers at the wire supports in a horizontal direction perpendicular to the line. The vertical load at these supports is that caused by the one-half inch ice-coated wires; and, in addition, it is customary to add the weight of a man with block and tackle. The load in the direction of the line depends entirely on the strength of the conductors. The best practice would seem to indicate that for strain towers allowance should be made for the breakage of all conductors; while, for intermediate towers carrying three conductors and one ground wire, for the breakage of one conductor*; and for a six-conductor tower with two ground wires, for the breakage of two conductors.

Fig. 8. Flexible Steel Tower on Lines of Rochester and Sodus Bay Power Co.

*Some engineers figure on the breakage of two conductors in both three- and six-conductor towers.

The question then arises as to what proportion of the ultimate strength of the conductors should be taken as the load. If a cable breaks on one side of a tower it is obvious that the unbroken cable in the adjoining span might be strained to its ultimate strength, and that this load would be transmitted to the cross-arm. When the smaller sizes of conductor (No. 4 B.&S.) are under consideration, the loads are usually figured on this basis. For the larger sizes (2/0 and above), however, except in the more conservative designs the loads are figured on the basis of the cable never exceeding its elastic limit, or approximately 50 per cent of its ultimate strength. For sizes between Nos. 4 and 2/0 intermediate percentages of the ultimate strength are used.

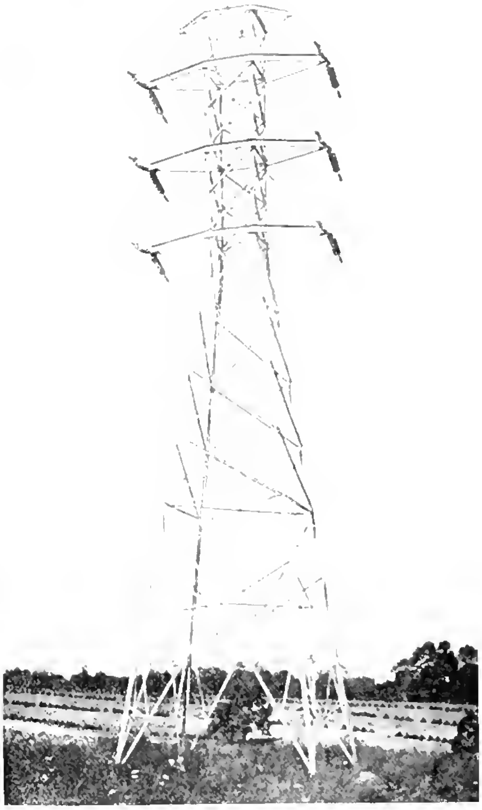


Fig. 9. Intermediate Strain Tower, Pennsylvania Water and Power Company

The argument for this practice is that the cable stretches when its elastic limit is reached, thus reducing the stress; and that it is only some exceptional loading, such as a tree across the line or an unusually heavy coating of ice, which would bring the conductor to the breaking point. Even with these conditions the stretch in the conductor is likely to release the strain, so that the load is not likely to equal the ultimate strength of the conductor.

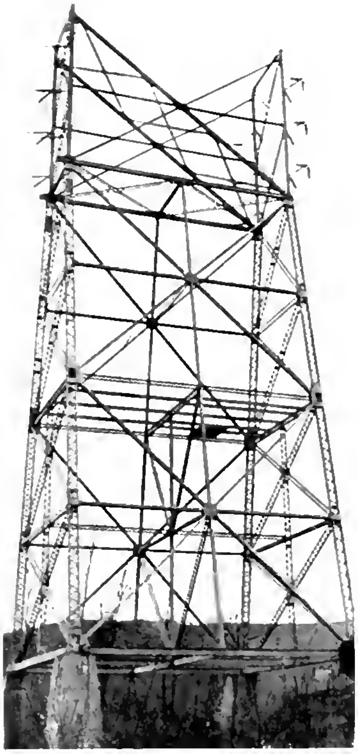


Fig. 10 Terminal Tower at Susquehanna River Crossing, Pennsylvania Water and Power Company

Factors of Safety

Having settled upon the loads which the tower is to stand it becomes necessary to choose a factor of safety. The amount of factor of safety for any structure depends on

(*a*) The character of the load—whether steady, intermittent or otherwise;

(*b*) On the knowledge one has of the amount of load;

(*c*) On the ease or difficulty of calculating the structure to care for the assumed load;

(*d*) On the possibility of faults in manufacture and erection; and

(*e*) On the risk to life and property.

In a transmission structure the load is intermittent and reversing, and our knowledge as to its amount is not definite. These features would tend to demand a relatively large factor of safety. This tendency, however, is more than counterbalanced by the fact that it is not difficult to calculate the stresses when the load is assumed; that the chance for faults in manufacture and erection are few, owing to the simplicity of the structures; and that the risk to life and property is a minimum, in contrast to buildings, bridges, etc.

Another feature which makes it possible to use a small factor of safety is that a sample tower may easily be tested with assumed loads and with ultimate breaking loads. Obviously, if a factor of safety is used which will permit the tower to be strained with the assumed loads without being permanently deformed, then such a factor of safety will be satisfactory, provided the assumed loads correspond with the actual loads. The factor of safety for these conditions is two, if it is considered that the elastic limit of the metal is one-half of its ultimate strength. Many transmission towers have been built on this basis with a consequent saving in the cost of the line.

On the other hand, conservative engineers have in many cases used values of three and even four, the former being chosen for strain towers in which the load conditions are known, and the latter for intermediate towers in which the loads are uncertain. The use of these large values, however, makes the cost of the line excessive; and for this reason it is common practice to use smaller values, two, two and one-half and three for the intermediate towers, and three or three and one-half for strain towers. With this arrangement the main part of the line will be safe except in case of some unusual conditions which produce very much worse loads than those assumed; and in the event of such an accident the strain towers will prevent the trouble from traveling to the next section of the line.

Arrangement of Conductors

The arrangement of conductors on the towers is an important detail from the standpoints of accessibility and safety against short-circuits. Continuous service is to-day the demand of power users; and frequently this leads operating companies to install duplicate lines, each capable of carrying a large percentage of the load. If one circuit is accidentally put out of commission the other must be kept going at all costs. In a number of the more important installations the individual circuits are placed on separate towers to insure the desired continuous service. This is, of course, the most reliable arrangement, and one which makes it possible to repair a damaged line while the other is in service, without danger to repair men or of further interrupting service. When the two circuits are supported on the same towers the difficulty of working on one line while the other is alive is relatively great; but it is possible to make the clearances such as to permit repair work to be done in safety, and provision for this should always be made.

As a precaution against the conductors swinging together in the middle of spans liberal spacing should be allowed between conductors of each circuit. This spacing should be greater for suspension than for pin insulators, and for long spans than for short. Also, when possible, the conductors should be placed one immediately above the other, especially when suspension insulators are used. Many lines are built with this vertical arrangement of conductors; but when sleet and wind conditions are bad the mishaps have been numerous, in some cases compelling changes in the tower construction to eliminate the trouble. The breaking away of sleet from a wire in one span and not in the adjoining, the melting of ice and the formation of icicles at the center of spans, and the bobbing up and down of conductors due to gusty winds, are common causes of this trouble.

Insulators

Insulators and their fittings offer perhaps the most troublesome detail in the design of a high-voltage transmission line, and in their selection rests the success or failure of the system. Their mechanical strength and durability, the methods of attachment to the tower and to the conductor, and their electrical strength both at operating frequency, and at higher frequencies or suddenly applied potentials, are all points which should be carefully considered. With the pin type insulator, which is in general use up to about 60,000 volts, there is little difficulty in securing ample mechanical strength; but with the suspension type, especially when used at dead ends or strain points in the line, more frequent trouble is experienced. The difficulty can, however, be overcome by mounting two strings of insulators in multiple, this scheme being used for long span work or for all strain and dead ends in lines using heavy conductors (No. 0000 or greater).

The method of attaching the insulator to the tower is an important although a simple matter. Some form of link which will allow free play with the minimum amount of wear is desirable. The fastening for the conductors is more difficult to arrange. With pin insulators, clamps have been used but little,

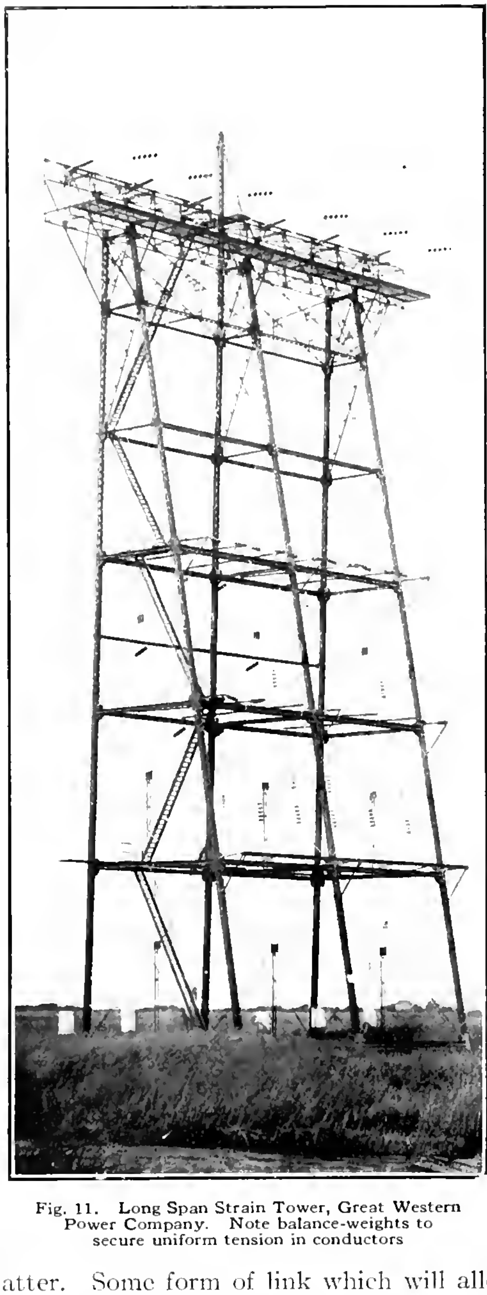


Fig. 11. Long Span Strain Tower, Great Western Power Company. Note balance-weights to secure uniform tension in conductors

due probably to the fact that available designs lack flexibility, and damage the conductors to such an extent as to produce breaks. Soft metal tie wires have proved most effective and injure the conductor less than any form of clamp. With the suspension insulator there are greater opportunities for flexibility; but even here there is considerable danger that the clamp will grip the cable too abruptly, and nick or kink it in such a manner that crystallization will take place as it swings in the wind. A clamp to be satisfactory should have a long smooth grip with gradually belled ends, and a flexible link connection to insulator. Under no consideration should the grip be roughened; since it is often necessary to draw the cable up after it is once installed, and a roughened surface on the cable is a positive weakness.

As regards the electrical characteristics of the insulators little will be said here as the subject has been ably discussed in previous issues of the REVIEW.* It is important that liberal factors of safety be allowed; that dry, wet and puncture tests be made at normal frequency and, if possible, arc-over and puncture tests at high frequency; and that uniformity in quality and dielectric strength be insisted upon.

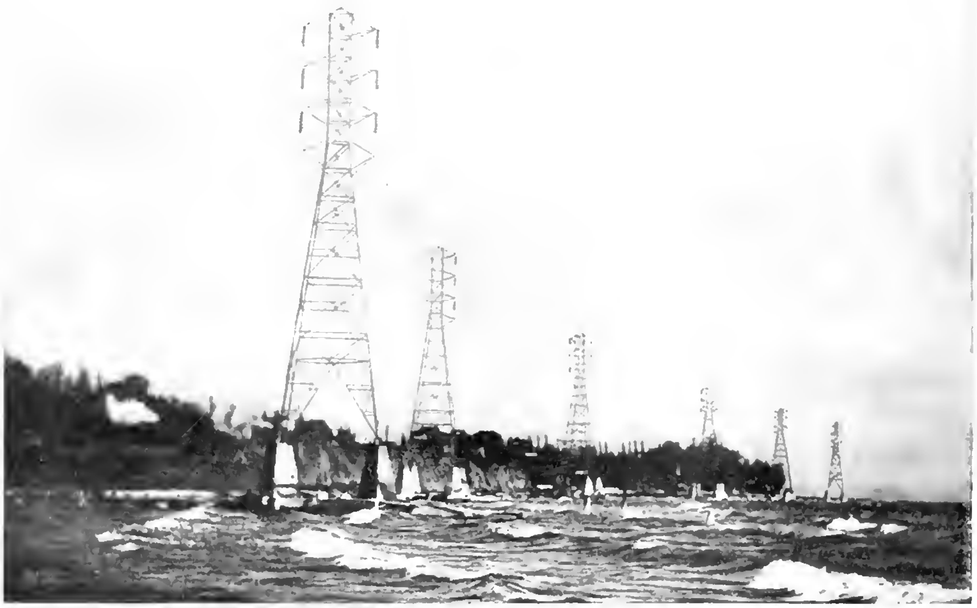


Fig. 12. Double-Circuit Towers, Hydro-Electric Power Commission of Ontario. This construction is used along lake shore at entrance to Toronto

Right of Way

In the selection of a right of way attention should be given to the following points: accessibility for transportation, erection and repairs, possibility of land or snow-slides or floods, necessity of clearing, danger from willful interference, danger from lightning and wind, necessity for long spans, distance from important telephone and telegraph lines and from populous districts.

The difficulties which may result from the neglect of these precautions are evident, so that their mere mention is all that is necessary. For moderate-voltage lines advantage can well be taken of rights of way already opened, such as highways or steam railroads; but for the higher voltages these should be avoided because of the many annoyances likely to occur, even though the other routes may be more difficult to reach and will have

*"The Line Insulator in Modern High-Voltage Transmission Systems," by F. W. Peek, Jr., June, 1912; and "High Tension Insulator Tests, a Study of Design Factor," by F. F. Brand, April, 1913.

greatly increased first cost. In farming sections it is not usually necessary, nor desirable, for the power company to own a right of way outright, but sufficient that it simply have the privilege to erect and maintain its towers and keep a strip of the land clear of trees. A liberal policy with the property owners in such sections will be found to be a distinct advantage. They will take an interest in the line, report broken insulators or other troubles, and prevent intentional damage.

Conclusion

One cannot, of course, expect to have an ideal line from all standpoints and oftentimes some very valuable feature must be sacrificed; but the nearer we approach the ideal the more reliable will be the service and the more satisfied will be the customers.

A CLASSIFICATION OF PROTECTIVE APPARATUS USED IN HIGH-VOLTAGE LINES

By V. E. Goodwin

Power and Mining Engineering Department, General Electric Company

This article is intended as a short resumé of all apparatus whose function is protection against abnormal conditions of service—not alone the devices that have been perfected for the discharge of dangerous potentials, generally referred to as lightning arresters. Excessive potentials and currents are the phenomena that are mostly to be feared; but these are often directly attributable to high frequency surges or to what the author classifies as accidental conditions; and here the function of the protective device is to suppress the contributing cause of trouble, or else insulate it, so to speak, from those parts of the system where it will engender damaging potentials or currents.—Editor.

In the design and construction of electrical apparatus the insulation is so proportioned and distributed about the conductors as to provide an ample factor of safety above the normal operating potential. Furthermore, it is well known that during operation there are frequently abnormal or transient conditions against which it is impracticable to attempt to insulate the conductors; and it is, therefore, necessary to provide lightning arresters and other forms of protective apparatus.

Briefly stated, there are four classes of abnormal conditions* which may cause injury to the insulation, namely:

(1)—Abnormal voltages
(2)—High frequencies
(3)—Excessive currents
(4)—Accidental conditions.

The common expression, "abnormal disturbance" may refer to any one of the above, or to a combination of two or more which may occur simultaneously or in sequence.

1. *Abnormal voltages* occur principally as a result of lightning, resonance, sudden changes in magnetic fields, and the reflection of traveling waves. This class of disturbance causes temporary strains in the insulation, which may result in permanent injury or even complete rupture of that medium.

2. *High frequency oscillations* may be induced from adjacent circuits or lightning discharges, or may result from internal causes. Sudden or forced changes in electromagnetic or electrostatic conditions cause a circuit to oscillate. An arcing ground and the opening or closing of a circuit are also examples of this condition.

3. *Excessive currents* damage the insulation by overheating, and by abrasion resulting from the mechanical distortion of the conductors by the flux.

4. Under the heading of *accidents* may be classified such conditions as breaking of lines from wind, sleet or other causes, improper switching or handling of apparatus, faulty workmanship in design, construction or installation, and numerous other similar troubles.

Numerous forms of protective apparatus have been perfected to guard against these abnormal conditions. The ideal to attain is of course a protector which would prevent the origin of these disturbing elements. Many of the disturbances are, however, beyond the control of man, while others are the result of accidental conditions. Protectors have consequently been devised which under some conditions meet the ideal requirement, but under other conditions dissipate the energy of the transient before it reaches a dangerous value. Other forms of protectors are designed with a view to confining the disturbance to some section of the system

*A very interesting and lucid discussion of these abnormal conditions has already been made in the Review, and in considerable detail. See "Abnormal Strains in Transformers," by Dr. C. P. Steinmetz, December, 1912.

where it would do no harm. Another form operates automatically to substitute a disturbance which can be controlled for the original disturbance.

Forms of Protective Apparatus

Protective apparatus commonly used on electrical circuits includes many forms of lightning arresters, reactance coils, automatic circuit breakers, relays, arcing ground suppressors, short-circuit suppressors, overhead ground wires, etc.

The Aluminum Lightning Arrester†

The electrolytic films on aluminum cells possess ideal characteristics as a protector against high voltage and high frequency disturbances. These films introduce a barrier to the normal potential of the system; but allow the energy of an abnormal disturbance to be easily dissipated by discharging through the cells.

The arrester may be represented diagrammatically by an electrolytic condenser with a low series resistance. Under conditions of an abnormal rise in potential the electrolytic condenser automatically changes from condensance to a low resistance. While this apparent transformation is gradual, it takes place before the potential reaches a value which is dangerous to the insulation. As the energy of the transient is dissipated and the potential decreases again to normal, the condensance is automatically restored. For high frequency disturbances the electrolytic condensers with their low series resistance offer the ideal mode of dissipation.

The design of aluminum arresters involves not only a thorough knowledge of transients but also of the properties of electrolytes and films, and efficient means for heat dissipation. The cells should be oil-insulated and cooled, baffles being used to effectively direct the circulation of the oil.

Alternating current arresters which inherently require a series horn gap should be provided with charging resistances. These resistances tend to increase the life of the arrester and make its operation more reliable. In construction they are arranged with a special gap mounted above the main gap so as to provide selective discharge paths. If the discharge is exceptionally heavy, it takes the main gap; but is instantly intercepted by the upper gap, the final arc dying out through the resistance.

Other forms of arresters such as multigap, horn gap, magnetic blowout and mechanical break types are so well known as to require no explanation in this article.

The new vacuum-tube type signal and telephone is a very excellent protector for low voltage alternating and direct current circuits. The arrester consists of a gap element sealed into a metal tube. The space about the gap contains a rarefied atmosphere of special gases to give the desired spark potential to the gap. The arresters are strong, durable and have a very reliable seal. The metal enclosing tube provides large cooling surfaces; so that the unit has a good discharge rate for dissipating such abnormal disturbances as may occur on signal and telephone circuits, without allowing injury to the delicate insulation used on these circuits.

Reactance Coils*

Protective reactance coils, by virtue of their inductance and resistance, may be used to limit the power to safe values at times of short-circuit, to absorb and reflect high frequency oscillations, or as retardation or choke coils as auxiliaries to lightning arresters.

The field of application of power limiting reactances is constantly increasing with the concentration of power in large transmission systems. Accidents in the operation of these large systems would result in tremendous short-circuit currents, if the normal reactance of the apparatus were not augmented by external reactance. These power reactances must be so proportioned as to limit the short-circuit current to a value which will not introduce excessive mechanical strains in the windings and insulation of the apparatus.

Coils of high inductance have been used to some extent as protective devices; but, since they must carry the power current as well as the high frequency transient current such large amounts of copper and high cost are involved, as to make their use impracticable.

The retardation or choke coil mentioned above is the most common application of reactance coils. Their primary function is to retard and reflect an incoming impulse or oscillation sufficiently to allow the lightning arresters to better perform their duty. Air-insulated coils of from 20 to 40 turns are ordinarily used for this purpose. They should

†"The Construction, Installation and Maintenance of Aluminum Arresters and their Auxiliaries," by R. T. Wagner, GENERAL ELECTRIC REVIEW, January, February and March, 1913; and, "The Charging of Aluminum Lightning Arresters," by E. E. F. Creighton, April, 1913.

*Dr. C. P. Steinmetz in REVIEW, September, 1911, and E. D. Eby, December, 1912; "The Use of Power-limiting Reactances in Large Power Stations," by C. M. Davis on page 365 of this issue.

be installed in the transmission lines between the station apparatus and the lightning arresters, preferably just outside the station, as they then give better protection to the entrance leads. In cases where this arrangement is not feasible, they can be installed just inside the entrance to the station.

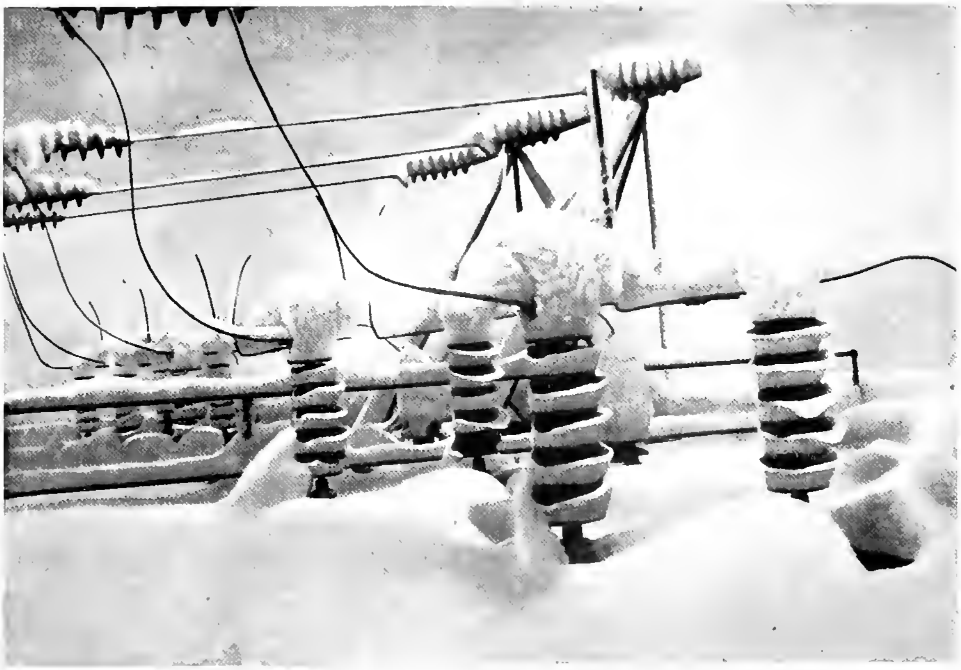
Ground Wires†

The cost of high voltage arresters makes their installation impracticable for line protection. Overhead ground wires have been used very successfully for the protection of transmission lines. While there seems to be no tangible way to measure the protective value of these ground wires, a comparison of the line troubles of a large number of systems operating with and without them prove them to be of great value. The action of ground wires in affording protection to line insulation includes the shielding of the line wires from direct lightning strokes, and the absorption of transients by mutual induction and increased capacity to ground. The efficiency of ground wires is, therefore, greatly increased by frequent and reliable connection to earth. It occurs to the writer that a material improvement in protection would result if several ground wires were installed over the transmission lines for the first mile or so from each station.

† "The Ground Connection in Lightning Protective Systems," by E. E. F. Creighton, January and February, 1912, General Electric Review.

Insulator and Line Construction

Weak insulators and poor line construction invariably result in many interruptions to service and damage to apparatus. To give point to this statement we may cite the case of a large system operating at 100,000 volts. The system had averaged, during two years operation, one serious interruption per month. The line construction was improved; with the result that no interruption has since occurred, during approximately seven months operation to date. A careful consideration of the condition of insulators and line construction may be regarded as an insurance against trouble; and its inclusion in an article on protective apparatus is therefore entirely in place.



Snow on Lightning Arrester Horn Gaps on Lines of Great Falls Power Company, Butte, Montana

AUTOMATIC REGULATORS FOR THE CONTROL OF SYNCHRONOUS CONDENSERS IN POWER SYSTEMS

By H. A. Laycock

Power and Mining Engineering Department, General Electric Company

This article describes and shows the connections for an automatic regulator to be used with a synchronous condenser placed near the center of distribution of a supply system, giving an arrangement which will automatically compound for line loss and maintain constant voltage at the distributing station. On long lines where, through the condensive reactance, the voltage may be considerable higher at the receiving end than at the generating end, a special combination of exciters must be used for furnishing current to the condenser fields. The latter part of the article describes a very ingenious arrangement for such cases, by which a range of excitation from zero to 250 volts is secured on the condenser, and the voltage on the direct current control magnet of the regulator prevented from ever reaching zero.—Editor.

When automatic regulators are not used the usual method of voltage regulation, in both steam and hydraulic plants, consists in operating the exciters at their normal rated voltage and adjusting the generator voltage by use of the generator field rheostat. In a great many instances the loss in the generator field rheostat is such as to require two exciters, whereas one could normally be used if automatic voltage regulators were employed, as the generator rheostat could all be turned out, and thus the dead loss in these rheostats be avoided. Voltage regulators which operate automatically, by opening and closing a shunt circuit across the exciter field rheostat, allow the exciter to be operated at a voltage required by the alternator field under different conditions of load. An alternator requiring 125 volts excitation, for example, has usually a drop across the field at no load of about 70 volts and at full load 130 volts, at a power factor of about 80; and as the alternator field rheostat is all turned out a large saving in exciter energy is accomplished.

The advantages of the automatic regulator in such instances as this are sufficiently obvious and are well understood. In addition, the principles of this apparatus have by now been successfully applied to the solution of many other problems in the economic and satisfactory operation of electric power systems; and to-day the automatic voltage regulator, in any one of many forms, is performing a variety of functions in electric supply. Some of these forms have already been described in the Review*, such as the regulator, which, by automatically adjusting the excitation of synchronous motors in the load circuits of a power system, provides automatic power-factor regulation on the system; and a further equipment for automatically reducing the excitation on generators, in cases where, through sudden release of a short-circuit, the station voltage tends to rise excessively.

* See "Automatic Voltage Regulation of Power Transmission Systems," by H. A. Laycock, Review, June, 1912.

The extended use of synchronous condensers in improving the regulation of long transmission lines—and even short lines—which are subjected to low power-factor conditions has provided a notable use for the automatic regulator in assisting the condenser to discharge these valuable functions. Synchronous condensers not only increase the energy output of the station; but can be so arranged that, by placing a standard automatic voltage regulator on the condenser, the voltage of the line may be maintained constant over a broad range of varying power-factor. This assumes, of course, that the condenser is of sufficient capacity that, under the worst conditions of load, the excitation of the condenser can be increased so that a leading current will be supplied to the line when the power-factor is low, and, in case the power-factor runs above unity, a lagging current will be supplied to the line automatically by the use of the regulator.*

Assuming that the condenser and regulator are placed near the center of distribution, a current transformer or compensator can be placed in the line so that the line loss will be automatically compounded for, and absolutely constant voltage at the center of distribution be, in this manner, automatically maintained. A simple diagram of connections showing a small type of voltage regulator used on standard synchronous condensers is given in Fig. 1.

This regulator has a range of approximately 2:1, but for special applications the range of excitation which it will take care of can be somewhat increased. The control magnet of the regulator is connected across the exciter

* A useful cross-reference may here be made to Mr. Dewey's article (see pages 357 and 358) in which he shows the extent of the demand which a sudden no-load condition may place upon the regulation of the line; and to Mr. Peek's paper on page 430, in which he gives a mathematical treatment of the effect of a condenser of given size on the regulation characteristics.

bus; and, with this type of regulating apparatus, it is necessary that excitation of the control magnet shall never be reduced as low as zero, although it may, as in the case of the ordinary alternating current generator, drop as low as a no-load excitation on the condenser. In other words, assuming that the condenser requires a no-load excitation of 60 volts, a standard regulator can be used.

On long transmission lines, however, it frequently occurs that the charging current of the lines is sometimes such that the voltage is higher at the receiving end than it is at the generating end; and, in order to take care of such conditions, the excitation of the condensers must be practically zero, at times, as it is impossible to get automatic regulation by allowing a regulator to stop working. In the case of lines having a heavy charging current therefore a combination of exciters such as that shown in Fig. 2 must be employed. It will be noted that the main excitation of the condenser is supplied

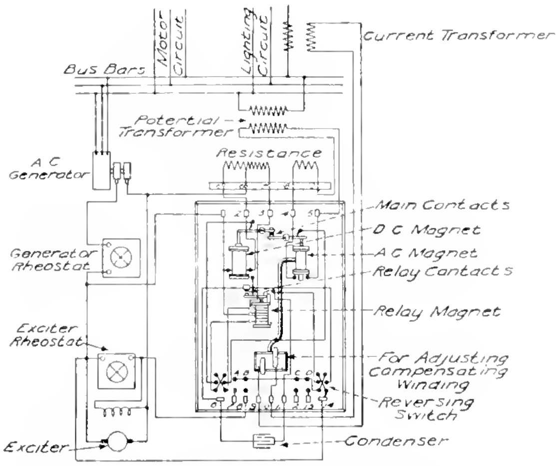


Fig. 1. Connections of Automatic Voltage Regulator for Use with Synchronous Condenser in Transmission Systems

from a 250-volt exciter. With this scheme either the field of this exciter is designed for 125 volt excitation, or a standard 250-volt machine may be used with the fields connected in multiple. This exciter is separately excited from two small exciters which are running series bucking. One of these exciters is designed for 125 volts and the other designed for 250 volts. The regulator is placed across the 250-volt exciter as will be

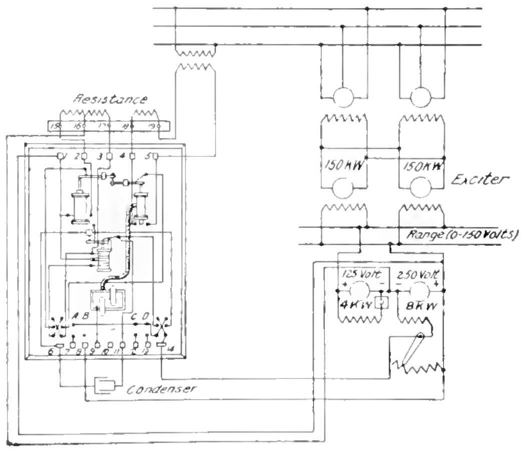


Fig. 2. Connections of Synchronous Condensers, Combination of Exciters, and Automatic Voltage Regulator, for Use on Transmission Lines Having a Heavy Charging Current. The Arrangement Provides a Range of Excitation on the Condenser from Zero to 250 Volts

noted from the diagram. With each of these exciters delivering 125 volts, zero current will flow in the fields of the larger exciter. Should the demand of the system require the condensers to deliver heavy leading current the exciter which is designed for 250 volts will have its voltage increased by the regulator. This will increase the excitation of the larger exciter from zero to 125 volts; and therefore, with the fields of this machine connected in multiple, 250 volts will be delivered to the fields of the synchronous condenser.

It will be noted that the purpose of this combination of exciters is to prevent the voltage which is supplied to the direct current control magnet of the regulator from ever reaching zero. The range is from 125 to 250 volts on the regulator, which gives an excitation on the condenser of from zero to 250 volts.

PRACTICAL CALCULATIONS OF LONG DISTANCE TRANSMISSION LINE CHARACTERISTICS

(Regulation, Efficiency, Phase Control of Voltage, etc.)

By F. W. Peek, Jr.

Consulting Engineer, General Electric Company

The characteristics of a short transmission line may be obtained with sufficient accuracy by the use of any one of the several methods which neglect the capacity of the line and consider the inductance as concentrated at certain points. Such a method is given in the article by Mr. Waern on page 460 of this issue. For long lines, however, both the capacity and the inductance of the line must be taken into account, and be considered as evenly distributed; and in this article Mr. Peek develops formulæ, applicable to such lines, which are simple in application and capable of yielding the required degree of accuracy. The latter part of this paper constitutes a highly valuable sequel to Mr. Dewey's article on operation, on page 355. The condenser method of voltage regulation again comes up for attention; and is here considered from the standpoint of how to determine mathematically the size of condenser for meeting the requirements of a given line. The author first explains the principles of the case and the general application of the method; and proceeds to illustrate it by taking up a practical problem and working out mathematically the effects of the condenser selected upon the voltage characteristic. —Editor.

Line

In calculating the characteristics of high voltage, long distance transmission lines, it is necessary to consider the resistance, reactance and capacity as evenly distributed.* This leads to a very complicated expression, which, fortunately however, may be expanded into a rapidly converging series. Most of the terms may, therefore, be neglected, and simple formulæ be obtained which give very accurate results. These formulæ are, in fact, much simpler to use than the so-called approximate methods.

The formulæ are:

$$(1)\quad E_1 = E_0\left(1+\frac{ZY}{2}\right) \mp ZI_0\left(1+\frac{ZY}{6}\right)$$

$$(2)\quad I_1 = I_0\left(1+\frac{ZY}{2}\right) \mp YE_0\left(1+\frac{ZY}{6}\right)$$

With regard to the double sign, the sign + applies if E_0 and I_0 are voltage and current at the receiving end, and the sign − if E_0 and I_0 are voltage and current at the generating end.

It must be remembered that these are vector quantities. In practical work E_0 and I_0, power, and power-factor are generally known at the receiving end and it is desired to find E_1, I_1, and power at the generating end.

E_0 is then taken as the reference line, or without component.

In calculations, to avoid confusion, the following nomenclature will be used throughout.

E_g = Volts between lines at generator end.
I_g = Amperes line at generator end.
E_r = Volts between lines at receiver end.
I_r = Amperes line at receiver end.
e_g = Volts to neutral at generator end.
e_r = Volts to neutral at receiver end.
e_1 = In-phase component of e_g or e_r.
e_2 = Out-of-phase component of e_g or e_r.
i_1 = In-phase component of I_g or I_r.
i_2 = Out-of-phase component of I_g or I_r.
I_L = Load current.
I_c = Condenser current.

The reference line will be E_r, corresponding to the E_0 as previously noted.

It is more convenient in getting line constants to use volts to neutral.

Thus for three-phase:

$$\frac{E_r}{\sqrt{3}} = e_r$$

Power-factor $= \cos\phi$

$$I_r = \frac{\text{Power}}{\sqrt{3}\,E_r\cos\phi}$$

** $I_r = i_1 + j\,i_2$ for lagging current
$I_r = i_1 - j\,i_2$ for leading current
$i_1 = I_r\cos\phi$
$i_2 = I_r\sin\phi$

r = Total resistance of one conductor in ohms.

† X = Total reactance of one conductor in ohms (reactance to neutral).

$Z = r - j\,x$ = Impedance of one conductor, or to neutral.

‡ C = Capacity in farads of single conductor to neutral, i.e., twice the single-phase capacity between two conductors, each of the same length as the line considered.

$Y = g - j\,b$

* See "Transient Electric Phenomena and Oscillations," by C. P. Steinmetz.

** The dot beneath a symbol means a vector value. Thus, $I_r = i_1 + j i_2$ while $I_r = \sqrt{i_1^2 + i_2^2}$ = absolute value.

† $x = 2\pi f L$, where f is the frequency and L is the self inductance in henrys, per conductor, per 1000 feet.

$$L = \left|1.41\log_{10}\left(\frac{S}{d}\right) + 0.576\right|(10)^{-4}\text{ henrys}$$

where S = spacing between two conductors and d = diameter of conductor.

‡ The formula $C = \dfrac{7.354\,(10)^{-9}}{\log_{10}\left(\frac{S}{r}\right)}$, gives the capacity in farads of one conductor to neutral per 1000 ft.

S = spacing between two conductors
r = radius of conductors.

In the above formula r is assumed to be small as compared with S.

Here g is due to insulator loss, corona loss, etc.

In a practical line g is negligible.

Hence:

$Y = -j\,b = -2\,\pi\,f\,C\,j$

where f is frequency.

These may now be substituted in formulæ (1) and (2) and e_r and I_r obtained.

e_g and I_g will have the form

$e_g = e_1 + je_2$

$I_g = i_1 + ji_2$

$Tan\ \theta = \frac{e_2}{e_1}$ gives the angle between

e_g and the reference voltage e_r.

$Tan\ \alpha = \frac{i_2}{i_1}$ gives the angle between I_g and e_r.

The power-factor angle at the generator is thus

$(\alpha - \theta) = \mp\phi_1$. (See Fig. 1.)

When ϕ_1 is positive the power-factor is lagging and when negative it is leading. Care must of course be taken that α and θ have their proper signs, according to the polar diagram.

The absolute values of the voltage and current at the generator end are:

$e_g = \sqrt{e_1^2 + e_2^2}$, volts to neutral.

$I_g = \sqrt{i_1^2 + i_2^2}$ amperes.

Voltage between lines at generator is thus:

$E_g = \sqrt{3}\ e_g$.

Power at generator $= \sqrt{3}\ E_g\ I_g\ Cos\ \phi_1$.

Line loss = (Power at generator − Power at Receiver).

$$\text{Line eff.} = \frac{\text{Power receiver}}{\text{Power generator}}.$$

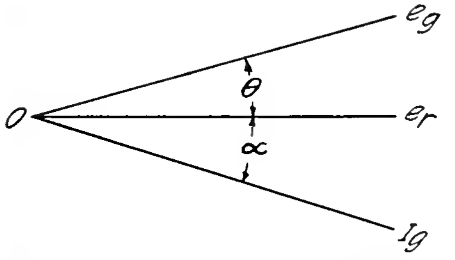


Fig. 1. Polar Diagram, Showing the Phase Displacement Between Generator Voltage and Current

Transformers

Thus far, the calculations have not taken into account the transformer reactance and resistance. The transformer reactance voltage varies approximately from 4 to 7 per cent, and the resistance voltage from 0.5 to 1.5 per cent of the impressed voltage. In the absence of definite information, 6 per cent and 1 per cent may be assumed as fair values. The reactance and resistance in ohms are calculated as follows, the results being the same whether delta or Y connection of transformers is assumed.

Let

P = The power in watts.

$cos\ \theta$ = The power-factor.

D_x = The per cent reactance drop assumed for the transformer.

Then

$$I_r = \frac{P}{E_r\sqrt{3}\ cos\ \theta}$$

$$e_r = \frac{E_r}{\sqrt{3}}$$

$$\frac{100\ I_r x}{e_r} = D_x$$

$$x = \frac{D_x}{100} \times \frac{e_r}{I_r} = D_x \frac{E_r}{\sqrt{3}} \times \frac{E_r\sqrt{3}\ cos\ \theta}{P \times 100}$$

$$= D_x \frac{E_r^2\ cos\ \theta}{P \times 100}\ \text{ohms.}$$

Likewise the total transformer resistance is,

$$r = D_r \times \frac{E_r^2\ cos\ \theta}{P \times 100}\ \text{ohms.}$$

When it is desired to find the voltage at the generator, and on the low voltage side of the transformer at the receiver end, i.e., include transformer regulation, the transformers at both ends are considered as part of the transmission line, their resistance and reactance being added to that of the line proper to get the total. Though this is not a strictly accurate procedure, the error is entirely negligible except in extreme cases.

All calculations are made in terms of the high tension circuit and the results if desired in terms of the low tension side are obtained from the ratio of transformation.

Phase Control of Voltage

Problems as usually presented require the determination of the regulation of the line from full load to no load, curves of power-factor, efficiency, current, etc., from the conditions as given; viz., size and kind of conductor, spacing, length of line, power transmitted, power-factor, frequency, and voltage at one end. It is also frequently required to find the size of a synchronous condenser to place in parallel with the load, so that if the voltage at the generating end is held constant, as for instance by an automatic voltage regulator, the voltage at the load end may also be held at some constant value. This is accomplished by adjusting the synchronous motor field, which changes the phase angle at the receiving end of the line. This may be done automatically by a voltage regulator. As a lagging load increases, the motor field is adjusted to make the motor take a leading component, and thus prevent a change in receiver voltage. For very heavy loads, it may even be necessary to make the total receiver power-factor leading (synchronous motor and load), to prevent voltage change. At light loads it is necessary to make the motor take lagging current to prevent a voltage rise. The motor may, sometimes, be large enough to hold the same voltage at both ends from no load to full load. The smallest motor possible for regulation from no load to full load would be one to give such a ratio between $\frac{E_{gen.}}{E_{rec.}} = \text{constant}$, that full lagging current is required at no load and

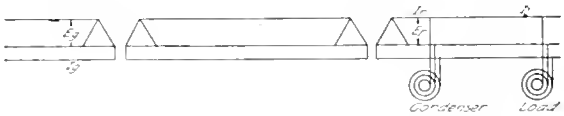


Fig. 2. Representative Diagram of a Transmission Line with its Connected Transformers, Synchronous Condenser and Power Load

full leading current at full load. At about half load such a motor would take approximately zero kv-a. This condition is not always practicable, as the motor characteristics may not always allow this range. Sometimes it, also, may not be required to hold voltage from zero load to full load. The practical economic condition should generally work out in such a way, that the power-factor at normal load is very nearly unity at both ends of the line—perhaps slightly leading at generator and slightly lagging at receiver—thus approaching direct-current operation.

A convenient way of making these calculations is best shown by a specific problem. Fig. 2 shows three-phase connections. In this diagram E_1, E_2, I_1, I_2, etc., are shown in the low tension side, but in the calculations these are referred to the high side for convenience. This is done by including the transformer impedance at both ends, or the equivalent, including the transformer regulation at both ends. This assumes voltage held on the low tension side at each end. The voltage may be held, of course, on either side of the transformers at either end, but in case the voltage is held on the high side, the transformer impedance at that end is not included, if held on the low side the transformer impedance is included. The voltage regulators are operated from potential transformers, when potential is held on the high side. However, holding voltage at the low side at each end, as in this problem, is probably the most practical condition.

Fig. 3 shows diagrammatically a circuit suggesting the resistance of one conductor and the corresponding inductance and capacity to neutral and indicates the manner in which the line constants are considered.

Transmission Problem

Given:

Length of line, 130 miles.
Conductor, 250,000 cm. copper cable.
*Spacing, 15 ft. vertical, 20 ft. average.
Two circuits, three-phase, 60 cycles.
Load per circuit (receiver), 22,000 kw.

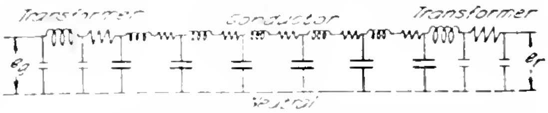


Fig. 3. Diagrammatic Representation of the Distribution of Inductances, Resistances and Capacities Concerned with a Transmission System, where the Transformer Impedances are Considered as part of the Distributed Line Impedance

Power-factor load, 0.85 lagging.
Volts receiver, 120,000.

Calculations per circuit.

Line

Resistance per mile, per conductor = 0.219 ohms.

$$r = 130 \times 0.219 = 28.41 \text{ ohms.}$$

Reactance per 1000 ft. per conductor = 0.16 ohms.

$$X = 130 \times 5.28 \times 0.16 = 110.1 \text{ ohms.}$$

Capacity per 1000 ft. between two conductors = 0.00126 mf.

$$C = 2 \times 130 \times 5.28 \times 0.00126 \times (10)^{-6} = 1.735 \times (10)^{-6} \text{ farads.}$$

Transformers

Assume 6.5 per cent reactance and 1 per cent resistance drop.

$$2\,r = 2 \times 0.01 \times \frac{120^2 \times 0.85}{22} = 11.13 \text{ (both ends)}$$

$$2\,x = 2 \times 0.065 \times \frac{120^2 \times 0.85}{22} = 72.3 \text{ (both ends)}$$

* The average spacing is $\frac{15+15+30}{3} = 20$ ft.

Line and Transformers

$r = 28.41 + 11.13 = 39.5$ ohms.

$x = 110.1 + 72.3 = 182.4$ ohms.

$Z = r - j\,x = 39.5 - 182.4\,j.$

$Y = -j\,2\pi f C = -j\,2\pi\,60 \times 1.735 \times (10)^{-6}$
$= -0.000654\,j.$

$ZY = -0.1193 - 0.02588\,j.$

$1 + \frac{ZY}{2} = 0.9404 - 0.01294\,j.$

$Z\left(1 + \frac{ZY}{6}\right) = 38 - 178.9\,j.$

$Y\left(1 + \frac{ZY}{6}\right) = -0.00000282 - 0.000641\,j$

$e_g = e_r\left(1 + \frac{ZY}{2}\right) + I_r Z\left(1 + \frac{ZY}{6}\right)$

$I_g = I_r\left(1 + \frac{ZY}{2}\right) + E_r Y\left(1 + \frac{ZY}{6}\right)$

$e_g = e_r(0.9404 - 0.01294\,j) +$
$I_r(38. - 178.9\,j)$

$I_g = I_r(0.9404 - 0.01294\,j) +$
$e_r(-0.00000282 - 0.000641\,j).$

Calculations

$e_r = \frac{120{,}000}{\sqrt{3}} = 69{,}300$ volts to neutral.

Then for full load and 85 per cent power-factor,

$I_r = \frac{22{,}000}{120 \times \sqrt{3} \times 0.85} = 124.5$ amperes.

$I_r = I_r \cos\phi + j\,I_r \sin\phi$
$= 105.8 + 65.5\,j.$

$e_g = 69{,}300(0.9404 - 0.01294\,j)$
$+ (105.8 + 65.5\,j)(38. - 178.9\,j)$
$= 80{,}905 - 17{,}332\,j$

$e_g = \sqrt{(80{,}905)^2 + (17{,}332)^2} = 82{,}770$ volts

$E_g = 82{,}770\sqrt{3} = 143{,}400$ volts

$I_g = (105.8 + 65.5\,j)(0.9404 - 0.01294\,j)$
$+ 69{,}300(-0.00000282 - 0.000641\,j)$
$= 100.1 + 15.8\,j$

$I_g = \sqrt{100.1^2 + 15.8^2} = 101.3$ amp.

$\theta = \tan^{-1} - \frac{17{,}332}{80{,}905} = -12° \; 6'$

$\alpha = \tan^{-1}\frac{15.8}{100.1} = 8° \; 58'$

$\phi_1 = \alpha - \theta = 8° \; 58' + 12° \; 6' = 21° \; 4'.$

The power-factor at the generator is then $\cos\phi_1 = \cos 21° \; 4' = 0.933$ lagging.

Generator power =
$\sqrt{3} \times 101.3 \times 143{,}400 \times 0.933$
$= 23{,}478$ kw.

Line loss $= 23{,}478 - 22{,}000 = 1478$ kw.

Line eff. $= \frac{22{,}000}{23{,}478} \times 100 = 93.8$ per cent.

Regulation of line and transformers

$= \frac{143{,}400 - 112{,}900}{143{,}400} \times 100 = 21.5$ per cent.

For other loads the calculations are made in an exactly similar manner, and the results may be tabulated as in Table I and plotted as in Fig. 4.

Another and simpler method of obtaining generator power and power-factor is as follows (its advantage being that it is not necessary to calculate any angles):

$e_g = e_1 + je_2$

$I_g = i_1 + ji_2$

$P_g = 3(e_1 i_1 + e_2 i_2).$

j must not be considered, but multiplication made and algebraic sum taken as below.

$e_g = 80{,}905 - 17{,}332\,j$

$I_g = 100.1 + 15.8\,j.$

The generator power is,

$P_g = 3[(+80905)(+100.1) + (-17332)$
$(+15.8)]$
$= 23{,}478{,}000$ watts $= 23{,}478$ kw.

$I_g = 101.3$ amp.

$e_g = 82{,}770$ volts to neutral.

Generator kv-a. $= 3 \times 101.3 \times 82.77$
$= 25{,}180$ kv-a.

Generator power-factor $= \frac{23{,}478}{25{,}180}$
$= 0.933$ lagging.

Calculation for Phase Control of Voltage

As already stated, to improve operating conditions, it is desirable to hold the voltage constant, or nearly so, at the generating end as well as at the receiver, i.e., so that $\frac{E_{gen.}}{E_{rec.}}$ is constant. At no load, the large capacity current of long high voltage lines causes a rise of voltage from generator to receiver. At full load, the lagging current taken by the load will, in general, more than offset the capacity current and will cause a drop of voltage from generator to receiver. At some intermediate load (on long high voltage lines) the generator and receiver voltage will be the same. It is evident, then, that a synchronous condenser may be installed at the receiver end to require lagging current at no load and leading current at full load; in the first case to offset the effect of the line capacity current and in the second to offset the surplus lagging load current. Obviously, the smallest size of condenser that can be used will be such that its full kv-a. lagging capacity will be required at no load and its full kv-a. leading capacity at full load. With a given receiver voltage and a given maximum load and power-factor, there is a definite

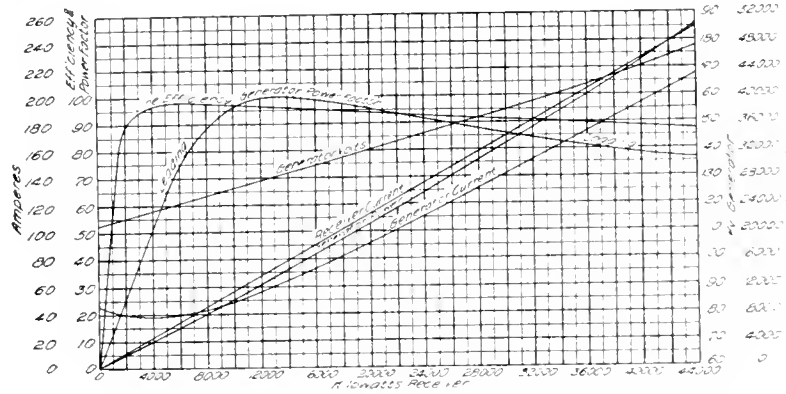


Fig. 4. Transmission Line Characteristic Curves for a Receiver Voltage of 120 kv. No Condenser Regulation

generator voltage that may be held to satisfy the above condition. To find this voltage, the effect on the generator voltage of varying the power-factor of the receiver, while holding a constant load, must be investigated, i.e., of varying the kv-a. condenser capacity in parallel with the load. This may be done by taking a constant load at the given load power-factor (as for instance, normal load at normal power-factor) and constant receiver voltage, and adding different leading and lagging kv-a., calculating the generator voltages for these new total receiver power-factors (load and condenser). It thus amounts to finding the variation in generator voltage with a change of receiver power-factor, at constant receiver voltage and load. Curves may be plotted for various loads under the above conditions, between generator voltage, and condenser kv-a. This is done in Fig. 5. It has been found that with constant receiver voltage and load, the change in generator voltage with change in kv-a. condenser capacity—or what amounts to the same thing, with change in receiver power-factor—may be approximately expressed by a straight line. The deviation therefrom increases with a decrease of power-factor; also, considering a constant receiver power-factor, there is a slight increase in this deviation with increase of load. The complex error introduced, however, is inappreciable for economic power-factors and line loads. The generator voltages, for the various loads and for no condenser in parallel with the load, have already been calculated for Table I. See Fig. 4.

These values give one point on the approximately straight line curves. To draw these curves for several loads it is thus necessary now to calculate one point, with condenser, for each desired load. For these points, a value of kv-a. condenser may be assumed

TABLE I

No Condenser Regulation — Receiver Voltage 120,000

Kw. Load	Line Kilovolts Rec.	Line Kilovolts Gen.	Line Amperes Gen.	Line Amperes Rec.	Kv-a. Gen.	Kv-a. Rec.	Kw. Gen.	Power-Factor Gen. Lead	Power-Factor Rec. Lag	Line Eff.
0	120	112.9	44.42	0	8690	0	81.36	0.0094	0.85	0
5500	120	120.1	38.45	31.1	8000	6470	55866	0.699	0.85	0.984
11000	120	127.6	51.9	62.2	11480	12940	11335	0.988	0.85	0.97
16500	120	135.3	74.9	93.4	17560	19410	17260	0.983 †	0.85	0.956
22000	120	143.4	101.3	124.5	25180	25880	23478	0.933 †	0.85	0.938
33000	120	160.1 *	157.1	186.7	43600	38820	36435	0.836 †	0.85	0.906
44000	120	177.3 *	214.1	249	65800	51800	50448	0.766 †	0.85	0.872

* Exceeds corona limit of voltage at sea level.
† Lagging power-factor.

Charging current at 112,900 volts = 44.42 amp
Charging kv-a. at 112,900 volts = 8690 kv-a.
Regulation of line and transformers at 22,000 kw. load = 21.5 per cent.
Regulation of line and transformers at 44,000 kw. load = 36.3 per cent.

and the corresponding value of generator voltage calculated.

Thus, at 44,000 kw. load, let 35,000 kv-a. condenser be assumed. This of course should be leading. Then,

$$\frac{35,000}{120\times\sqrt{3}}=168.1 \text{ amp. condenser}=-168.1j$$

$I_L=211.6+131\,j$

Then the receiver current, $I_r=211.6+131j-168.1\,j=211.6-37.1\,j.$

Under these conditions, the generator voltage is

$$e_g=69,300(0.9404-0.01294\,j)+(211.6-37.1\,j)(38.-178.9\,j)$$
$$=65,170-897\,j+1410-39,210\,j$$
$$=66,580-40,107\,j.$$

$e_g=77,700$ volts to neutral.

$E_g=77,700\sqrt{3}=134,500$ volts between lines.

At 22,000 kw. assume 12,000 kv-a. leading,

$$\frac{12,000}{120\times\sqrt{3}}=57.7 \text{ amp. condenser}=-57.7j$$

$I_L=105.8+65.5\,j.$

$I_r=105.8+65.5\,j-57.7\,j=105.8+7.8\,j.$

$$e_g=69,300(0.9404-0.01294\,j)+(105.8+7.8)(38-178.9\,j)$$
$$=70,584-19,501\,j$$

$e_g=73,300$ volts to neutral.

$E_g=73,300\sqrt{3}=127,000$ volts.

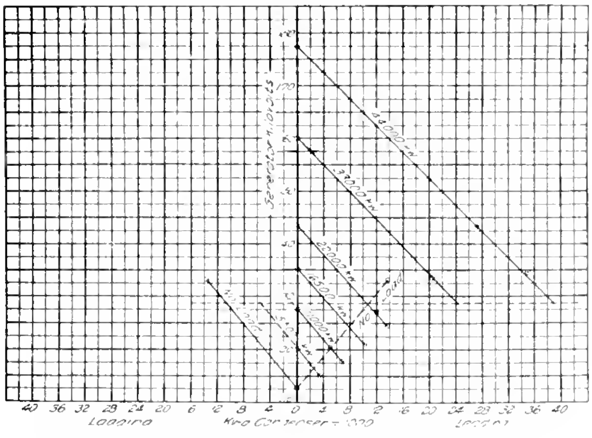


Fig. 5. Complete Curves of Variation of Generator Voltage with Condenser kv-a., for Various Loads at a Constant Receiver Voltage of 120 kv.

At 11,000 kw., assume 5000 kv-a. leading,

$$\frac{5000}{120\times\sqrt{3}}=24.04 \text{ amp. condenser,}$$
$$=-24.04\,j.$$

$I_L=52.9+32.75\,j.$

$I_r=52.9+32.75\,j-24.04\,j=52.9+8.71\,j.$

$$e_g=69,300(0.9404-0.01294\,j)+(52.9+8.71\,j)(38-178.9\,j)$$

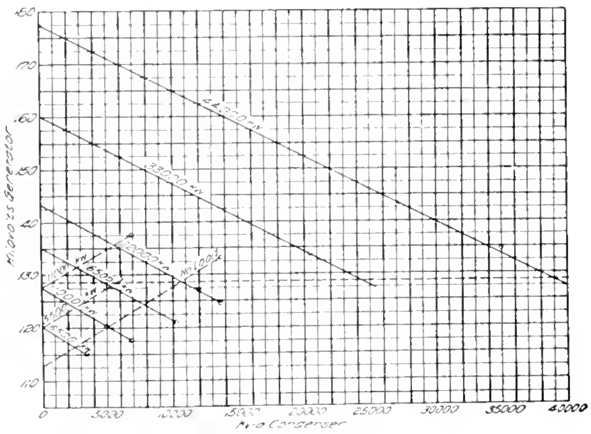


Fig. 6. The Usual Method of Plotting the Curves Shown in Fig. 5

$$=68,739-10,016\,j$$

$e_g=69,500.$

$E_g=69,500\sqrt{3}=120,500.$

The above three points were calculated to show the method. Several other points may be calculated for each load if the exact curve is desired. In actually calculating points as above, it shortens the arithmetic a little to assume the value of kv-a. which gives unity power-factor for receiver current.

For instance, at 22,000 kw. load the load current is $105.8+65.5\,j$. The out-of-phase component is 65.5 amp. lagging, and if the condenser kv-a. be assumed such that the condenser current is 65.5 amp. leading, the power-factor at receiver must be unity and

$I_r=105.8+65.5\,j-65.5\,j=105.8.$

The corresponding kv-a. is $120\sqrt{3}\times65.5=13,640$ kv-a.

The simplification helps in calculating the voltage generator. For instance, in the given equation for the full load value, instead of having to multiply by $(105.8+7.8\,j)$ the multiplier would be 105.8. Also, when there is no out-of-phase receiver current, the part following the plus sign in the voltage equations is directly proportional to the load.

A point for each curve on Figs. 5 and 6 was calculated at unity power-factor receiver;

and for the 11,000 kw., 22,000 kw. and 44,000 kw. curves, points at 5000 kv-a., 12,000 kv-a. and 35,000 kv-a. condenser, respectively. It will be seen that the ones at

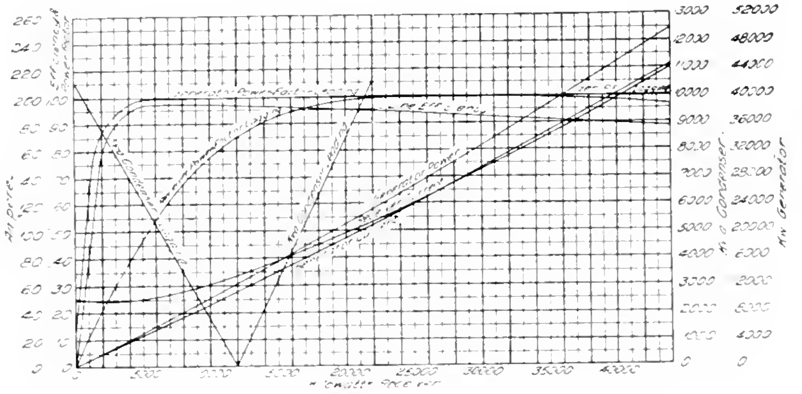


Fig. 7. Transmission Line Curves for a Receiver Voltage of 120 kv. and a Generator Voltage of 128.6 kv. Condenser Regulation Utilized

11,000 and 22,000 kw. fall on their respective curves, while the one at 44,000 kw. is less than 1 per cent above the voltage generator, shown by its curve. This was anticipated, as 34,000 kw. is a heavy load for this line. Obviously, where accurate determination of overload conditions are needed, it would be well to calculate several points on the corresponding curves.

A calculation for 22,000 kw. at unity power-factor receiver follows. Points on the other curves are found in the same manner. The no-load curve is found by taking points for lagging condenser current.

At 22,000 kw. load,

$e_r = 69,300$

$I_r = \dfrac{22,000}{120\sqrt{3}} = 105.8$ total (load + condenser).

$e_g = 69,300(0.9404 - 0.01294\,j) + 105.8(38 - 178.9\,j)$

$= 69,190 - 19,824\,j$

$E_g = 124,500$ volts.

The *load* still has 85 per cent power-factor so that the *load current* is

$I_L = 105.8 + 65.5\,j.$

The condenser current must then be the difference between the load and the receiver currents, or,

$I_c = I_r - I_L = -65.5\,j.$

$I_c = 65.5$ amp.

and the condenser leading kv-a. is

$3 \times e_r \times I_c = 3 \times 69.3 \times 65.5 = 13,640$ kv-a.

E_g and condenser kv-a. are found in the same way for all loads. For no-load take the same kv-a. condenser capacity as for full load, but lagging instead of leading, i.e.,

$I_r = I_c = +65.5\,j$

$e_r = 69,300$

$e_g = 69,300(0.9404 - 0.01294\,j) + 65.5\,j(38 - 178.9\,j)$

$= 76,880 + 1,593\,j.$

$E_g = 133,200$ volts.

The results may now be tabulated as in Table II and plotted as in Fig. 7. The other point on curve is obtained from Fig. 4 (0.85 power-factor).

There is some value of generator voltage such that the lagging condenser capacity required, to hold this voltage at no load, will

TABLE II

Showing kv-a. condenser capacity and generator voltage at different loads, under the following conditions:
First: Constant receiver voltage and a power-factor of unity, which includes load and condenser.
Second: Constant receiver voltage, no condenser.
Load power-factor = 85 per cent.
Receiver voltage = 120,000 volts.

Load Kw.	UNITY POWER-FACTOR AT RECEIVER				85 PER CENT POWER-FACTOR AT RECEIVER		
	Line Kv.		Kv-a. Condenser		Line Kilovolts		Kv-a. Condenser
	Gen.	Rec.	Lead	Lag	Gen.	Rec.	
0	133.2 *	120		13640	112.9	120	0
5500	115.1	120	3406		120.1	120	0
11000	117.7	120	6812		127.6	120	0
16500	121	120	10225		135.3	120	0
22000	124.5	120	13640		143.4	120	0
33000	133.6	120	20450		160.1	120	0
44000	143.3	120	27280		177.3	120	0

* Zero power-factor.

be equal to the leading condenser capacity required at full load. This is most easily found by swinging the no-load line to the right of the Y axis as shown dotted in Fig. 5. The intersection of this no load line and the full load line gives the required condenser capacity and the required generator voltage. These are respectively 10,600 kv-a. and 128,600 volts.

The diagram is usually drawn as in Fig. 6, Fig. 5 being used here merely to simplify the explanations. In Fig. 6 all of the load lines indicating lagging condenser kv-a. (i.e., those parts which in Fig. 5 lie to the left of the Y axis) are shown as broken lines. Broken lines, then, indicate lagging condenser kv-a. and full lines leading condenser kv-a.

As previously mentioned, however, the condenser kv-a. and generator voltage as just determined, may not be the ones required for a particular case. Suppose that the characteristics of the condenser are such that it will take twice as much leading kv-a. as it will lagging. From Fig. 5 it is seen that for 123,500 volts at the generator, the condenser kv-a. required at no load is 7200 lagging, and at full load is 14,400 lagging. This satisfies the previous conditions. Or, suppose it is only necessary to hold constant generator voltage from ¼ load to ¾ load. In this case a 5300 kv-a. condenser will be required and the voltage at the generator will be 127,800. These values are found by swinging the lagging section of the ¼ load curve to the right of the Y axis, and finding its point of intersection with the leading section of the ¾ load curve. Again, suppose that the full load is in the nature of a peak load, say of two hours duration, and that the condenser will take 125 per cent overload for two hours. The size of condenser required will then be reduced from 10,600 kv-a. to 8480 kv-a. the generator voltage of course remaining at 128,600 volts.

Let it be assumed that the full 10,600 condenser kv-a. is required at 128,600 generator volts for no load and full load, and that curves of efficiency, power-factor, etc., are required for these conditions. From Fig. 6 can be determined for each load how much lagging or leading kv-a. condenser capacity is required at that load to hold 128,600 volts at the generating end. Taking these values, the condenser current is found by:

$$I_c = \frac{\text{Condenser kv-a.}}{\text{Receiver volts } \sqrt{3}}$$

$$I_c = \mp I_c\, j.$$

Combining this with the load current,

$$I_r = I_L + I_c$$

the generator current, generator voltage (which should check and be equal to 128,600 volts), power, efficiency, etc., are found.

As an example, take a load of 5500 kw. The condenser capacity required to hold 128,600 generator volts is 5740 kv-a. lagging. Then,

$$I_c = \frac{5740}{120 \times \sqrt{3}} = 27.6 \text{ amp.}$$

$I_c = +27.6\, j$, since the kv-a. required is lagging.

The *load* current is

$$I_L = \frac{5500}{120 \times \sqrt{3} \times 0.85} = 31.1 \text{ amp.}$$

$$I_L = 26.45 + 16.37\, j$$

and the receiver current, or combined load

TABLE III

Showing line characteristics at different loads for constant generator and receiver voltages.

Generator voltage = 128,600 volts.
Receiver voltage = 120,000 volts.

Kw. Load	Amp. Cond.		Kv-a.		Power-Factor			Kw. Gen.	Line Eff.	Kv-a. Cond.	
	Gen.	Rec.	Gen.	Rec.	Gen.	Rec. Load +Cond.	Load			Lag	Lead
					Lag	Load	Lag				
0	3.6	51	802.5	10600	0.143	0	0	114.8	0	10600	
5500	25.55	51.4	5700	10680	0.994 *	0.515	0.85	5661	0.972	5740	
11000	51.1	64.3	12500	13360	0.995 *	0.822	0.85	11340	0.97	800	
16500	77.5	83.6	17270	17360	0.996 *	0.949	0.85	17211.3	0.959		4700
22000	104.8	106.7	23370	22180	0.997 *	0.991	0.85	23276	0.946		10600
33000	162	160	36100	33230	0.999	0.991 *	0.85	36058	0.915		24300
44000	222	220	49920	45700	0.998	0.961 *	0.85	49833	0.883		39000

* Leading.

and condenser current is

$I_r = I_L + I = 26.45 + 43.97\,j$

$I_r = \sqrt{(26.45)^2 + (43.97)^2} = 51.4.$

Then,

$e_g = 69{,}300(0.9404 - 0.01294\,j) + (26.45 + 43.97\,j)(38 - 178.9\,j) = 74{,}025 - 3{,}954\,j$

$e_g = \sqrt{(74{,}025)^2 + (3954)^2} = 74{,}200$ volts.

$E_g = 128{,}600$ volts (check)

$I_g = (26.45 + 43.97\,j)(0.9404 - 0.01294\,j) + 69{,}300(-0.00000282 - 0.000641\,j) = 25.3 - 3.32\,j$

$I_g = \sqrt{(25.3)^2 - (3.32)^2} = 25.55$ amp. per conductor.

Generator power is

$3(74.02 \times 25.3 + 3.9 \times 3.32) = 5661.4$ kw.

Generator kv-a. is

$\sqrt{3} \times 128.6 \times 25.55 = 5700$ kv-a.

Generator power-factor is

$\frac{5661}{5700} = 0.994$ leading.

Receiver power-factor is

$\frac{26.45}{51.4} = 0.515$ lagging.

Line eff. $= \frac{5500}{5661.4} \times 100 = 97.2$ per cent.

The results may be tabulated as in Table III and plotted as in Fig. 7.

ELEMENTS OF ELECTRIC TRANSIENTS

By G. Faccioli

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On account of the great destructive power of high-frequency and high-voltage transients in the modern network, and the necessity for eliminating them as far as possible or at least for guarding against them, an almost incalculable value attaches to the work which has been done in the last few years to reduce this matter to a science, which will explain the nature of transients, why they exist, upon what they depend, how they behave, and how they must be met, and which will serve as a basis for a design for the manufacturer, and a sane method of switching, protection, etc. for the operating man. In the present article, Mr. Faccioli presents an exceedingly simple exposition of the subject, analyzing transients into two main classes, single-energy and double-energy transients, and explaining the nature and genesis of the oscillation, the travelling wave, and the standing wave.—Editor.

This paper is intended to give a review of the fundamental principles of the "electric transient," and presents only those formulæ which an engineer generally carries in his mind.

An electric system through which energy flows has, at a certain point, a potential e and a current i. If the conditions of the circuit are changed, the potential and current at the point under consideration will no longer be e and i, but will assume new values after the system has reached its new position of equilibrium. Although the change which disturbs the equilibrium of the circuit may be instantaneous, a definite length of time is required by the system to adjust itself to the new conditions. If, therefore, these new conditions require that at the point under consideration the voltage be e_1 and the current i_1, these values are not obtained at the instant the change is made, but after some time has elapsed. During this time the voltage and current assume transitory values, which start from e and i and end with e_1 and i_1.

These transitory values of the voltage and current can be divided into two components. One component is e_1 and i_1, that is to say, the final values required by the new conditions, and which could not be reached instantaneously. The second component constitutes the *transient* term of voltage and current. For instance, if we apply to an inductive circuit suddenly a constant electromotive force, the current grows from zero to its final value, i, according to Fig. 1. The "transient" in this case is the current i_0 shown in Fig. 1.

The presence of transient phenomena, when a system passes from one position of equilibrium to another, is not a peculiarity of the electric system, but occurs in other forms of energy.

We wish to find out why transients are required to readjust electric equilibrium. In an electric system energy is generally stored in two forms, electromagnetic and electrostatic. The electromagnetic energy is $\frac{L\,i^2}{2}$ and the electrostatic energy is $\frac{C\,e^2}{2}$. This means that when e and i are changed the energy stored in the system must also change. Such change of the stored energy cannot happen instantaneously, because an instantaneous change of stored energy necessitates an infinite supply of power. A definite length of time is then necessary to bring about the variation in the stored energy. Hence the *transient*.

Since electric energy can be stored in two different forms, electric transients may be of two kinds, single-energy transients and double-energy transients. In a single-energy transient one form of energy only is varied, and a single-energy transient, therefore, consists only in the increase or decrease of one form of energy. The transient shown in Fig. 1 is a single-energy transient, because in that case the magnetic energy of the circuit was changed from zero to $\frac{L\,i^2}{2}$ and the circuit was assumed to have zero capacity, therefore no electrostatic energy stored in it. Double-energy transients consist in a variation of both forms of energy, or in a transformation from one form of energy into the other. The transient which transforms energy from electromagnetic into electrostatic, or *vice versa*, is an *oscillation*.

During an oscillation no energy is supplied to the circuit from the outside, and no energy is supplied by the circuit to the outside; but a fixed amount of energy seesaws in the circuit from electromagnetic to electrostatic, and *vice versa*. During this process, however, energy losses occur in the circuit or around the circuit, so that generally the original amount of energy of the oscillation decreases and disappears.

In a pure oscillation, i.e., where no losses occur, at a certain instant all the energy is electromagnetic and equal to $\frac{L\,i^2}{2}$. A little later all the energy is electrostatic and equal to $\frac{C\,e^2}{2}$. Since the circuit does not dissipate energy, $\frac{L\,i^2}{2}$ is equal to $\frac{C\,e^2}{2}$, and therefore $e = i\sqrt{\frac{L}{C}}$. $\sqrt{\frac{L}{C}}$ is in the nature of an impedance, because multiplied by a current, it gives a voltage. $\sqrt{\frac{L}{C}}$ is called the *natural impedance of a circuit*. This natural impedance is of great importance in the study of transient phenomena. So far we know that it represents the ratio between the voltage and the current of an oscillation.

The frequency, f, at which energy is transformed from magnetic into electric, and *vice versa*, is $\frac{1}{2\pi\sqrt{LC}}$, when both the inductance L and capacity C are concentrated. This means that during the time $2\pi\sqrt{LC}$ a com-

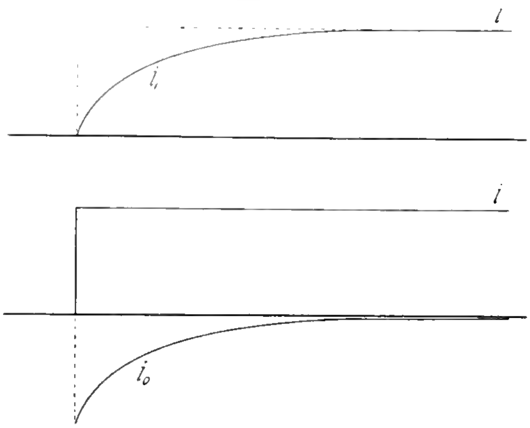

Fig. 1

plete cycle of the oscillation occurs. So that, if we start at the instant in which the voltage is maximum and the current is zero, the voltage will again be maximum and in the same direction and the current will again be zero, after a time $2\pi\sqrt{LC}$.

If the inductance and capacity are not concentrated, but uniformly distributed, the frequency of the oscillation is given by $\frac{1}{4\sqrt{LC}}$. For instance, let us consider the case of a line of uniformly distributed constants, connected at one end to a generator and short-circuited at the other end. Let l and c be respectively the inductance and capacity of the line per unit length; and let m be the length of the line, so that $ml = L$ is the total inductance of the line, and $mc = C$ is the total capacity of the line. We open the switch which connects the line to the generator. The energy which is stored in the line at the instant in which the line is disconnected from the generator produces an oscillation, whose frequency is

$$\frac{1}{4\sqrt{LC}} = \frac{1}{4m\sqrt{lc}}$$

This frequency is called the "natural frequency" of the line.

$\frac{1}{\sqrt{lc}}$ however, is the velocity at which electric energy travels through a circuit whose inductance and capacity per unit length are l and c. In our case this velocity is the velocity of light, namely, 300,000 kilometers per second, or 188,000 miles per second. The natural frequency of a line is then

$$\frac{188{,}000}{4m} \text{ cycles per second,}$$

where the length m of the line is given in miles, or

$$\frac{47{,}000}{m}$$

If we have a line 150 miles long, the natural frequency of the line is 310 cycles, etc.

Now, a frequency of 310 cycles has a wave-length of 600 miles (velocity of light divided by frequency), that is to say, the wave-length of this natural frequency is four times the length of the line. We say, therefore, that at 310 cycles the line oscillates at "one-quarter wave-length." This is the lowest frequency at which this line can oscillate. If the line did oscillate at half wave-length then the frequency would be 620 cycles, and if the line did oscillate at full wave-length the frequency would be 1240 cycles. However, the last two modes of oscillation are not possible when the line is open at one end and short-circuited at the other end, as in our example.

In "oscillations" the current and the electromotive force are in quadrature, since no transfer of energy occurs from or to the circuit. These oscillations are generally called *free* oscillations, to distinguish them from *forced* oscillations which are produced by the application to the circuit of power from an outside source at a certain definite frequency which has no relation to the natural constants of the circuit.

An oscillation, however, is not the only form of transient. Other transients are possible in which the current and potential are in phase. These transients do transfer energy to the circuit into which they enter and from the circuit out of which they pass, and are called "traveling waves." In general, a transient of a complex circuit is a combination of oscillations and of traveling waves.

The progress of traveling waves through circuits of different constants is of great importance. Let us picture a traveling wave at the instant in which it passes from a circuit of inductance L_1 and capacity C_1 into another circuit of inductance L_2 and capacity C_2. The voltage of the traveling wave in the first circuit is e_1 and the current is i_1. The energy carried by the wave is $e_1 i_1$. If we call Z_1 the "natural impedance" of the first circuit, we have:

$$Z_1 = \sqrt{\frac{L_1}{C_1}} \text{ and } \frac{e_1}{i_1} = Z_1$$

At the point of transition between the two circuits a "reflection" and a "refraction" occur. If n is the ratio between the "reflected" and the "incident" wave, we obtain

	Voltage	Current
Incident wave	e_1	i_1
Reflected wave	ne_1	$-ni_1$
Refracted wave	e_1+ne_1	i_1-ni_1

So the traveling wave enters the second circuit with a voltage e_1+ne_1 and a current i_1-ni_1.

But

$$\frac{e_1+ne_1}{i_1-ni_1} = Z_2 = \sqrt{\frac{L_2}{C_2}}$$

Hence

$$n = \frac{Z_2 - Z_1}{Z_1 + Z_2}$$

If Z_2 is larger than Z_1, the voltage of the traveling wave *increases* when the wave passes from the first circuit to the second.

Therefore, if a traveling wave coming from an overhead line enters a transformer, the voltage of the traveling wave will be increased because the natural impedance of a line is about 400 ohms, while the natural impedance of a transformer is around 3000 ohms (this natural impedance of a transformer is obtained by considering the leakage inductance of the transformer, that is to say, all primary currents of the transformer are supposed to be reproduced in the secondary). Similarly an underground cable has a much lower natural impedance than an overhead transmission line. Therefore, a traveling wave originating in an underground cable will enter an overhead line with a rise of voltage at the junction, between cable and line. *Vice versa*, a traveling wave coming from a line and entering a cable will do so with a decrease of voltage at the junction; and a wave coming from a transformer and entering a line will also have a lower voltage at the transition point, etc.

Let us consider a traveling wave arriving at the end of an open line. This wave progressing along the line has a voltage e and a current i. Fig. 2 represents the wave of voltage and the wave of current, which are supposed to have a square wave front and a length m. If l and c are respectively the inductance and the capacity of the line per unit length, the traveling wave possesses an electrostatic energy equal to $\frac{1}{2}\,cme^2$ and an electromagnetic energy equal to $\frac{1}{2}\,lmi^2$. The electromagnetic energy and the electrostatic energy are equal in value. As the wave strikes the end of the line no current can flow because the line is open; and, therefore, the voltage of the wave will increase and the current will disappear so that the electrostatic energy of the wave increases as the electromagnetic energy decreases, while the total energy remains constant because no losses occur. The result is that both the voltage and the current are reflected; but, while the reflected wave of voltage has the same direction as the incident wave, the reflected wave of current is opposite in direction to the incident wave of current.

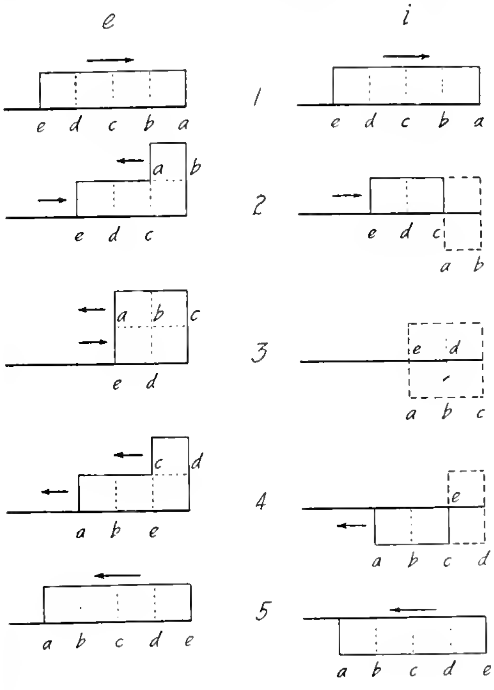

Fig. 2

At a certain instant all the current has disappeared and the electrostatic energy of the wave is $\frac{1}{2}\,c\,\frac{m}{2}\,(2e)^2 = cme^2$. The voltage has increased from e to $2e$, and the energy of the wave is all electrostatic and equal to the sum of the electrostatic and electromagnetic energy of the original incident wave. The process of reflection then goes on until both the potential and current waves are totally reflected, as shown in Fig. 2. In this figure, the wave is divided into imaginary sections, *a-b*, *b-c*, *c-d*, and *d-e*. By noting the various positions occupied by these sections, the different steps in the process of reflection may be readily understood.

If, instead of the single wave shown in Fig. 2, a "wave train," in which all the waves are simple harmonic functions of the same amplitude and frequency, arrives at the open end of a line, the phenomena of reflection are substantially the same as previously shown. Thus the reflected wave of voltage is equal in value to the incident wave of voltage and in the same direction; so that the reflected wave of voltage adds to the incoming wave of voltage while the wave of current is totally reflected with reversal of direction, and, therefore, the reflected wave of current subtracts from the incident wave of current. A close consideration of this phenomenon shows that the resultant wave (of voltage, for instance), which is the sum of the incident and the reflected waves, produces on the line points which are always at zero potential, and points whose voltage oscillates from a maximum positive to zero and to a maximum negative. The maximum values of the resultant wave are double the maximum values of either the incident or reflected waves. The distance between two successive points which are always at zero potential is equal to one-half the wave length of the original incoming wave.

Potential and current follow the same laws, with the difference that the open end of the line corresponds to a maximum of the wave of voltage and to a zero point of the wave of current. Therefore, the zero points of the wave of current occur along the lines where the maximum points of the wave of voltage occur. The points which are always at zero value are called "nodes"; and the points which have the maximum variation of potential or current and which are located midway between the nodes are called "antinodes." All other points between the nodes and antinodes have variations of potential gradually changing from zero to maximum. This phenomenon is called a "standing wave."

We see, therefore, that in order to produce definite nodes and maximum antinodes in a standing wave, it is necessary that the reflection of the incoming wave be complete and that no damping be present, so that the maximum value of the reflected wave is equal to the maximum value of the incoming wave.

If the line is not open at the end, but is short-circuited, then at the end of the line no e.m.f. can exist, and at that point all the energy must be electromagnetic. This means that the wave of current will be totally reflected, so that the reflected wave adds to the incoming wave; and the wave of potential will also be totally reflected, but the reflected wave of voltage will be opposite in direction to the incoming wave of voltage. In other words, since no voltage can exist at the end of the line, the reflections will be such as to annul the potential of the line and to double its current.

Between these two extreme cases, i.e., *open line* and *short-circuited line*, intermediate conditions of the end of the line will give intermediate combinations of reflections and refractions. So if we assume that the line is closed on a varying resistance, and we start from the value of resistance equal to infinity (open line) down to the value of resistance equal to zero (short-circuited line), we know that, in the first case, the wave of voltage is entirely reflected in one direction; and, in the second case, that the wave of voltage is entirely reflected in the opposite direction. It is evident that there must be a critical value of the resistance which gives no reflection. This value must be such that the arriving voltage and the arriving current at the end of the line may coexist in the resistance. But since the ratio between voltage and current of the incident wave is the natural impedance of the line, if the resistance has a value equal to this natural impedance, voltage and current will enter the resistance unchanged. No reflection and no refraction will occur, and the energy of the wave will be entirely absorbed by the resistance.

In all the preceding review we have assumed that the waves traveling along the line are not damped, that is to say, that the maximum values of the waves remain constant as the wave progresses along the line. Generally this is not the case, as the various losses which a wave encounters in flowing through a line, tend to decrease its maximum value. If a voltage wave has a maximum value E_0 at a certain point, after a time t its maximum value is E, as given by the equation

$$E = E_0\, e^{-at}$$

in which e is the base of the natural logarithms, and a the "time damping coefficient," equal to

$$\frac{1}{2}\left[\frac{R}{L}+\frac{K}{C}\right]$$

where R, L, K, and C are respectively the resistance, inductance, conductance, and capacity per unit length. After the time t the wave has traveled a distance equal to t times the velocity of the wave, which is generally the velocity of light. It is then possible to express E as a function of E_0 and of the distance traveled on the line.

In closing this elementary review, it is needless to point out the importance which these phenomena have in the modern transmission of electrical energy. Every operating man is interested in what is commonly called "high frequency." By high frequency is meant the electric transient, which is not necessarily a high frequency phenomenon. For instance, if 150 miles of a 100,000-volt line oscillate with a 10,000-kw., three-phase transformer, the frequency of oscillation is about 30 cycles. These oscillations occur when the line and unloaded step-down transformer, connected at the far end of the line, are disconnected by high-tension switches from the generating system at the power house. After the high-tension switch is open, the circuit consists of the line and the step-down transformer; and whatever energy was stored in the circuit, at the instant the switch is opened, dies out through oscillations between the capacity of the line and the inductance of the transformer. If the same line oscillates with the leakage inductance of a 10,000-kw. transformer, the frequency of oscillation is about 120 cycles. This case occurs when a dead line and a step-up transformer are connected by low-tension switches to the generating system at the power house. The line is brought up from zero potential to full potential by an oscillation between the capacity of the line and the leakage reactance of the step-up transformer.

Other examples of transients of comparatively low frequency could be cited, but the above cases will be sufficient to convey the idea that the frequency of transients is not necessarily high, although it may be very high in lightning phenomena.

OSCILLOGRAPHIC STUDIES RELATING TO PROTECTIVE APPARATUS

By E. E. F. Creighton

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This article, the second of a series of three by the same author on the aluminum cell lightning arrester, is in the main a discussion of some very interesting oscillograms that have been made from time to time in the development of this arrester and in the study of phenomena on transmission lines. A short summary is first made of the principal points brought out in the preceding installment and some further analysis is given of the changes that take place in the cells during charging and continuous operation—a matter regarding which we are all still pretty much in the dark. Other characteristics of the aluminum cell, such as the performance of the arresters over a wide range of voltage and the length of time the units may be expected to retain their electrostatic charge, come in for consideration. As a preface to the discussion of the oscillograms, some pertinent remarks are made on the limitations of the oscillograph and the degree of accuracy that may reasonably be expected of it. Certain of the oscillograms shown illustrate the magnification of various harmonics and the forms of current surges, while others show the current and potential of aluminum arresters under normal conditions and under such abnormal conditions as over-potential, poor films, various gap lengths at the horns, etc.—Editor.

Summary: A Few Brief Statements of Some of the Salient Features of the Previous Installment*

When an aluminum arrester can be connected from line to ground without the use of an air gap in series and not wear out appreciably, it gives an ideal form of protection at the point of the circuit where it is connected. The direct current aluminum arrester is actually used this way, but the wear on the a-c. arrester plates prohibits the practice in general.

Since in a-c. circuits a series gap is essential, and since the film is slowly soluble in the electrolyte, charging becomes necessary. Current rushes, surges, etc., can, if desired, be reduced to nothing. An inexpensive and simple construction is obtained by the use of a medium value of charging resistance. This resistance is sufficient to prevent heavy current rushes and damage to the arresters, and at the same time aids the arrester in damping out any tendency to oscillate. The spring clips at the horns complete the circuit of the arrester and cut out all sudden variations of current. This is valuable in reducing induction on underhung telephone lines.

There are two resistances to be considered in the arrester circuit: first, the resistance of the electrolyte; and second, the charging resistance. There is also the initial energy loss and electrochemical work in the cells, which, from the standpoint of damping out surges, may be considered as an equivalent resistance. A table of resistances, corresponding to a wide range of arresters, shows the thorough damping in the circuit of the arresters. Since most of the damping is obtained by the peculiar losses in the films, there is no sacrifice of the discharge rate of the arrester.

Characteristic curves of the aluminum cell are shown which give the following relations: The current is almost directly proportional to the potential. The curve of the internal losses of the aluminum cell resemble those of core loss in transformers; that is to say, the watts increase more rapidly than the volts. Another curve is given which shows the natural wear of an aluminum cell. For a cell operating continuously it requires three days to reach its maximum loss. The loss then decreases somewhat and continues constant thereafter during the remainder of the life of the cell. The ratio of the initial loss to the final loss is about 1 to 5. At a discharge of 10 sec. per day it would require 70 years to give an equivalent of three days continuous run. The cell is by no means worn out at this time, but may be counted on to operate at least five times as long. These figures are not given to prove that the arrester should last so many years, for each arrester will no doubt get more than 10 sec. discharge per day. The figures do indicate, however, that under favorable conditions of care the aluminum plates may easily have a life of ten years.

Calculations of the stored energy and lost energy show that a large part of the energy in the aluminum cell, in its function as a condenser, is used up in the films.

Further Analysis of Electrochemical Action in the Films

What is actually taking place in the films of an aluminum cell is still shrouded in considerable mystery. The whole action has so far been considered electrochemical in its nature. This term is more convenient than accurate. There is both electrochemical action and a resistance effect in the films. There is lacking in our language, moreover, a term to express a resistance that is sometimes present, and sometimes absent. The

*General Electric Review, April, 1913.

film apparently acts as a resistance up to a certain voltage, and absorbs energy, as any resistance should when current flows through it. The film, however, no longer constitutes a resistance for excess potentials. In order to distinguish between the electrochemical actions in the film and the heat losses, two extreme conditions are chosen for illustration. In the initial formation of a film, the electrochemical losses predominate; a large part of the energy is represented by the changes in the chemical structure of the aluminum and electrolyte. Then, at the other extreme, where the film is completely formed and operating continuously, the electrochemical changes are comparatively slight and the energy losses show themselves directly in heat on the surface of the aluminum plate. For example, if the 7 watts lost in the aluminum cell when operating continuously are replaced by 7 watts dissipated in a rheostat placed in the cell, the temperature of the cell will remain constant. This shows that very little of the lost energy under the condition of continuous operation is used up in non-reversible electrochemical processes. Whenever an aluminum arrester operates by a spark at the horn gaps, both these losses in the aluminum films are present. Electrochemical energy is needed to reform the film taken away by dissolution, and heat energy is given to the film by the slight leakage current through the high ohmic resistance of the film (high resistance at normal potential).

Since the energy losses in the aluminum cell are analyzed into two parts, it is desirable at this time to add a further analysis, namely, the energy stored in the film. The cell is a condenser of relatively high capacity; for a half cycle it stores energy in the form of electrostatic charge. Experiments indicate that it is possible that part of the storage is not electrostatic but actually a reversible electrochemical process. This factor is of academic interest. The reversible electrochemical process would not, of course, show up as losses of energy in the cells.

After the foregoing explanation it seems clearer to use the term *film losses* to cover both the *electrochemical* and the *heat* losses in the film. This corresponds to the term *core losses* in transformers, to cover both the *hysteresis* and *eddy current* losses.

Summary of all the Forms of Energy in the Aluminum Arresters:

1. Film losses (electrochemical).
2. Film losses (heat).
3. Momentarily stored energy in electrostatic charge.
4. I^2R energy loss in the electrolyte (small except for abnormally high potentials).
5. I^2R energy loss in the charging resistance (if such is needed).

Discharge Rate of an Aluminum Arrester

In the previous article, one discharge rate for the aluminum arrester was given, which is consistent and safe. It does not, however, represent the maximum rate of discharge in either the arrester alone or the arrester combined with its charging resistance. The complication in getting the discharge rate is due to the consideration of the films on the aluminum cells, and the cells as condensers. As a condenser, the aluminum cells have only the resistance of the electrolyte to limit the discharge rate of a lightning stroke. We are considering now only the very first instant of discharge. Since there will be nothing but the resistance of the electrolyte in circuit, the initial rate of discharge at an assumed potential equal to double delta potential between lines and ground will be approximately 1200 amperes. This current will be gradually but rapidly decreased as the aluminum cells take their charge. When the cells take their full charge, the current is then reduced to about 600 amperes, and is due solely to the excess potential on the film. A numerical example is given to illustrate the working conditions. What is the energy absorbed by a 45 kv. arrester before it reaches normal potential (charging resistance being shunted out by the severity of the discharge)? The energy absorbed per phase of the arrester in electrostatic charge will be 16 joules. The minimum energy absorbed by reformation of the film will be 50 joules. The total minimum energy absorbed to bring the potential of the arrester to normal potential is the sum of the two, namely, 66 joules.

This value of energy has no more significance than so many red chips, unless interpreted in terms of induced lightning strokes. One mile of single overhead conductor charged to a potential of 115 kilovolts would contain a stored energy of about 66 joules. The absorption of energy by the arrester, without calling on the valve action of the cells, is thus equal to a lusty induced lightning stroke at nearly three times normal potential.

When next we consider the discharge through both the aluminum cells and their charging resistance, we have again the same relative conditions. Initially, the discharge current at double potential will start at 34 amperes; but as the film forms up the current will be reduced to a lesser value. If the potentials across the charging resistance and aluminum cells were in phase, the current would actually be reduced to 17 amperes when the applied potential is at double delta value. As a matter of fact, the voltages are nearly at right angles to each other, and therefore the current will be considerably greater, probably between 17 and 30 amperes. This combination produces an unusual relation. A resistance which would allow 10 amperes at Y potential and over 30 amperes at double delta potential between line and ground, actually takes only ½ ampere at normal potential, due to the fact that the condenser action of the aluminum cells limits the dynamic current. This feature will be mentioned again in the subsequent article when comparing the action of the aluminum arrester to the European practice of combining a simple resistance with a horn gap in series. In the case of a simple resistance, the dynamic current at Y potential will be 10 amperes instead of ½ ampere, and would, therefore, absorb considerable energy from the generator.

In review then, an a-c. aluminum arrester of the usual dimensions and at double normal potential will have the following rates of discharge for lightning under the general conditions enumerated.

1st. Initially, through the charging resistance, while the cells acting as condensers are taking their electrostatic charge, the current is about 34 amps.

2nd. An instant later, through the same circuit, there will be an indefinite value of current depending on the natural frequency of discharge. The range of this discharge current is from 17 to about 30 amps.

3rd. Initially, through the cells only, while the cells are taking their electrostatic charge, the current starts at 1200 amps.

4th. An instant later when the cells have been charged and when any further passage of current depends on the electric valve action of the film, the current is 600 amps. approximately.

Characteristics of Aluminum Cells Over a Wide Range of Voltage

In the last article curves were given which represented the characteristics of an aluminum cell in which the maximum potential was 353 volts and the minimum potential 200 volts. There is some important phenomena taking place in the aluminum cell just above the critical potential. The critical potential, as has already been stated, is temporarily the

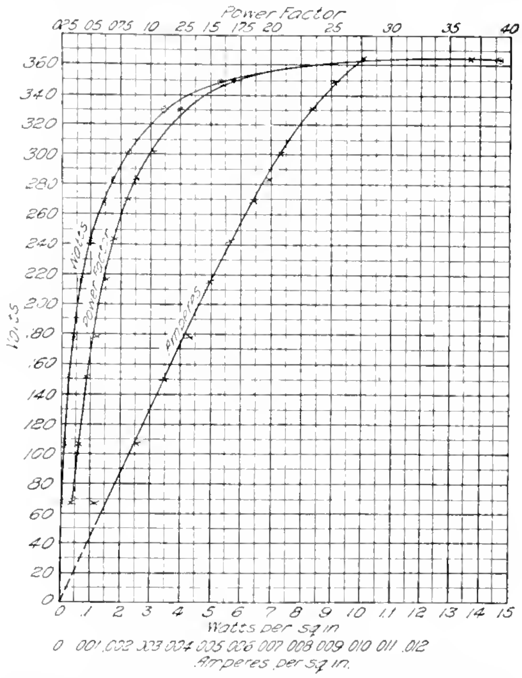


Fig. 1. The relation of the impressed voltage on an aluminum cell to each of the following factors: Watts per square inch of aluminum film; amp. per square inch of aluminum film (numbers at the bottom of the cut); and power-factor (numbers at the top of the cut)

potential at which the film is formed, usually about 260 volts per cell. If, however, a higher potential is applied, more film will be formed, until, with a certain electrolyte, a limit will be reached above which no further film can be formed. For a given electrolyte, then, there is a maximum critical potential above which the film will not form, even though the energy be applied for a long time.

In Fig. 1 is shown the watts loss per square inch, and power-factors for a range of voltage from 70 volts to 364 volts. Effective values of potential and current are given. Even when the critical value of potential is exceeded, it is remarkable that the first change takes place in the sudden increase of the power-factor rather than a visible increase in the whole current. As a basis for this statement it should be noted that the curve of current in Fig. 1 only begins to bend over slightly at the high values of potential. The current is really responding to the supercritical potential; but since all the current added is at 90 degrees phase relation to the current at lower voltages, the resultant current of these two components, which are at right angles to each other, is comparatively small.

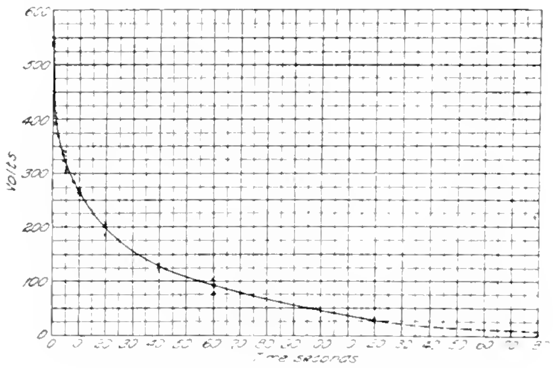


Fig. 2. Leakage of electrostatic charge from two d-c. aluminum cells in series, charged to 540 volts

The potential across the cells was measured by means of an electrostatic voltmeter. At the end of the first second the voltages dropped from 550 to 400; at the end of 10 seconds the voltages dropped to 270; at the end of a minute the voltages dropped to 93 volts; at the end of two minutes the voltages dropped to 25 volts. The d-c. aluminum cells fall off in potential slower at the high values than the a-c. aluminum cells. The charge in an aluminum cell is contained in the film. The aluminum plate acts as one electrode, and the electrolyte as the other. When disconnected from the circuit, the cell begins to discharge through the resistance of its film, which varies somewhat with the value of the applied potential. In consequence of this variation in resistance, the rate of decrease of potential does not follow strictly a simple logarithmic law. The resistance of the film per square inch, as calculated from this curve, is roughly 200 meghoms (1400 meghoms per sq. cm.).

If the film formation had been carried only to 260 volts, the form of the curves would have been similar to the ones shown in Fig. 1, with the exception that the critical voltage would be lower. If the power should be continuously applied for several seconds, the critical voltage would gradually increase toward the final stable value of 364 volts.

How Long Will an Aluminum Cell Retain its Charge?

The answer to this question has importance from at least two different viewpoints. The first of these is involved in the question: When is it dangerous to handle an aluminum arrester that has been disconnected from the circuit? Since the aluminum arrester has a considerable electrostatic capacity, it is possible to get a severe shock from it if it is fully charged. The second viewpoint relates to gap setting on d-c. aluminum arresters intended for certain kinds of service, and includes the interest in the theoretical explanation of what is occurring in aluminum cells.

Figs. 2 and 3 show the rate of leak of charge in d-c. and a-c. aluminum cells. These curves show that it requires several minutes for an aluminum arrester to lose its charge. If the arrester is to be handled within a few minutes after it has been charged, it must be treated in the same way as an ordinary Leyden jar, that is to say, the condenser should be short-circuited momentarily to discharge the electrostatic energy in the films.

General Remarks on Oscillographic Studies and Surges

In connection with the development of the aluminum arrester, several thousand oscillograms have been made, and during the past few years many records of various currents and potential have been taken on operating lines. From these oscillograms a number have been selected for reproduction, which illustrate the magnification of various harmonics and show the forms of current

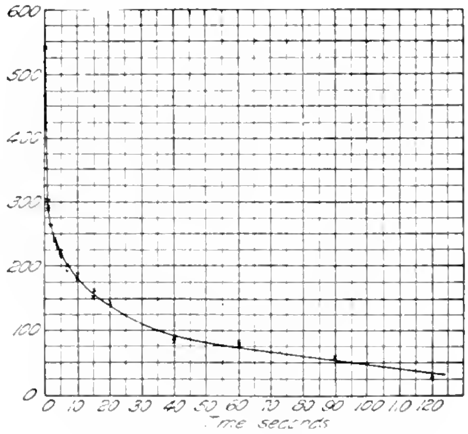


Fig. 3. Leakage of electrostatic charge from two a-c. aluminum cells, charged from a 60 cycle circuit

Since the circuit may be broken at any point of the wave of potential, there is consequently a considerable variation in the first value of potential read immediately after the cells are disconnected from the circuit. One of these curves is shown in Fig. 3 where the potential drops from 540 volts applied, to 300 volts, after the first second. For subsequent seconds the potential falls off even at a slower rate than given by Fig. 2 for d-c. cells. At the end of 10 seconds the potential is 180 volts at the end of a minute the potential is 175 volts; at the end of two minutes the potential is 30 volts. In order to get a practical idea of what potentials would exist on a stack of cones of a lightning arrester the values are best expressed in percentages. On an arrester charged to 60,000 volts the potential will be 50 per cent (about 30,000 volts) after one second, and about 17 per cent (10,000 volts) after a minute.

surges. Various oscillograms are also shown of currents and potentials of aluminum arresters under normal conditions, and also under various abnormal conditions, such as over potentials, poor aluminum films, various gap lengths at the horn, etc.

There is very little knowledge of the transient surges which occur daily on transmission lines, caused by the various forms of customary switching. At the moment of opening and closing a switch of any kind there are always surges of a more or less appreciable nature. There is no such thing as a circuit without capacity and inductance, and wherever these two factors are involved oscillations may take place unless they are damped out. Even with a damping resistance in series great enough to prevent oscillations, there is still the existence of a sudden change of current. The more nearly a circuit is non-inductive, the more quickly will the changes in current take place. As a matter of fact, however, electrical apparatus is designed with factors of safety in the insulation sufficient to withstand all such variations of current. So far as operation is concerned, there is no more interest in this class of surge than there is in the little ripples on the surface of the water of a lake. While they are a part of the phenomena of the electric circuit, they have nothing to do either with the transmission of the salable power or with the continuity of service. It is only when circuits are not damped that the questions of oscillation becomes important.

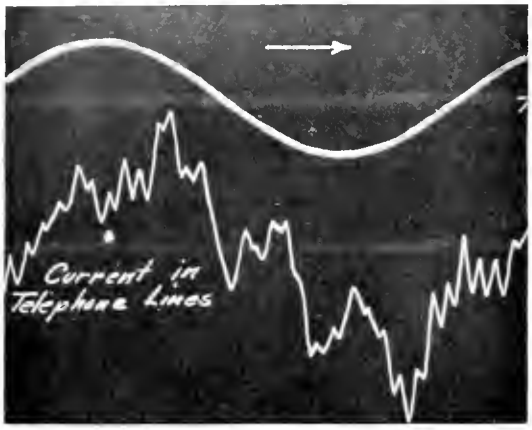
In a great many of the circuits of a transmission system there is included in the loops of the conductors an iron core in which internal losses take place in the form of eddy currents and hysteresis. Whenever the circuit includes such losses the surges are very quickly damped. A series resistance will also damp out the surges. In the main circuit of a transmission system, however, it is impracticable to place series resistance to absorb the surges, as such a resistance would also absorb an undesirable amount of the useful energy. It is the local circuits formed by capacity and inductance without the intervention of series resistance that have to be investigated—they form the lair of the ubiquitous oscillation.

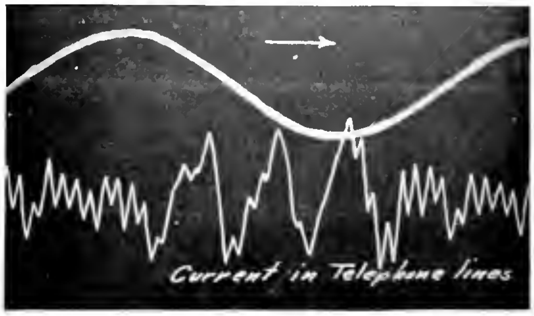
The effects of switching in electric circuits have had much less study than has been given to lightning arrester practice. Where such studies have been made, however, there has been a surprising condition of oscillation. The most complete set of oscillograms which have appeared on this subject were those taken by Mr. G. Faccioli, and published in the Proceedings of the American Institute. This interesting work is available to all, and although it is of great importance and bears directly on the subject in hand, none of the oscillograms will be reproduced here. Since we can get well balanced conceptions of these phenomena only by comparing the oscillograms of usual conditions, which are harmless, with other conditions which may be harmful, a number of different wave forms are herewith reproduced for comparison.

Interpretation of Oscillograms

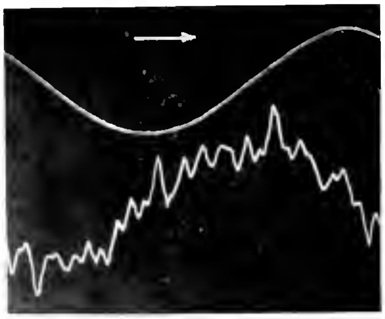
Considerable care has to be exercised in any case in interpreting the records of an oscillogram. Some of these precautions will be reviewed. Although an invaluable instrument, the oscillograph has its very definite limitations. This is especially true in regard to the limits of frequency which it will register. The natural frequency of a vibrator of an oscillograph will range from 2000 cycles per second to 10,000 cycles per second, according to the size of the parts and the tension on the bifilar ribbons. Occasionally one sees an oscillogram showing the frequency of 4000 to 6000 cycles per second. If the oscillograph is not carefully damped, these oscillations may be due to the natural frequency of the vibrator. At any rate resonance of the electrical current with the natural frequency of the vibrator would tend to magnify any oscillations which exist in the circuit. One cannot count on even a fair degree of accuracy with frequencies above a few hundred cycles per second. This statement applies in both directions; that is to say, the deflection may be either greater or less than would be represented by the actual value of current. If the vibrator is properly damped, the deflection will be less than the corresponding values of very high frequency current.

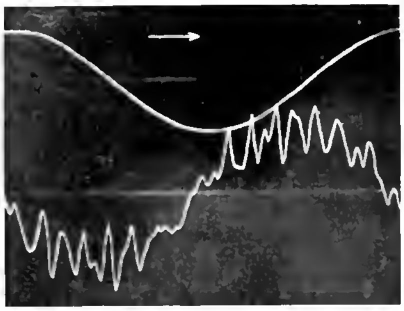
Another source of erroneous wave form in oscillograms comes from the use of current transformers. The current transformer is applicable only where the current is varying continuously in accordance with some simple law like the sine law. To illustrate this point, suppose the primary of a current transformer is placed in a d-c. circuit. When the current starts from zero to a certain value, say 10 amperes, there will be an increase of flux in the core of the transformer which will produce a current in the secondary of the transformer in the opposite direction to the direct current. As the direct current approaches its final value of 10 amperes the current in the secondary of the transformer begins to decrease. When finally the direct current reaches 10 amperes constant, the current in the secondary of the transformer reaches zero and remains there, although the actual current to be registered is 10 amperes in the main circuit. In brief, the matter can be stated as follows: The current in the secondary of a current transformer depends upon the rate of change of current in the primary, therefore, the current transformer will show zero current for every value of current in the primary that is not varying. If a current starts and stops in the primary without reversing its direction, it will produce an alternating current in the secondary circuit.





Figs. 4 and 5. Induced current in a telephone line situated under a power line at a distance of about ten feet





Figs. 6 and 7. Induced current in a telephone line situated under a power line at a distance of about ten feet

There are many cases where one is forced to use current transformers, but it is necessary to place a special interpretation on the results. The current transformer always distorts the sudden variations of current by giving distorted alternating current effects for simple impulses.

After all the favorable things have been said in regard to oscillograms, there remains the fact that much of the phenomena connected with high frequency effects in transmission circuits can not be profitably studied with the oscillograph.

Descriptions of Oscillograms That Have Nothing to do With Aluminum Arresters

There are 15 oscillograms in this group. They are intended to show wave forms of current and potential connected with various phenomena which occur from time to time, or continuously, in an electric circuit. The first four oscillograms, Figs. 4, 5, 6 and 7, show the induced currents in a telephone line which is placed about 10 feet under a power line operating at 33,000 volts. The currents were obtained by using the connections shown in Fig. 8; in brief, the two telephone wires were connected directly to an impedance of 62,000 ohms at 60 cycles. The middle point of this impedance coil was connected to ground. This apparatus is sometimes known as a drainage coil, and is standard for telephone circuits. Since any current flowing from the two telephone wires to ground will pass around the iron core in opposite directions, the impedance from the two telephone lines to ground will be only a small fraction of the impedance from line to line. The actual value was 52 ohms at 60 cycles. Since the ohmic resistance was

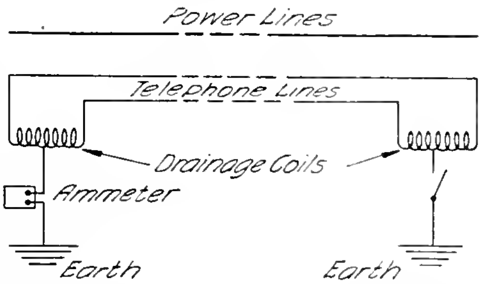


Fig. 8. The general scheme of connections of the oscillograph to the telephone circuit to obtain the oscillograms of Figs. 4, 5, 6 and 7

42 ohms, the reactance was 32.2 ohms. In terms of inductance we have: line to line, 164 henrys; and lines to ground, 0.085 henry. The ratio is 1930 to 1. The ammeter of the oscillograph was placed between the neutral of this drainage coil and earth.

A remarkable thing about these curves is not only the irregularity as shown in Figs. 4, 5, 6 and 7, but also their incessantly

line is, therefore, both electrostatic and electromagnetic. No attempt was made to separate these two effects. These curves suggest a method of studying surges on a transmission line without appreciable interference from potential and current on the power line. It is evident that the telephone circuit picks up the variations which occur in the power circuit, and probably magnify them considerably.

Figs. 9 and 10 show the peculiar magnification of irregularities that take place in any kind of a series inductance. The particular kind of series inductance involved here is a potential regulator on 2300 volts. In both of these figures the 13th harmonic is plainly visible in the potential wave. The current wave (not shown here) in the 2300 volt circuit, however, was quite smooth. In spite of these comparatively smooth waves of main current and delta potential, the potential across the regulator is exceedingly jagged. Fig. 9 shows, besides a prominent 13th harmonic, a much higher harmonic. This superposed higher harmonic was due to the teeth of certain motors on the secondary circuit. Fig. 10 was taken after six o'clock, when some of these motors had been disconnected from the circuit.

Figs. 11, 12 and 13 represent three different conditions of arcs on the circuit. Fig. 11

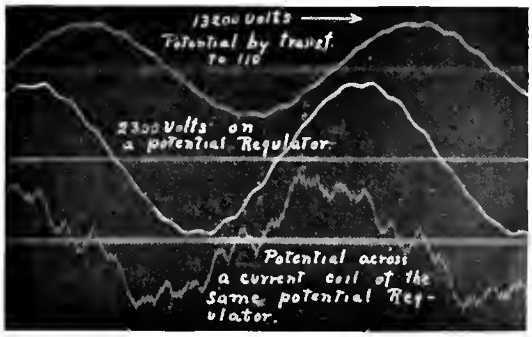


Fig. 9. Potential across a series coil of a potential regulator of the induction type operating at 2300 volts line potential (lower curve). Prominent harmonics are: the 13th from the teeth of the generator and still higher harmonics from the reactions of the teeth of motors. The upper and middle curves are potentials of the 13200-volt and 2300-volt circuits. The potential waves show only the 13th harmonic superposed on the fundamental wave at 60 cycles

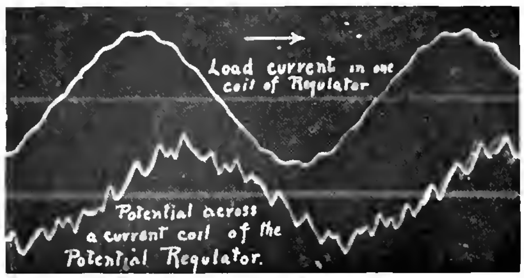


Fig. 10. Potential across a series coil of a potential regulator, the same as used in Fig. 9. The motors were disconnected so that some of the very high harmonics shown in Fig. 9 have disappeared. The 13th and some other higher harmonics are still present

changing characteristics from moment to moment. As shown in these curves, the electromotive force waves at 40 cycles are unusually smooth. The system was carrying its normal day load at the time these curves were taken. The induction on the telephone

shows the potential across a d-c. circuit and a current in a fuse which is being blown. As soon as the short circuit is thrown on, the potential drops from 550 volts to about 180 volts average. Both the electromotive force and current show numerous variations, although none of them could be considered serious unless the variations produced resonance.

Fig. 12 shows a continuous arc of 3.6 amperes between the middle electrode and the surface of a strong electrolyte contained in a metal can. The initial gap between the metal electrode and the surface of the electrolyte was 1/4 in. The arc crater, however, produced a variable depression in the surface of the electrolyte and varied the arc length. The maximum potential across this arc was 3400 volts. The variations in potential can be seen in the lower record of Fig. 12. Here, again, the variations in potential may be harmful if they synchronize with the natural frequency of the circuit.

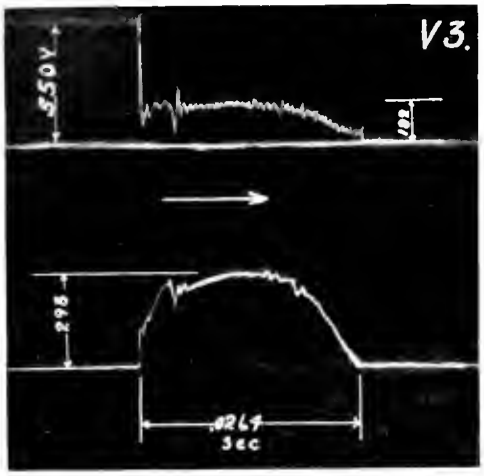


Fig. 11. Current in a fuse (lower curve), and potential across the remaining part of the circuit (upper curve). Note the many oscillations in the potential wave which have nearly a constant frequency

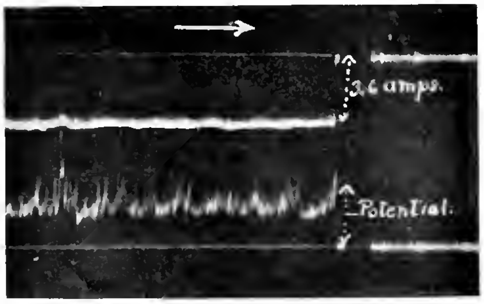


Fig. 12. Current and potential of an arc between a metal electrode and a liquid electrode of good conductivity. The power is taken from a constant current transformer. The potential variations are considerable. This condition of arc sometimes occurs in accidental arcing grounds when broken wires fall on wet ground

Fig. 13 shows an undesirable condition in a magnetic blowout. As the current is started through the magnetic blowout, the voltage drops from about 540 to 403 volts. The current wave on the lower record is carried off the scale of the oscillograph and is therefore indicated by dotted lines. As the deflection returns within bounds, the current wave is seen to be very jagged. To begin with, for about two oscillations the frequency is about twice the frequency for the succeeding four oscillations. Should this oscillation correspond to the natural frequency of any part of the circuit, resonance potentials would be set up in such a local circuit.

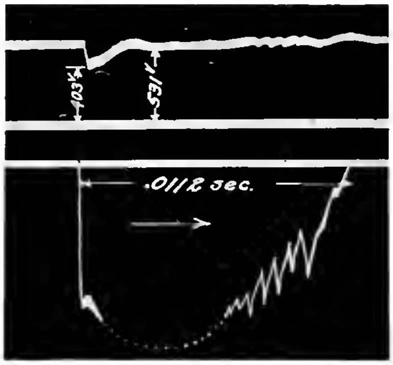


Fig. 13. Current wave in a badly designed magnetic blowout operating on a 550 volt trolley circuit. There are undesirable but not serious oscillations of current and potential as the arc is being extinguished

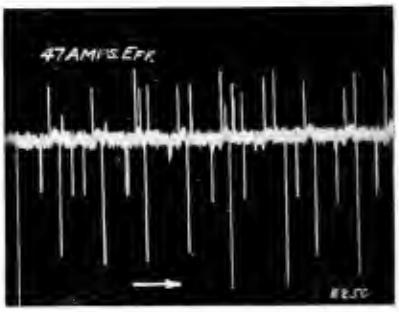


Fig. 13-A. Oscillogram of a frequency too high to be recorded by the oscillograph (see text)

Fig. 13-A: *Current in an Oscillating Circuit.* This oscillogram is taken to show the response of the vibrator to frequencies that are far above its own natural frequency. The total effective current was 47 amperes. The natural frequency of the circuit was 200,000 cycles per second. Each one of the

long lines represents the discharge of a quantity of electricity through the vibrator at 200,000 cycles. The vibrator in this case acts as a ballistic galvanometer, and shows by its deflection a resultant quantity of electricity flowing in a certain direction. Not only can the vibrator *not* follow the changes in the frequency at 200,000 cycles, but also the time movement along the axis of the photograph is too slow to bring out the separate oscillations of such a high frequency.

In the next group, Figs. 14, 15 and 16, there is shown the usual magnification of harmonics in a generator wave by the electrostatic capacity of the transmission circuit. In this case the potential was 13,200 volts from a turbo-generator. (Public Service Electric Company.)

Fig. 14 shows in the upper record the potential of a generator when disconnected from a cable circuit. The middle record shows the current to ground when one phase is grounded. This current is simply the electrostatic charging current of the generator. Since on the generator there are 18 teeth per pair of poles, the 17th harmonic (n-1) is magnified by the electrostatic capacity.

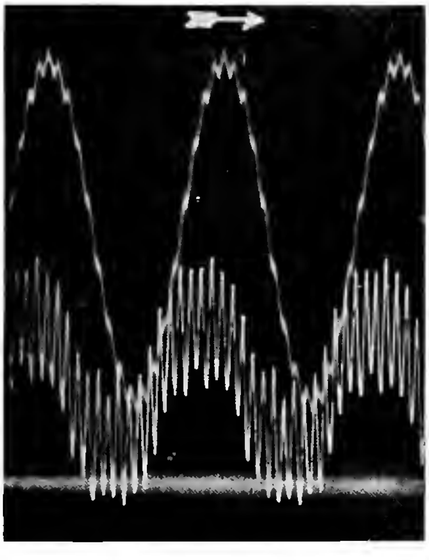


Fig. 14. Generator harmonics produced by the teeth of the armature. Upper record is the delta potential of the generator and the middle record is the current to ground. No connections to cable or line

Fig. 15 shows the charging current from the same generator to three phases of a cable, when one phase, .iz., phase 2, is grounded. The peak value of current on phase one is 8.7 amperes; on phase two, 3.1 amperes; and on phase three, 9.0 amperes. The frequency is 60 cycles.

Fig. 16 shows the charging current from another generator to a cable when one phase

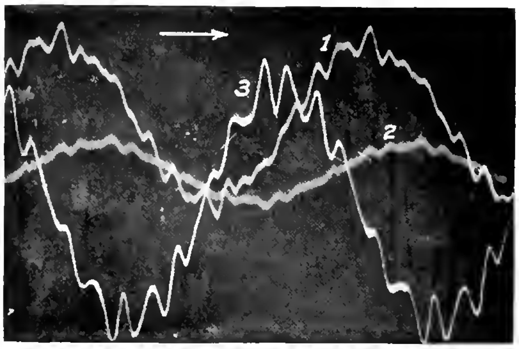


Fig. 15. Generator harmonics magnified by being connected to an unloaded cable and grounded at one place through a small resistance. All these records are of charging current in the phases of the cable

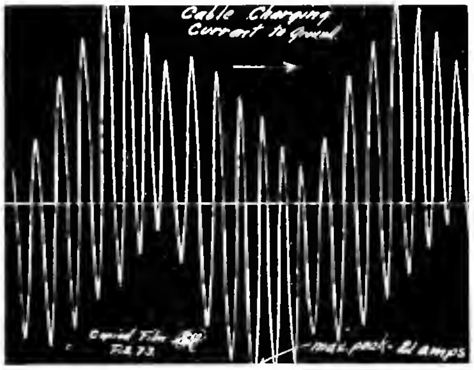


Fig. 16. Generator harmonics magnified by being connected to an unloaded cable. The single record shows the current to ground. The 13th harmonic is stronger than the fundamental frequency

of the cable is grounded. In this case there are 12 teeth per pair of poles, and a 13th harmonic (n+1) is magnified. As a matter of fact, the 13th harmonic in this current wave is stronger than the fundamental wave. The fundamental wave is represented by the medium points of the 13th harmonic oscillation.

In Fig. 16 there is only a little over a cycle and a half of the fundamental wave shown, while 20 cycles of the 13th harmonic are shown. The maximum peak current of the harmonics is 21 amperes. Harmonics in generator waves are greatly magnified by capacity current because of the fact that the leading current in the condenser tends to increase the flux on the tooth of the armature as the tooth becomes active under the pole. It is a particular case of the general condition that leading currents in an a-c. generator tend to increase the magnetism in the field, and thus raise the potential.

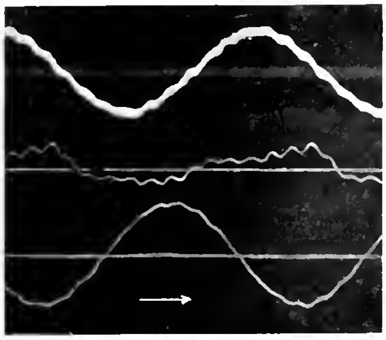


Fig. 17. Charging current in a healthy aluminum arrester with no gap in series (middle curve). The upper and lower curves are voltages on the same circuit. The 13th harmonic is prominent

As is well known, lagging currents have the opposite effect, and a greater excitation is required to maintain normal potential, due to the de-magnetizing effect of the lagging main currents.

Wave Forms of Charging Currents in Aluminum Arresters

Figs, 17, 18 and 19 show three typical wave forms of aluminum arresters taken on three different power circuits. The gap at the horns was entirely closed, so that

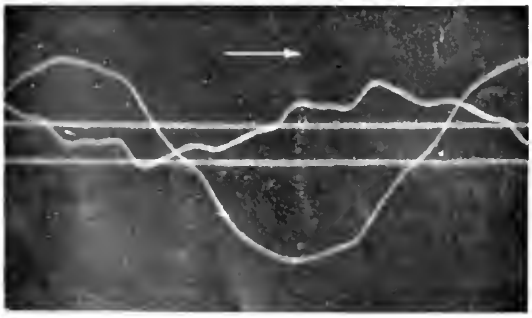


Fig. 19. Charging current of a healthy aluminum arrester with no gap in series (upper curve). The lower curve is the potential at the terminals of the arrester. This wave is similar to the one in Fig. 18

there were no sparks in the circuit. The action of the aluminum cells is that of a condenser which tends to magnify any latent harmonics in the circuit. These three cases are typical of the charging current of aluminum arresters.

Fig. 17 shows two electromotive force waves, and the charging current of a 14,000 volt aluminum arrester at 60 cycles. The main potential wave has a prominent 13th harmonic which shows itself directly in the

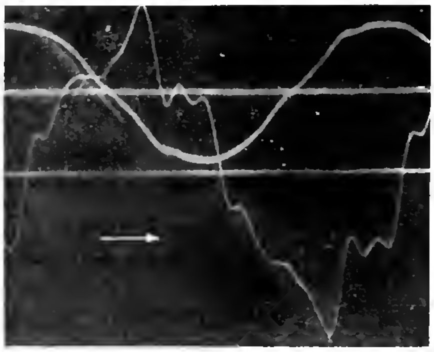


Fig. 18. Charging current in a healthy aluminum arrester with no gap in series (lower curve). The upper curve is the potential at the terminals of the arrester

charging current of the aluminum arrester. Potential waves are shown by the upper and lower curves; the current in the aluminum arrester by the middle curve.

Fig. 18: Several harmonics are noticeable in the charging current (lower curve) of this arrester. The potential wave (upper curve) is fairly smooth.

Fig. 19: The charging current (upper curve) in the arrester in this case shows a prominent 7th harmonic.

Fig. 20: *Initial current rush of the aluminum arrester:*

Fig. 20. Normal charging current, through an arc, of an aluminum arrester

This arrester consisted of 8 cells on a 2200 volt circuit. The voltage per cell was 275 volts. The arrester had stood 24 hours. The upper record shows the current, and the lower record the electromotive force. The initial current rush is 10.8 amperes maximum in the positive direction, and a current somewhat less for the initial value in the negative direction. All subsequent currents are too small to show clearly on this oscillogram. This charge represents a lightning arrester in normally good condition.

Fig. 21: *Charging current of a 33 kv. aluminum arrester after standing six weeks without charging.* The arrester was charged through a charging resistance which limited the current to 15 amperes maximum. This oscillogram is illustrative of the valuable conditions brought about by the use of charging resistances. This arrester would have been hopelessly damaged if it had been connected directly to the circuit without the use of charging resistances. As a matter of fact, the arrester was brought back into condition within 15 seconds. The oscillogram of Fig. 21 shows the building up of the potential on the aluminum cells and the decrease in the current. The upper record is the potential across the aluminum cells, while the lower record is the current in the aluminum cells. It should be noticed that the direction of the current in the vibrator was reversed relative to the potential; consequently in interpreting the oscillogram the negative direction in the upper record corresponds to the positive direction in the lower record. Since, at the offset, the aluminum cells are operating very slightly as condensers, it can be stated approximately that the potential across the resistance is equal to the full Y potential, viz., 19,000 volts, less the potential across the cells.

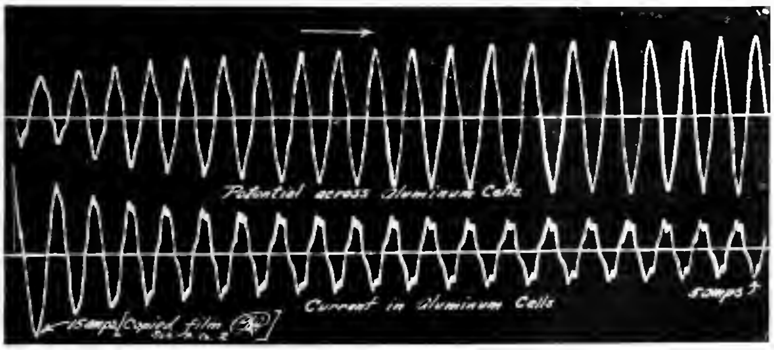


Fig. 21. The current and potential of 33 kv. arrester after the films had stood six weeks in electrolyte without charging. This oscillogram shows the valuable function of charging resistance. A fuller analysis is given in the text

The potential across the cells as given in the upper record is not symmetrical on the positive and negative side, due to the difference in formation of the films on the upper and lower side of the aluminum cones. The negative potentials of the successive waves on the upper record are as follows: 5840, 5800, 9000, 11,100, 12,100, 13,800, 14,900, 15,500, and in the 20th cycle, 17,500. It will

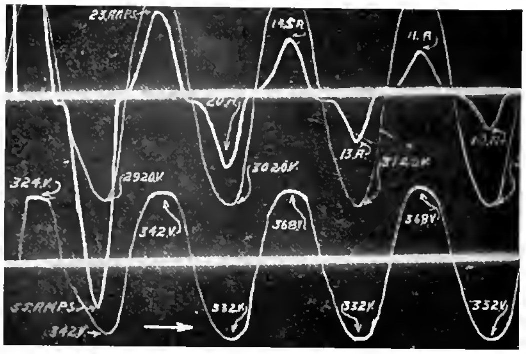


Fig. 22. Charging current and e.m.f. of an aluminum arrester in which the film is only partially formed (see text)

be seen that in these 20 cycles the potential rose to almost its normal value. On the positive side the potentials across the aluminum cells for the successive cycles rose as follows: 8100, 9700, 10,800, 11,680, 12,390, 14,000, 15,340, 16,080, and in the 20th cycle, 17,500. The current in the aluminum arrester started off at an effective value of 9 amperes, i.e., 15 amperes maximum, and gradually decreased to 3.3 amperes effective, 5 amperes maximum, at the 20th cycle. After this oscillogram was taken the arrester was given 15 seconds continuous discharge and another oscillogram was taken. The current had then reduced to its normal value at 40 cycles.

This arrester is situated on the power lines of the Schenectady Power Company, and due to an accident to a tower by an ice flow near the terminal station, it was necessary to leave the arrester without charging during six weeks. Meanwhile the arrester was standing in a warm room. This represents an unusually long period for an arrester to stand without charging. The time was early spring and the temperature of the room was probably about 15 to 20 degrees C. Very much greater dissolution would have taken place in the summer time when the temperature would have been higher. The indications were, however, that by using a charging resistance, as was done in this case, the arrester would have been able to

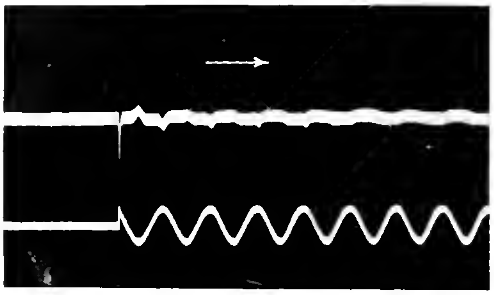


Fig. 23. Oscillogram of the electrostatic charge in an aluminum arrester practically independent of the current needed to reform the film. Note the initial current during the first half-cycle in the upper record. The lower record giving the e.m.f. across the cell starts at nearly its maximum value. This initial value of potential produces the extra current to charge the capacity of the cell

withstand still further dissolution and still have been brought back into good condition by a little care in charging.

Fig. 22: *Phase Relations of Current and Electromotive Force in an Aluminum Arrester in Which the Film is Only Partially Formed.* No charging resistance is used. The upper record gives both the electromotive force across 8 cells on a 2300 volt circuit, and the current in the 8 series cells. The lower record gives the potential across one cell. The applied potential was 3200 volts maximum. During the first half cycle the circuit to the arrester is closed, and the current immediately goes off the scale of the oscillogram. The movement of the vibrator was so rapid that it left no trace. The curve was drawn in from the zero line by reference to the record of the voltage across a single cell, as given in the lower record. In the next half cycle (the 2nd from the beginning) the current maximum is seen to be 55 amperes and the current is approximately in phase with the electromotive force. The electromotive force has dropped from 3200 maximum to 2920 volts maximum, due to the regulation of the circuit. It will be noticed that the current has a tendency to hang around the zero value before rising to a maximum. This is the natural characteristic of a current in an aluminum cell where the voltage on the film is in excess of its critical value. The current hovers around the zero until the voltage rises sufficiently to reach the critical film voltage, then the current rises rapidly. In each succeeding half cycle it will be noted that the current hangs a successively longer time near the zero value. The peak values of current meanwhile decrease as follows: 55 amperes, 23 amperes, 20 amperes, 14.5 amperes, 13 amperes, 11 amperes and 10 amperes. It will be noticed that all the way through the maximum current takes place at the time of maximum potential, showing that the electrostatic capacity of the cell plays no part in the reformation of the films. In other words, reformation represents energy taken from the circuit and not given back.

Fig. 23: This oscillogram shows the initial current in the aluminum cell, giving it the electrostatic charge. This arrester was in excellent condition and had been previously charged. There was no charging resistance in series. The second half cycle shows the charging current only slightly above normal value.

Fig. 24: *Endurance of an Aluminum Arrester to Continuous Heavy Discharge.* A voltage of 690 maximum was applied to an arrester, but due to the heavy current the regulation brought the potential down to 558 volts maximum. The upper record shows the potential across a series fuse in the arrester circuit. The middle record shows the current flowing in the arrester. There

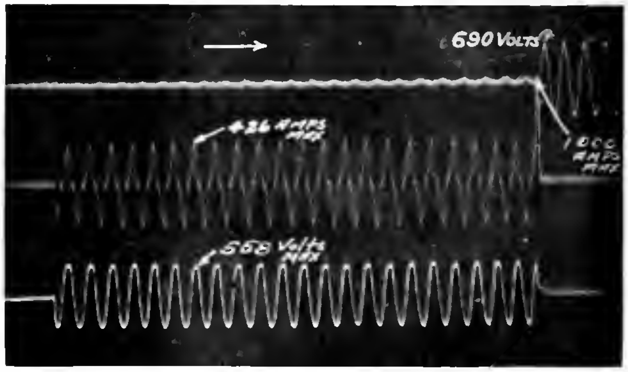


Fig. 24. Endurance of an aluminum arrester in discharging continuously heavy currents at abnormally high dynamic potentials (see text)

was an average value of 426 amperes. The lower record shows the voltage across a cell. The effective potential was 400 volts, which is only about 100 volts above the critical film voltage. The effective current is 300 amperes. At this heavy current it required 23 cycles to cause an arc to pass from cone to cone, cutting out the electrolyte. The passage of the arc is represented in the 23rd cycle by an increase of current from 426 amperes maximum to 1000 amperes maximum. This caused the fuse to blow and the potential across the fuse terminals rose to 690 volts. Summing up the total energy that passed through the cell to cause its failure, we find 63,000 volt-ampere-seconds. A mile of line wire charged to 110,000 volts has stored up in it only one-thousandth as much energy, namely, about 63 joules, or volt-ampere-seconds. The spacing on this cell was 0.3 inch. Arresters for very high voltages have a spacing 50 per cent greater than this, and therefore the endurance will be considerably greater. It should be understood that this cell had purposely applied to it an excessive dynamic potential to determine its endurance. No arrester should be operated this way normally. Cases have arisen where a runaway generator and the regulation of long circuits have caused excessive dynamic potential on the arresters. This oscillogram gives a definite idea of what the arrester can be expected to do under such objectionably abnormal conditions. In the early work many tests were made on aluminum cells with these abnormal potentials in order to determine the spacing between the plates. As the current density on the plate increases

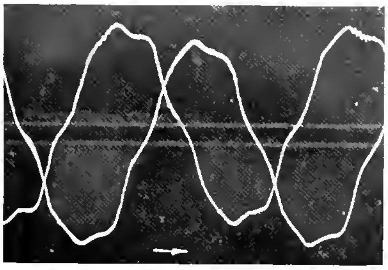


Fig. 25. Very small variations in potential caused by charging an aluminum arrester (upper curve)

the entire surface becomes brilliantly illuminated, until finally, due to some local accidental condition, a small arc darts out from one plate through the electrolyte and causes an arc from plate to plate. The quantity of electricity involved is equivalent to that necessary to blow a lead wire fuse of a rating of 50 amperes. In the protection of aluminum arresters, therefore, where such protection is demanded, a fuse of 25 amperes rating is used. This fuse is especially recommended on arresters that are used on busbars of power circuits.

Sixty thousand volt-ampere-seconds represents an energy many times greater than any lightning discharge or surge, with the exception, perhaps, of direct strokes.

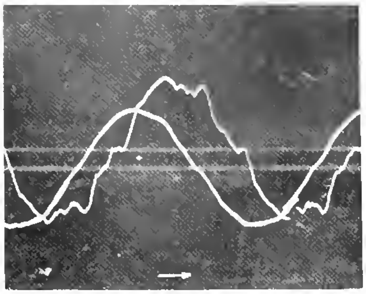


Fig. 26. Load current on a 2300-volt circuit (upper record) and e.m.f. of the circuit (lower record). There was no arrester being charged. Compare with Fig. 27

There is no way to adequately measure the quantity of electricity in a direct stroke, and any statement regarding this feature must be pure guess work. The only available information is represented by the size of conductors that have been fused by direct strokes. It has often been observed that small wires of both iron and copper have carried direct strokes without fusing. Occasionally,

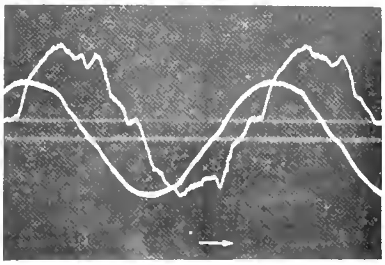


Fig. 27. Load current (upper record) and e.m.f. on a 2300-volt circuit (lower record) while an aluminum arrester is being charged. A very careful examination shows extra irregularities in the current wave which possibly might be the result of the charging current in the arrester. The irregularities in the curve are negligible

however, very large wires have been fused, but usually the fusing of large wires has been due to the arc crater rather than the I^2R loss in the wire itself. When the lightning bolt strikes a horizontal transmission line, it is the arc crater that melts the wire.

Fig. 25: *Oscillogram of Voltage Disturbances Caused by Charging an Arrester Through a Horn Gap.* There are two waves of electromotive force shown in this oscillogram; the lower record is the delta potential of the 12,500 volt system by transformation to 110 volts for the oscillograph; the upper record is the voltage of the 2300 volt system. The arrester that was being charged was placed on the 12,500 volt system. The conditions of inductance and capacity made the 2300 volt circuit particularly susceptible to oscillations. The intensity of these oscillations is shown in the upper record, up near the maximum value. There is no visible variation in the 12,500 volt wave.

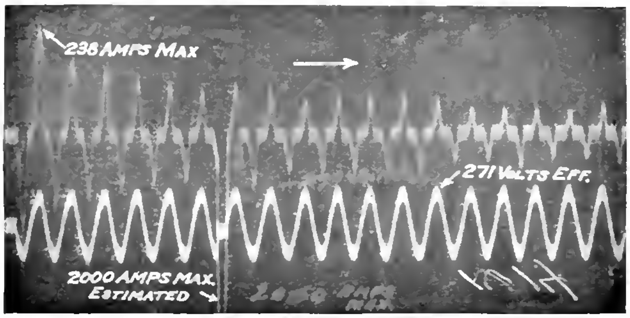


Fig. 28. Oscillographic records of the action of defective aluminum films in a foreign made arrester. An arc occurred between tbe aluminum plates but was extinguished in the same half cycle (Further description in the text)

Figs. 26 and 27: *The Effect on the Power Current of Charging a Lightning Arrester.* Fig. 26 shows the wave of current in the 2300 volt line when no lightning arrester is being charged. Fig. 27 shows the same load current during the charging of an arrester through arcs at the horn gap while charging resistances were used in series. The difference between the two curves is almost imperceptible. The current was measured by means of a current transformer If the load current had been lighter a greater relative effect would have been shown The conditions of this particular 2300 volt circuit were such as to make it susceptible to oscillations.

Figs. 28, 29, 30: *Studies of Aluminum Films in Poor Condition.* In these three oscillograms normal potential was applied to the cells. The arrester was of foreign make. The films were in very poor condition, but had not stood long in the electrolyte. The electrolyte was good and had a low specific resistance. The entire fault was in the kind of film on the plates.

Fig. 28: The applied potential in this figure is a normal value of 271 volts effective. The initial charging current should be about 10 amperes; instead, however, the initial rush is 238 amperes maximum. Furthermore, the current does not decrease rapidly, but comes down very gradually. The successive peaks of current in amperes in the positive direction are as follows: 238, 153, 136, 119, 102, 94, 102, 94, 60, 76, 68, 64 and 60. After 13 cycles the current is only reduced to about ¼ its initial value. This is the usual characteristic of a poor film.

Between the sixth and seventh cycle there is a very unusual occurrence. Due to some local irregularity, an arc formed between plates during the negative half cycle, but extinguished itself immediately and did not occur again during the test. The estimated current in the short circuit was 2000 amperes. During this time the electromotive force across the cell was very low, being only the potential across the arc. During the first half cycle after this arc it will be noticed that the current rose from 94 amperes to 102 and then dropped off again.

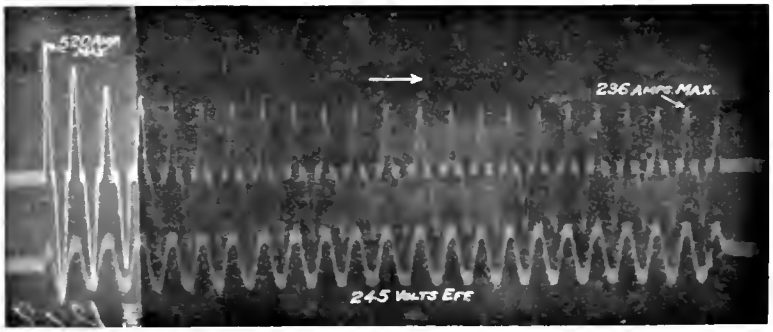


Fig. 29. Defective aluminum films with normal potential applied. There were twenty-two cycles of current, but no accidental arc between the aluminum plates

The record of the current shows the typical wave form of the formation of a film. This is shown in the time the current hovers near the zero value. During the first half cycle the current remains small for a very short time, but each succeeding cycle has a successively longer period of low current, as indicated by the lengths of the white lines near zero. This is interpreted as follows: In the beginning there is almost no film voltage, and therefore the current rises rapidly with the increase in potential. Each successive cycle of current forms the film up to successively higher voltages, and the current is therefore held at a lower value for longer intervals.

Fig. 29: Here again the impressed voltage is only 245 volts effective, and the initial current reaches a maximum value of 520 amperes. This shows excellent conductivity in the electrolyte. The current gradually decreases to 236 amperes maximum when the circuit is opened by means of a fuse. This is another case of a foreign-made aluminum film which required considerable expenditure of energy to properly form.

Fig. 30: In this case the applied potential was only 212 volts. The initial current was 472 amperes maximum, which caused a short circuit between plates in the fifth cycle. This short circuit blew a series fuse. The estimated value of the short circuit current in the arc between the aluminum plates was 1200 amperes. These oscillograms indicate, not a good film in poor condition, but a poor film in poor condition.

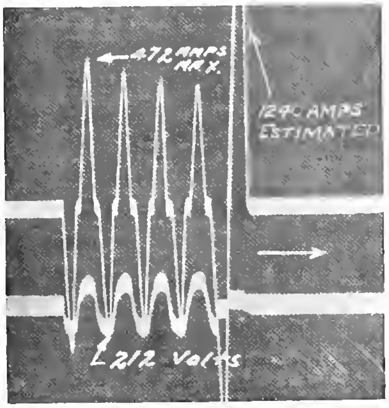


Fig. 30. Defective aluminum films with less than normal potential applied. An arc was formed between the aluminum plates in five cycles

Studies of the Effects of Series Arcs on the Wave Form of Current, Mostly in the Aluminum Arrester.

Fig. 31: *Arcs in series with the voltmeter vibrator of the oscillograph.* The resistance in series was about 15,000 ohms, giving approximately ½ ampere from line to ground on a 13 kv. circuit. The upper record is the potential from line to ground, taken without a gap. The lower record is

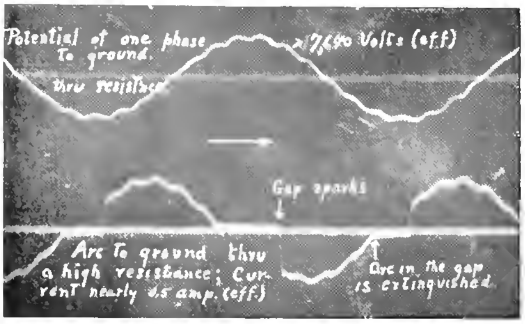


Fig. 31. Arc to ground through a high resistance on a 13,200-volt circuit (lower record). Delta potential of the circuit (upper record)

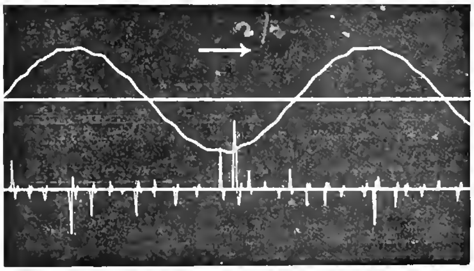


Fig. 32. Charging current of an aluminum arrester when there was a small gap in series (lower record). A current transformer was used, a single impulse giving a complete cycle of oscillations in the oscillogram. Delta potential, 13,200 volts, is shown in the upper record

the potential from line to ground, taken with the gap in series on another phase. The spark potential of the gap was about 8000 volts to 15,000 volts, according to the direction of current. Referring to the lower record, the current remains zero until the potential across the gap reaches the spark value. The current then jumps to the value represented by the quotient of the applied potential divided by the resistance. The current continues in the arc through the rest of the half cycle and then remains zero until the negative potential rises to a value sufficient to cause a spark at the gap. The change of current in this case is necessarily very sudden, as there is no appreciable inductance in the circuit.

Fig. 32: *Aluminum Arrester on 13 Kv. Circuit Charging Through a Small Gap.* The lower record shows the current as a

succession of currents of brief duration. As the potential rose sufficiently to spark over the small gap there was a small charge passed into the aluminum condenser, raising its potential to the instantaneous value of

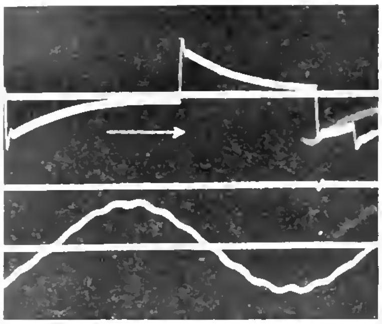


Fig. 33. Potential across the stack of aluminum cells while being charged through a long gap at the horns (upper record). Delta potential, 13,200 volts (lower record)

the line. As soon as the potential of the aluminum arrester rose to line potential, the current was reduced to zero, and the spark went out. The potential then continued to rise until it again produced sufficient difference of potential between the line and the arrester to again cause a spark to pass. A current transformer was used in the circuit of the aluminum cells, and therefore a single impulse in the cells produced a false alternation in the oscillographic record. The true state of affairs is better illustrated by the potential across the cells. This is shown in a later oscillogram.

Fig. 33: *Aluminum Arrester on 13 Kv. Circuit Charging Through a Long Gap at the Horns.* A gap at the horns was set at the maximum value that would spark. The potential of the aluminum cells was taken by means of a resistance directly in series with the vibrator of the oscillograph; in other words, there was no potential transformer used. The upper record is the potential across the aluminum cells, not including the gap. This same condition obtained also in the following two oscillograms. The cells take a maximum negative charge which leaks out through the resistance of the vibrator circuit during the rest of the half cycle. This leak follows approximately a logarithmic curve. There then follows a charge in the positive direction for the next half cycle, and again the charge leaks out through the shunting circuit of the oscillograph. It should be noted that this sudden decrease in the potential of the aluminum cell during a half cycle is due to the leak through the parallel resistance. In an earlier paragraph (Figs. 2 and 3), were shown the rate of leak of an aluminum cell through its own internal resistance. These curves show that the internal leak was comparatively slow. In 1/120 of a second the leakage would be inappreciable. Therefore, with an aluminum arrester charging through a gap, the potential of the arrester would immediately rise to the potential of the circuit, and remain approximately constant until the spark again took place at the horn gaps.

The middle record is taken through a current transformer, and therefore does not give a true record of the current in the cells. Furthermore, the current transformer was at the neutral of the three phases, and is slightly affected by the currents in the other two phases. The current consists really of a succession of charges at greater intervals than is shown in the previous oscillograms (Fig. 32). Due to the inaccurate operation of a current transformer, only one passage of current is visible in the current record. The lower record is the delta potential of the circuit, about 13 kv. effective. It is out of phase with the potential across the cells, or the Y potential.

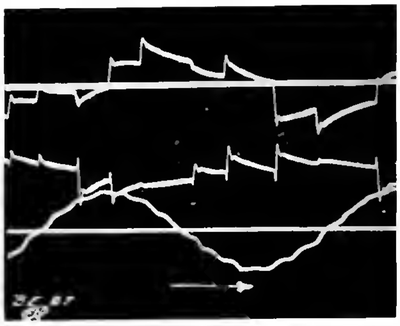


Fig. 34. Potential across a stack of aluminum cells while being charged through a gap of medium length (upper record). Delta potential, 13,200 volts (lower record)

Fig. 34: *Aluminum Lightning Arresters on 13 Kv. Circuit Charging Through a Gap of Medium Length at the Horns.* The same

remarks apply to this oscillogram, as were made in regard to the previous one, the only difference being that the gap length is shorter, and consequently more sparks take place per cycle.

Fig. 35: *Aluminum Lightning Arrester on 13 Kv. Circuit Charging Through a Gap of Short Length at the Horns.* The same general remarks apply to this oscillogram as were made for Fig. 33, except that the gap length is quite short. The charge in the aluminum cells does not have time to leak

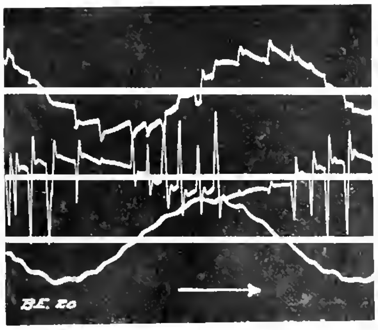


Fig. 35. Potential across a stack of aluminum cells while being charged through a gap of short length (upper record). Delta potential, 13,200 volts (lower record). The middle record is the erroneous results given by a current transformer through which the charging current passed

out very much during the short interval between the sparks, and therefore the potential is shown as a succession of small increases and decreases.

Fig. 36: *Charging Aluminum Arrester on 13 Kv. Circuit Through the Particular Value of Arc Length Which Magnified the Natural 13th Harmonic in the Potential Wave:* This is rather a valuable record, which illustrates a theory stated some years ago, viz., that for nearly every circuit there is an arc length which will tend to magnify the natural oscillations in the circuit. This condition is a very difficult one to find and maintain long enough to produce a record. The current in the arrester was slightly increased by the extra oscillations of the 13th harmonic. The conditions of current without a spark are shown in Fig. 17. It will be seen that the conditions brought about by the spark at the horn somewhat magnify the harmonic. Although this condition was harmless in the arrester circuit due to the fact that the current was so small, the record is valuable in showing what could take place on a transmission line during an arcing ground where the currents are sufficient to cause severe surges on the line. There is usually a certain arc length which will be much more destructive than any others. This condition has been tested out repeatedly on arcing

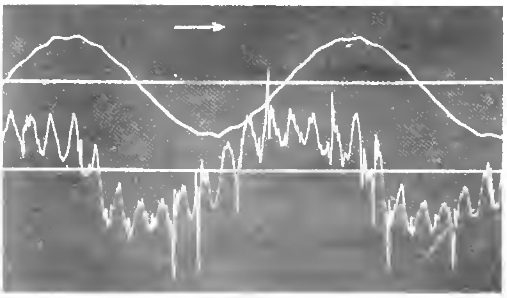


Fig. 36. Oscillogram of a current drawn through an arc of just the right length to magnify the 13th harmonic in the wave of e.m.f. Current is given in lower record and the delta e.m f., 13,200 volts, in the upper record

ground tests in drawing out an arc from line to ground. There is always a certain length of arc which causes the lightning arrester to discharge vigorously. In these aluminum lightning arresters, without charging resistance, that are in good condition and that have a tendency to flare at the horns, the magnification of the harmonic, as shown in Fig. 36, will usually explain the phenomenon. When the harmonic is magnified there is more current taken. It requires very little current above 1/2 ampere to produce enough heat in the arc to rise on the horns. When charging resistances are used there is always a greater tendency for the arc to rise on the horns and turn reddish, due to a different cause, namely, that the current is more nearly in phase with the electromotive force than when no charging resistance is used

A GRAPHICAL METHOD FOR THE CALCULATION OF SHORT TRANSMISSION LINES

By Fredrik Waern

Switchboard Drafting Department, General Electric Company

A graphical method which can be completely explained in a couple of minutes with the aid of pencil and paper is often difficult to describe in so many words. In the present case careful attention to the text should be sufficient to give the reader a clear idea of the way to use the chart, and when that has been done the use of the chart itself is the easiest thing in the world. Knowing power-factor, size of conductor, spacing and frequency, the resistance and reactance drop per mile per ampere for any line up to, say, 40 miles can be figured in a matter of a few seconds.—Editor.

The exact treatment of transmission line problems is sometimes performed by the use of higher mathematics and tedious calculations. In many cases, however, the time expended on the calculation plays a more important role than the accuracy of the result; and it is the object of this paper to develop an approximate graphical method by means of which the voltage drop of a short alternating current transmission line can be easily obtained.

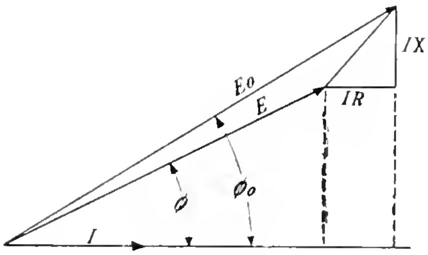


Fig. 1

For overhead transmission lines up to 40 miles at 60 cycles, for pressures not exceeding 44,000 volts, the error introduced by neglecting the condenser effect of the lines is generally of no practical importance. Within these limits it is possible to calculate the drop with an accuracy of about one-half of one per cent without figuring the condenser effect.

Fig. 1 shows the vectorial relations in an a-c. circuit with resistance and self induction.

E	phase voltage at receiver end.
ϕ	phase angle at receiver end.
E_0	phase voltage at generator end.
ϕ_0	phase angle at generator end.
I	line current.
R	line resistance per phase.
X	line reactance per phase.

For the generator end the following formulæ are easily derived

$$E_0 = \sqrt{(E \cos \phi + IR)^2 + (E \sin \phi + IX)^2}$$

$$\cos \phi_0 = \frac{E \cos \phi + IR}{E_0}$$

Neglecting the capacity effect these formulæ are exact, but are rather inconvenient to work with on account of the tedious work of evaluating the equation.

If the impedance triangle (Fig. 2) is projected on the E-line, the projection will be AB.

$$AB = IR \cos \phi + IX \sin \phi$$

$E + AB$ are, however, very nearly equal to E_0. The difference BC depends on the angle α, and in figures is expressed

$$BC = E_0 (1 - \cos \alpha).$$

As α generally is very small the term $(1 - \cos \alpha)$ will nearly be equal to zero.

From the above it is readily seen that the error introduced by using the projection AB, instead of the real drop AC $(E_0 - E)$, will be of no practical importance as long as the load power-factor is lagging. The drop will then be expressed by the following formulæ, if the load power-factor is lagging (as is usually the case).

$\delta = 2\, I\, (R \cos \phi + X \sin \phi)$ for single-phase.

$\delta = \sqrt{3}\, I\, (R \cos \phi + X \sin \phi)$ for three-phase.

The above formulæ are very convenient to work with mathematically, but possess an additional advantage in that they can easily be expressed graphically. When the condenser effect is neglected the line drop may be expressed in volts per mile per ampere. The accompanying double-page chart is based on this principle.

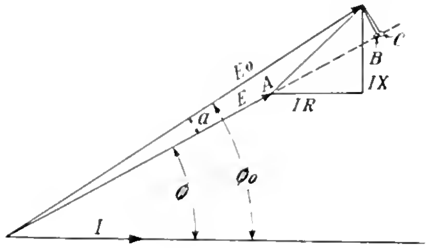
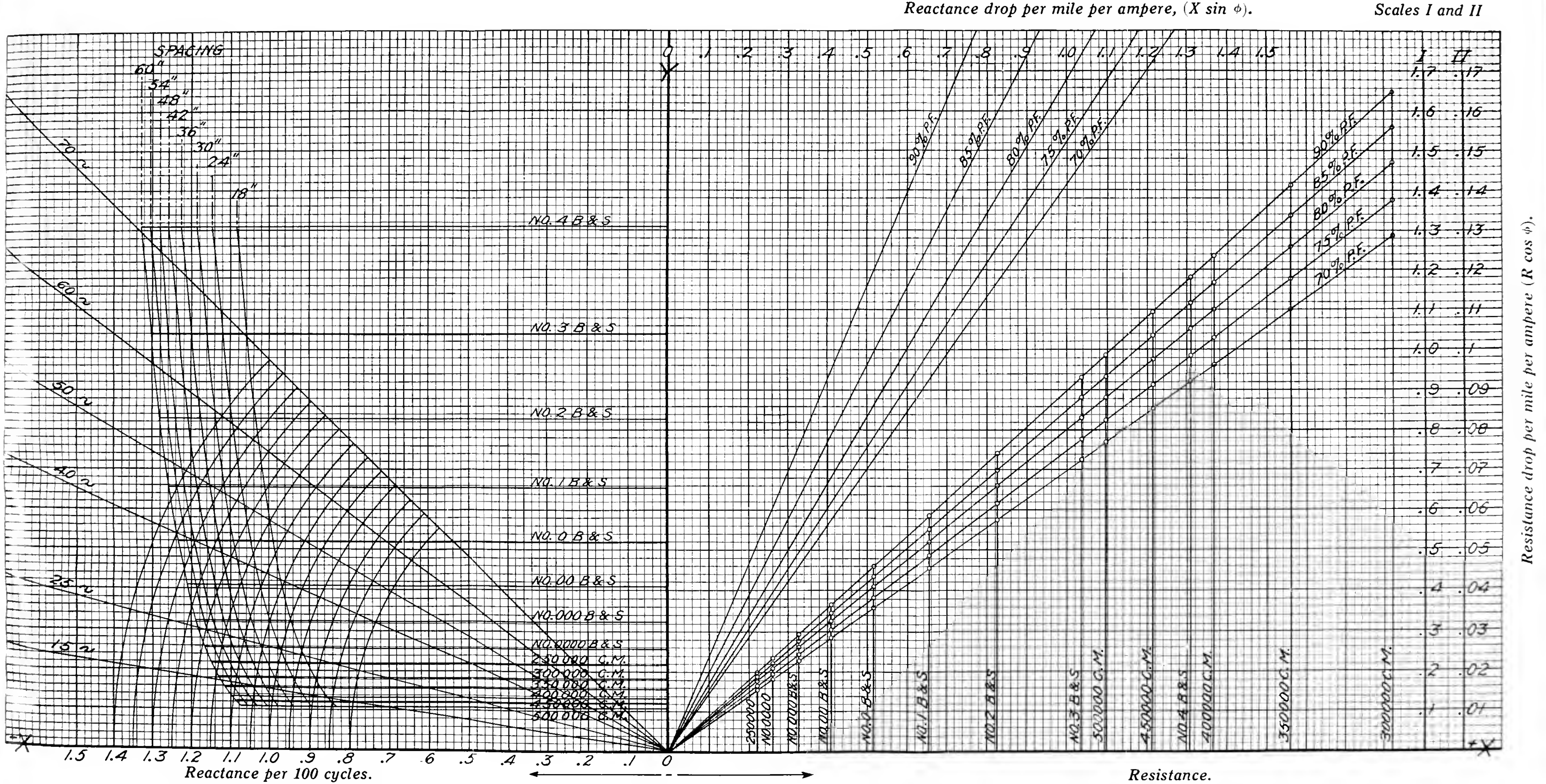


Fig. 2

The positive X-axis is assumed to represent the resistance values per mile of the conductor. The different sizes of wire are plotted along this axis in such a manner that their respective ordinates, intersecting the power-

CHART FOR THE GRAPHICAL CALCULATION OF SHORT TRANSMISSION LINE PROBLEMS

Supplement to Article "A Graphical Method for the Calculation of Short Transmission Lines" by Fredrik Waern, on page 460 of the General Electric Review, June, 1913.



$\delta = 2\ I(R \cos \phi + X \sin \phi)$ for Single-Phase.

$\delta = \sqrt{3}\ I(R \cos \phi + X \sin \phi)$ for Three-Phase.

For No. 4 B & S to 250,000 cir. mils. use Scale I.

For 300,000 cir. mils. to 500,000 cir. mils. use Scale II.

Neglecting the capacity eff
mulæ are exact, but are rathe

factor lines which are drawn at certain angles from the origin, are equal to the value of the resistance per mile multiplied by 0.80, 0.70, etc. ($\cos \phi$). These values are given to the right; column I to be used for sizes from No. 4 B.&S. to 250,000 cir. mils., and column II for sizes from 300,000 cir. mils. to 500,000 cir. mils. In this manner the first term in the formulæ ($R \cos \phi$) is obtained.

The different size conductors are plotted on the positive Y-axis in such a manner that a vertical projection on the negative X-axis of the point of intersection between the lines representing the size of wire and the spacing curves gives the reactance value corresponding to this size wire and the given spacing, for 100 cycles. To obtain the reactance at other frequencies, radial lines are drawn from the origin in the left-hand quadrant at such angles that the horizontal projection of the points of intersection between the circles (corresponding to the reactance at 100 cycles) and the frequency lines, upon the upper set of power-factor lines in the right-hand quadrant, indicate by their abscissæ values, as read upon the scale at the top of the right-hand quadrant, the reactance ($X \sin \phi$) at that desired frequency.

The reduced reactance and resistance values added together give the drop per mile per ampere, according to the previous formula.

The following example will clearly illustrate the use of the chart:

Three-phase power to be delivered, kw.	4300.
E.m.f. at receiver, volts	30,000.
Distance of transmission, miles	27.
Spacing of wires, inches	24.
Frequency, cycles	60.
Power-factor of load, per cent	80.
Size of wire, B.&S.	No. 0.

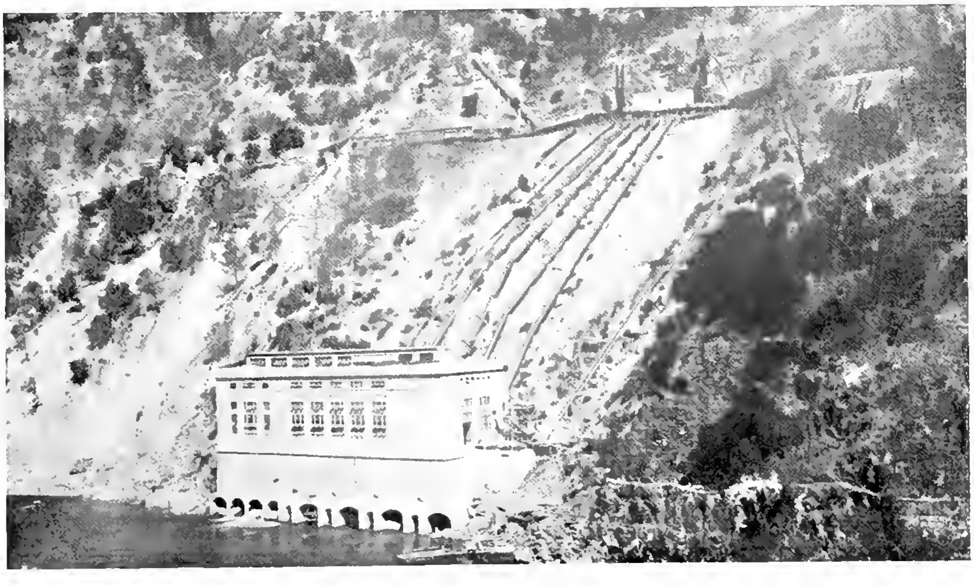
$$\text{Line current} = \frac{4300 \times 1000}{30000 \times \sqrt{3} \times 0.80} = 103.5 \text{ amp.}$$

Take the intersection between the No. 0 vertical line in the right-hand quadrant and the 80 per cent power-factor line. The value will be 0.410. Take the intersection between the No. 0 horizontal line in the left-hand quadrant and the 24-inch spacing curve. Go down vertically to the negative X-axis; follow on a circular path to the 60-cycle line; run horizontally over to the right-hand quadrant, and take the intersection with the upper 80 per cent reactance power-factor line. A value of 0.375 is obtained. The drop per mile per ampere will then be 0.410 plus 0.375 = 0.785 volts.

$$\text{Total drop} = \sqrt{3} \times 103.5 \times 27 \times 0.785 = 3800 \text{ v.}$$

$$\text{Regulation} = \frac{30000 + 3800}{300000} = 11.3 \text{ per cent.}$$

The line loss is calculated in the usual way by means of the resistance drop. The chart cannot, of course, be used for very long lines and higher voltages, but gives good results for short ones. It is especially convenient when matters call for an investigation about different spacings and frequencies. It likewise gives good service in checking calculations figured out after the more exact formulæ. If the drop in the above example is calculated by exact formulæ, it will be found to be 3840 volts, which shows that the accuracy of the chart is sufficient for practical purposes.



FROM THE CONSULTING ENGINEERING DEPARTMENT OF THE GENERAL ELECTRIC COMPANY

Varying Speed Spinning Frame Motors

A very interesting series of comparative tests of two types of varying speed single-phase commutator motors, designed for the operation of spinning frames in mill work, has just been concluded by the Consulting Engineering Department; and the motors are being installed in a mill to give them a comparative endurance and operation test before selecting the preferable type.

Revision of A.I.E.E. Standardization Rules

The enormous mass of material brought forward by the discussion of the papers read before the Mid-Winter Standardization Convention of the Institute, has reached the sub-committee on revision; and energetic work is being done to put all this material into useful shape and draft the new rules for submission to the Board of Directors at an early date.

Use of the Noble Gases in the Electrical Industry

A study of the noble gases argon, neon, helium is being made by the laboratories of the Consulting Engineering Department to determine their usefulness for industrial electrical engineering applications. It is probable that their chemical inertness and their low electrical disruptive strength may secure for these noble gases some important uses.

District Engineers at Pittsfield

Reference has already been made in these columns to the many lines of study followed by the Consulting Department at Schenectady and the Transformer Department at Pittsfield which seem to be lying in parallel directions. The engineers of the two organizations are continually in conference, and this team work always makes for real progress. The latest notable instance of this was furnished on the occasion of the meeting in Pittsfield of the District Engineers of the Company on April 30th and May 1st. Dr. Steinmetz delivered a remarkable address on Transformers, in which he clearly depicted the nature of some of the problems which have been forced upon the designers by the progress which the industry and they themselves have of late been making. The address was followed by a deeply interesting discussion, in which head office engineers, district engineers, and transformer designers all participated. Of special interest was the reference made by Mr. Moody, the Engineer of the Transformer Department, to the enormous production of 100,000 volt transformers which is now being handled—a reflection of the development which is being made in the central station business at large.

NOTES ON LIGHTNING ARRESTER DESIGN
PART II

By Dr. Charles P. Steinmetz

2. *Maximum permissible discharge resistance.*

Between the voltage e of a line disturbance, as electric wave or impulse, and its current i, the relation exists:

$$\frac{e}{i} = r_0$$

where:

$$r_0 = \sqrt{\frac{L}{C}}$$

is the "surge resistance," which in overhead lines usually is between 300 and 600 ohms.

If e_0 is the normal operating voltage, and p = safety factor of insulation of a transmission line against transient voltages, pe_0 is the transient voltage at which the line insulation fails. In well insulated modern transmission lines the transient safety factor p usually is from 4 to 6.

The maximum transient voltage, which can send a discharge along a transmission line, then would be:

$$e = (p-1)e_0$$

as any higher transient voltage, when adding itself to the normal line voltage, would break down the line insulation and logically discharge to ground, a not uncommon occurrence with lightning strokes at or near the line.

The maximum discharge current of a line, which the lightning arresters have to care for, thus is:

$$i_1 = \frac{(p-1)e_0}{r_0}$$

With n lines in multiple, obviously n times this current may appear as a maximum.

With $r_0 = 400$, $p = 5$, in a 60,000 volt line, that is, a normal voltage between line and ground, of $e_0 = \frac{60,000}{\sqrt{3}} = 34,000$, this gives 340 amperes.

If then r = resistance of the discharge path of the lightning arrester, the potential drop over this resistance during a discharge would be: $e_1 = ri_1$, and this then is the maximum transient voltage which may appear on the stations during a discharge of the lightning arresters.

To afford effective over-voltage protection by a lightning arrester, its discharge resistance r must be sufficiently low to bring the potential drop $e_1 + e_0$ below the safe margin of insulation strength of the protected apparatus.

Lightning arresters are designed to discharge at a certain over-voltage above the normal. This must be sufficiently low to be well within the disruptive strength of the protected apparatus, but must be high enough not to cause a discharge at every temporary rise of the normal line voltage—as occurs at a momentary decrease of load, etc. The discharge voltage of the lightning arrester is usually chosen at 50 per cent above normal line voltage, that is, at $e_2 = 1.5\ e_0$.

Obviously then, no material advantage exists in bringing the potential drop in the lightning arrester, e_1, that is, the voltage which exists during the discharge, below the voltage e_2, required to start the discharge over the arrester, since the voltage at the station has to rise anyway to e_2. It rather is an advantage to have the maximum potential drop e_1—which occurs at the beginning of the discharge—fairly close to the voltage e_2 appearing before the discharge, so as to reduce the shock of the sudden relief of over-voltage at the beginning of the discharge—which may produce high frequency.

Thus, $e_1 + e_0$ is limited to a maximum equal to $e_2 = 1.5\ e_0$, and this gives:

$$e_1 = .5\ e_0$$

or, as $e_1 = ri_1$, $i_1 = \frac{(p-1)\ e_0}{r_0}$;

$$r = \frac{.5\ r_0}{p-1}$$

as the maximum permissible resistance in the discharge path of the lightning arrester. In the above instance of a 60,000 voltage single transmission line, with surge resistance $r_0 = 400$, and safety factor $p = 5$, this gives as the maximum permissible lightning arrester resistance:

$$r = 50 \text{ ohms.}$$

QUESTION AND ANSWER SECTION

The Q. and A. Section has been started with the sole object of increasing the practical usefulness of the REVIEW; and in order that it may be made of real value, we invite correspondence from any of our readers who are looking for information on any technical matter in the field covered by this magazine, and which they think we can furnish.

Where possible the answers to such inquiries will be the work of this office; where desirable we shall obtain our authority from that engineering or commercial party in the General Electric Company's organization best fitted for handling the particular subject. We hope our readers will not hesitate to avail themselves of the expert engineering opinion which should be made available through this section of the REVIEW. Information on matters of general importance and interest will be published here; questions of interest solely to the querist will be handled by mail.

Sketches should accompany questions in all cases where this is necessary to give us complete and accurate information on the point at issue. Scale drafts will be made up here from correspondent's rough pencil sketches. Questions must be accompanied with the name and address of the sender, although these will not necessarily be for publication, and should be addressed to the Editor, Q. and A. Section, GENERAL ELECTRIC REVIEW, Schenectady, N. Y.

MINE LIGHTING

(27) Can a 230-volt lighting system be safely operated in a mine, when using as a source of supply some 230-volt taps on the 4600/2300 volt, 25 kv-a. transformers, which are distributing power? Twelve of these transformers will be installed and will operate continuously 10 hours out of the 24. Is it advisable to cut out the whole system with a main oil switch?

Lighting installations are frequently laid out in this manner, and the arrangement seems advisable for the present case. The most serious disadvantage would be a fluctuation, to a more or less extent, of the brilliancy of the lamps, on account of the power loads connected thereto. In a mine this variation need not be troublesome, provided it is not too great.

Since the capacity of the power load is not mentioned, the additional heating caused by a lighting load cannot be predicted. The placing of a main cut-out switch at the mouth of the shaft is certainly to be recommended. This is a universally accepted scheme in all electrical installations.

E.C.S.

REACTANCE OF A TRANSMISSION LINE

(28) How can the reactance drop in a three-phase line be calculated if the wires are located in a plane and not at the vertices of an equilateral triangle?

In a problem of this nature commercial accuracy is usually sufficient. These requirements are fully complied with by using the ordinary method for obtaining the reactance of a transmission line which has its wires spaced equilaterally, with the following exception. The value which is used for the space between conductors must be the mean of the following dimensions: distance from first to second, second to third, and first to third. For instance, with the wires in a plane at 10 ft. spacing, the mean distance to be used is $\frac{10+10+20}{3} = 13.3$ ft.

This distance would then be used in the reactance formula.

A still closer approximation may be made by taking the reactance as $\frac{X_{10\text{ ft.}} + X_{10\text{ ft.}} + X_{20\text{ ft.}}}{3}$

These methods assume the usual transposition for balanced voltages, and such arrangements as would exist in practice.

F W P.

USE OF INDUCTIVE SHUNT IN D-C. MACHINE

(29) Why are reactance coils sometimes placed in series with the commutating field shunts of large direct-current machines?

The reason for placing a reactance coil in series with the resistance shunt which spans the commutating pole winding of many large direct current machines, particularly those generating 500 volts and over, is to enable the machine to better commutate a varying or fluctuating load. If a non-inductive shunt is placed across the commutating pole winding, the current through the coils for any constant load on the machine, will automatically assume the correct value for commutation. When, however, a load suddenly changes or fluctuates, the division of current between the commutating pole winding and its shunt (if non-inductive) is no longer such that an amount of current proportional to the load passes through the field during the change period. This is the result of the unequal reactance of the two circuits.

In order to avoid the trouble caused by this unequal reactance, a coil having a low resistance, large carrying capacity, and a reactance equal to or slightly greater than that of the field, is placed in series with the non-inductive shunt. By this means the same division of current will be obtained under a fluctuating as well as a constant load.

H.S.P.

TIME LIMIT RELAY WITH OIL SWITCH

(30) Does the addition of a time limit relay change the rupturing capacity of an oil switch?

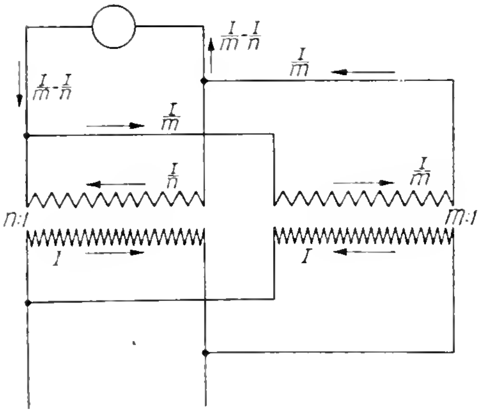
No. The addition of any relay can not change the actual rupturing capacity of an oil switch, since that is an inherent property of the switch itself. The effect which a relay does have, however, is to influence the selection of an oil switch, for the following reason. The continuous short circuit current, in an alternating current circuit, has a value much less than the instantaneous rush of current when the short circuit first occurs. By delaying the opening of the automatic switch until the short circuit current falls to its minimum value, the switch is called upon to perform less work and opens the circuit with greater ease than when it acts instantly. This allows its use on correspondingly larger circuits.

E.B.M.

TRANSFORMER EXCHANGE CURRENT

(31) Two single-phase transformers are connected in parallel, primary and secondary. A cross current of I exists between the windings which have a resistance of R. What is the watts loss due to this current? Are the voltages in phase?

The condition which would cause a cross-current to flow between the secondaries of the transformers is that the two machines are not of exactly the same ratio. If this is the case, then a circulating current of effective value I will flow through the secondary windings in series, and corresponding compensating currents $\frac{I}{n}$ and $\frac{I}{m}$ will flow in the primary windings, (n and m being the ratios of transformation). A current is supplied by the generator, which is the difference between $\frac{I}{m}$ and $\frac{I}{n}$. If each secondary



has a resistance R_2 and each primary a resistance R_1, then the loss due to the circulating current is $I^2\left(R_2+\frac{R_1}{n^2}\right)$ for one transformer, and $I^2\left(R_2+\frac{R_1}{m^2}\right)$ for the other transformer. If n and m are nearly alike, we may represent the equivalent resistance of each transformer as R. Then the total resistance loss for both transformers equals $2\ I^2R$. The voltages of the secondaries are in phase, although they are not of the same value, which latter fact is responsible for the unbalancing and causes the cross-current to flow to maintain equilibrium.

W.W.L.

OIL SWITCH ON DIRECT CURRENT

(32) Why is it not possible to make an oil switch for direct current as well as for alternating current?

The use of an oil switch on a direct current circuit is not impossible, except under certain conditions, but it is generally inadvisable. This will be better understood by keeping in mind the action by which an oil switch opens an alternating current circuit. As the contacts first separate an arc is established between them. At the zero point of the wave this arc is extinguished by the inflowing oil, but re-establishes itself when the potential in the reverse direction has risen to a sufficient value to break down the intervening oil film. This is repeated until the contacts move so far apart as to prevent a further breakdown of the intervening oil. If applied to opening a direct current circuit the switch would be severely handicapped, for the potential never falls to zero. Consequently, since the action gasifies the oil, it will maintain continuously a gas-filled pocket between the contacts. Thus, the dielectric effectiveness of the surrounding liquid oil is not brought into play and the arc will only be extinguished when the contacts have separated to a considerable distance. During this time they will probably have been considerably burned and a quantity of oil will have been carbonized. Thus it will be seen that opening a short-circuit would be indeed a very severe requirement to make of an oil switch; while, in contrast to this, it may be said that a properly designed air circuit-breaker will open any current which is not heavy enough to weld the contacts together before they can open.

Oil switches have been installed to operate on direct current circuits, where, on account of the danger due to an exposed arc in an inflammable atmosphere, any air break would be prohibited. In selecting an oil switch for these conditions, one of standard design would be chosen, but would be of sufficiently great capacity that it would ordinarily always be used below its alternating current rating.

E.C.S.

GROUNDING OF STREET LIGHTING CIRCUITS

(33) In the line construction of series lighting circuits, what special precautions, if any, are taken to guard against grounding of the lighting wires by trees near which it may be sometimes necessary to run them?

Practically the only precaution which can be taken to guard against this danger is the common-sense one of cutting away any tree branches which are at all likely to interfere with the safety of the line. The N.E.L.A. report on overhead line construction has a ruling on this matter, which seems to cover the question thoroughly. It specifies that any trimming which seems necessary must only be carried out with care and judgment, and under the immediate supervision of the superintendent, line foreman, or other responsible person. Before any trimming is done the consent of the owner of the tree should be obtained. Any opposition which he might show could usually be removed by the offer to employ a professional gardener for the purpose. Trees can generally best be trimmed in the fall and winter, when they are bare of leaves and less likely to show the effects of the shears; and when the operation has been performed the stubs should always be painted, both for their protection and to render them less unsightly. When lines must be carried through trees that cannot be trimmed, so as to give a clear passage for the wires, "tree wire" should be used. Sections of this approved wire are cut into the line and wound tightly with tape at each end. If there is any danger of limbs or large branches chafing the insulation when this tree wire is used, a wooden abrasion moulding is employed. Before being placed on the line the moulding is treated with one coat of P.&B. paint to increase its insulating qualities; and is attached at its ends to the wires, by three tight wraps of No. 12 copper wire which is wound around the moulding. The Report specifies that this moulding should never be used on weatherproof wire carrying over 600 volts.

D.S.M.

MAXIMUM OUTPUT OF D-C. MOTOR

(34) The maximum output of a direct current motor is said to be obtained when its load is such an amount as to reduce its speed to one-half normal. What is the proof of this?

To prove this it is necessary to run the motor separately excited. Friction and core loss may be neglected, since the independent variable is the speed, and these losses, although of considerable magnitude, vary but little with a change in speed. The only difference then between the input and the output is the I^2R of the armature.

Let

V = the applied voltage
E = counter e.m.f.
I = armature current at any time.

Then

Input $= IV$
Output $= IE$
Copper loss $= I^2R$
Output = input − copper loss

(1) $IE = IV - I^2R$

Setting the differential equal to zero

$$\frac{d\,(IE)}{dI} = V - 2IR = O$$

(2) $I = \frac{1}{2}\frac{V}{R}$

Dividing (1) by I, $E = V - IR$.
Substituting value of I from (2),

$$E = V - \frac{1}{2}\frac{V}{R}R = V - \frac{1}{2}V = \frac{1}{2}V.$$

Since E is proportional to the speed, and being equal to V at full speed, the motor runs at half speed while delivering maximum output.

Ref.—Dynamo Electric Machinery, S. P. Thompson, Vol. 1, 7th ed., page 800, "Theory of Motors."

E.C.S.

POWER-FACTOR CALCULATION

(35) Is there any method, and formula connected therewith, for finding the power-factor of a three-phase circuit, with a three-phase indicating wattmeter as the only instrument available?

The power-factor of a three-phase circuit can be easily and accurately obtained through the use of a polyphase indicating wattmeter, when supplemented by the curve shown in Fig. 1. To apply this curve, connect up the polyphase wattmeter in the customary manner, as shown in the diagram in Fig. 1. With first one potential coil open and then the other, take each nominal single-phase reading, making a note at the same time of the algebraic sign of the separate readings. This latter point is easily determined; if both measurements are positive, each separate reading will be up scale, while if one is negative, this one will read down scale. That point of the curve which then has for its abscissa a value equal to the ratio of the smaller reading to the greater will indicate by its ordinate the power-factor of the circuit. In using the curve, since the abscissæ scale is symmetrical about the center axis, care should be taken to use that side which corresponds to the algebraic signs as determined on the meter.

E.C.S.

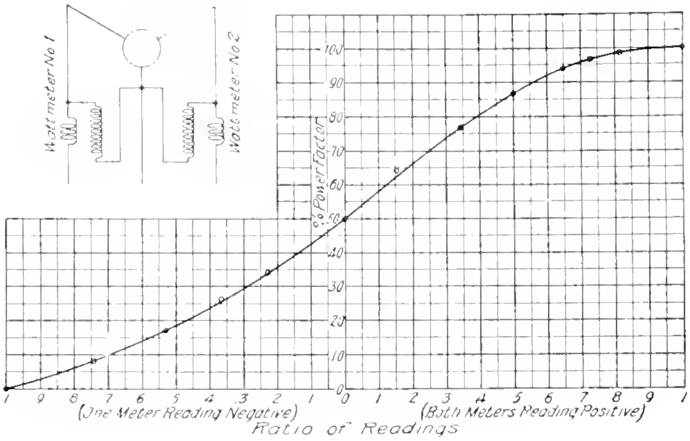


Fig. 1

BEAM INTENSITY OF LIGHT FROM A PARABOLIC REFLECTOR

(36) Is it strictly correct to specify the intensity of a beam of light from a parabolic reflector (such as a searchlight or automobile headlight) as so many candle-power?

This is a matter which has received considerable discussion among illuminating experts; and, while it is impossible to generalize, it may be said that in many cases the usage is quite permissible. If the rays from the reflector were parallel, as in the ideal case, candle-power could not apply on account of the failure of the law of inverse squares. Practically, however, at distances where the beam can be considered as a single cone of light, it is apparent that the section of the beam will vary proportionally in area with the square of the distance from the reflector; so that, neglecting absorption of the atmosphere, intensities at such distances will be inversely proportional to the square of the distances. In working at long range there is no reason why the beam should not be specified in candle-power, provided that it is properly defined so as to avoid confusion with the candle-power of the original light source. For example, it might be referred to as "beam candle-power" at a great distance. On occasion certain authorities have also specified the distance at which the measurement was made, so as to give an idea of the accuracy of the tests. If the beam be quite narrow, the maximum candle-power in the center of the beam is usually given. For wide-angle beams, such as are sometimes used for headlights, it is well to indicate the distribution by means of a curve, which may be supplemented by the mean value.

Ref.—G. H. Stickney in December, 1912, REVIEW "The use of tungsten lamps with parabolic reflectors"; F. Nerz in "Searchlights, their theory and application"; and Prof. W. S. Franklin, in the last edition of his "Electric Lighting."

D.S.M.

COMBINED POWER-FACTORS

(37) A power system carrying 2500 kw. has a power-factor of 85 per cent. It is desired to add an 800 kw. synchronous motor at the distributing end. What will be the system power-factor when the synchronous motor carries full load at unity power-factor? What will be the system power-factor when the synchronous motor carries 560 kw. mechanical load and 560 kv-a. leading current?

The diagram shown in Fig. 1, constructed according to the same methods as employed in the solution of Question 8, will be found to fit the first part of this question. Therein, *BA* represents the kv-a. value of 2500 kw. at 85 per cent power-factor, *AD* the 800 kw. mechanical load of the synchronous motor, and *DBC* the angle whose cosine is the resultant power-factor of the whole circuit.

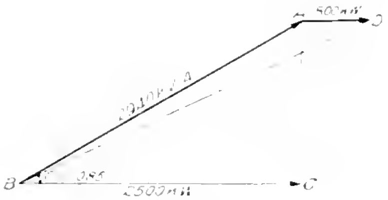


Fig. 1

Fig. 2

This will be found to be 90.5 per cent. According to the same conventions, Fig. 2 will fit the second part of this problem. *BA* remains as before, but the synchronous motor load *AD* is now made up of two components, viz., *AE* 560 kv-a. leading load and *ED* 560 kw. mechanical load. The power-factor of the circuit under these conditions is equal to the cosine of the angle *DBC*, which is [illegible]5.5 per cent. E.C.S.

FIRES IN ELECTRICAL MACHINES

(38) What are the most efficient means of checking fires in large electrical machines?

Fires in electrical machines usually originate from one of two causes, either the breakdown of insulation due to an excess voltage, or the overheating on account of continued overload. The oxygen to maintain the combustion of a fire generated by the first method is principally obtained from the air. This is because the burning insulation is exposed, owing to the rending action of the short circuit arc.

If a machine has been under a continuous overload, to such an extent that the temperature of that portion of the insulation in immediate contact with the conductor is raised to its ignition point, then the insulation will burn outward from the conductor toward the surface of the winding. Provided the overheating is discovered and the load removed from the machine before the combustion reaches the surface, practically nothing further can be done to hasten the extinguishing of the fire, since it is not exposed. For that very reason, it will shortly be smothered on account of the lack of sufficient oxygen to support combustion. In case the fire has reached the surface of the insulation from within, it will then be exposed and will permit the same treatment as a fire generated by an arc.

The load on any machine which has caught fire should be instantly removed, and those machines which rotate should be stopped as soon as possible to eliminate the fanning action of the ventilating air. Open machines, in case of a severe fire, may be treated with sand or some specially-prepared fire-extinguishing chemical. When forced ventilation is used, as in turbo-generators and air-blast transformers, the air supply should be shut off at the earliest moment. The oil of oil-cooled transformers will produce a dangerous conflagration, if a large quantity of it has been heated to its ignition point; and consequently all large oil-cooled transformers should be furnished at the base with a quick opening valve, whereby the oil in the case may be quickly drawn off into the sewer or a storage tank. The fire in the winding may then be smothered out by tightly closing all openings into the case which may, in addition, if the fire prove stubborn, be filled with carbon dioxide gas.

A.H.K.

ARRESTER CHARGING RESISTANCES

(39) What are the purpose and action of carbon resistance rods as applied to aluminum lightning arresters?

Resistance rods enable an aluminum arrester to be more easily maintained in a normal condition and improve its operation. Aluminum arresters should be regularly charged to render their best service. When this is not done, or when the films for other reasons, such as high room temperature or overheating from long continued discharge, have become partially dissolved, the arrester will be subjected momentarily to a heavy rush of charging current, if it is charged without this resistance. When the cells are charged regularly, the resistance also acts as an electric buffer; and, by limiting the arc at the make and break of the contacts, it will, if of the critical resistance value, modify the current wave and actually reduce the value of the charging current. The rods also permit an arrester which has been out of service for some time, to be safely charged at line potential. These facts should, of course, lengthen the useful life of both electrolyte and cones.

In the normal operation of the arrester the resistance rods also perform a valuable service. The arrester is connected to the line by two gaps of different settings, the smaller one of which is connected in series with the resistance. An increase of voltage on the line, if only moderate, breaks down the smaller gap, and the discharge current passes through the resistance and arrester. If the rise is of a greater amount the main gap arcs over. In either case, however, the final arc will be extinguished at the smaller gap, and consequently surges which might otherwise follow are dampened out by this resistance. V.E.G.

BOOK NOTICES

A HANDBOOK OF INCANDESCENT LAMP ILLUMINATION

Published by the General Electric Company

150 pages, $2\frac{1}{2}$ in. by $5\frac{1}{2}$ in. Illustrated Price, 50 cents

This book has been off the press for some months now, and we regret that we have not had an earlier opportunity of making some notice of it in the REVIEW. It has been prepared by the publication staff of the Edison Lamp Works at Harrison, N. J.; and, apart from its actual value, which, by the way, is very high, is of great interest in that it represents a new departure for the lamp manufacturer. Primarily it is a textbook, but is the kind of a textbook which only a manufacturer could prepare, as he alone possesses the data to fill it. It is, of course, no uncommon thing to see a book on some class of electrical apparatus purporting to be written by a college professor, which is in reality little more than a collection of catalogues from various manufacturers, credit being sometimes given and sometimes withheld as to the source from which the data were derived. In the present instance we have the manufacturer himself taking charge of the preparation and publication of the data. The principle is a good one, as the factory can hand out its own information in its own way; while the reader can always see how much is advertising and how much isn't, and can profit accordingly. This lamp book combines the purely technical features with the frankly advertising features; but the wealth of information to be found in the former amply justifies the fifty-cent published price at which the book is issued.

Physically it consists of nearly 150 pages, fully illustrated. It is bound in an exceedingly neat leather cover; and, as the stock used is of very light weight, it is an easy matter to carry the handbook in one's vest pocket. We have been doing this, and our vest pockets are of normal size. The page dimensions are $2\frac{1}{2}$ in. by $5\frac{1}{2}$ in., so that the "handbook" claim is no bluff. The press work is excellent throughout; and we imagine that the reader will require no knowledge at all of the making of books to appreciate the skill with which the pages have been laid out, and the line cuts made and arranged. A particular genius is required for this kind of work, and the editor of the handbook seems to be an artist at the job. He is to be complimented as highly for the practical value of his material. Much of the information has not been published before; and certainly no book on incandescent lamps which we have seen has contained so much practical workaday information as this. The earlier parts of the book in particular seem very ably handled, and contain exactly the data which one would want to have in a pocketbook. The pages dealing with photometry, candle-power relations, illumination calculations, reflectors, intensities for various services, and the lighting of trains, signs, streets and mills are done as well as they could possibly be done, and with a due regard for completeness, conciseness, order and relevancy. The publication should be invaluable to the lamp salesman, illuminating engineer, and contractor; and any member of these fraternities who has not got a copy should hurry up and get one.

The preface makes a very frank invitation for criticism. "As this is the first publication of this nature, it is to be expected that some sections will contain superfluous matter, while others will not be covered thoroughly enough to meet the requirements as intended. Suggestions, criticisms and corrections from those who find use for this book are earnestly solicited, as such will help materially in the preparation of future editions." The most obvious criticism that one can make is that the arrangement of contents leaves something to be desired. In any case it should be an inviolable rule that the contents page, immediately following the preface, should contain the page numbers. In the present case the section headings and subheadings are given on this page, and it is therefore difficult to see why the list was not keyed with the page numbers. There is an index at the end, it is true; but this is an index to subjects and not to chapters. The order in which the earlier sections are arranged and the grouping of the subsections seem for the most part logical and correct; but the same remark does not apply to the pages giving "general information on incandescent lamps." We think an improvement would result here if the information on such purely general subjects as history, energy losses in filaments, prevention of static effects, visual acuity, luminescence, and so on were grouped quite distinctly from such sections as those dealing specifically with Mazda lamps, which are purely manufacturer's statements and relate to such things as factory sizes, average performance, and instructions for ordering. If the contents page were numbered the distinction would not be so important; but, as it stands, this section seems to have been put together with little regard for the subject matter of the subsections. It may even be doubted whether many of these paragraphs (such as those on acuity and luminescence) come within the province of a handbook at all. They should certainly be grouped entirely apart from concrete data on lamps and cost of lighting.

Regarding the section on transformers, we imagine that anyone who is sufficiently well acquainted with electrical matters to understand the diagrams showing delta-delta and delta-Y connections will need no introductory paragraph telling him what a transformer is; and we would suggest that all this introduction, including the formulæ for hysteresis and eddy current losses, could be omitted. In the section on distributing systems, we think the mercury arc rectifier looks as little as though it were dragged in. The paragraphs explain exactly how the apparatus works, but no mention is made of its application to incandescent lighting, and the reader would be left somewhat in the dark on this point. We will not be at all positive as to the reasons why it is in the book, since we realize that when you are dealing with $2\frac{1}{2}$ inches by $5\frac{1}{2}$ you cannot always obtain the sequence which you desire, and, on occasion, you may have to resort to filling. We think it would be a good plan if, in future editions, a little space could be found in this section for other instruments besides the watthour meter. This is an important piece of apparatus; but brief mention might be made of voltmeters, ammeters, maximum demand indicators, and so on, if only in glossary form.

There are a few other trivial matters which might be mentioned, but these will probably already have received notice. The principal suggestion which we make, and which we proffer with the best intentions in the world, in the hope that possibly it may be of some small assistance, is that a certain amount of regrouping be done, and that a better use be made of the many different sizes of capital letters which are at the printer's disposal. Thus all the headings to the main sections should be set in capitals of one and the same size; while the headings of all subsections in these main sections should be set in a smaller type, consistent for all such subsections. At present this rule, which is a most important one, is not followed.

The very existence of the book is of course a fine advertisement for the Mazda lamp, and there is little necessity for any direct eulogy within the volume itself. The reader will probably detect the greatest advertising in places where the publisher least expects it. Thus he may read of a steel reflector with a porcelain enamel finish that "*the enamelling is so heavy and the metal so rigid that there is no liability of the porcelain being chipped off if hit accidentally by the operative.*" Now that is real advertising—not so much for the reflector as for the lamp. Why say anything about strength of the filament when you have said a thing like that? One pictures a light-hearted buck-laborer swinging a crow-bar round his head, and playing the Westminster chimes on a row of reflectors. One wonders if he is going to chip off the porcelain. One doesn't even think of the wretched filament inside the lamp. Do you need any stronger encomium on the filament?

D.S.M.

THE ART OF ILLUMINATION

Second Edition, Fully Revised

By Louis Bell, Ph. D.

McGraw-Hill Book Co.

353 Pages | **170 Illustrations** | **$2.50 net**

The second edition of this book which has recently appeared brings forth two facts when comparing it with the old edition published ten years ago. The first is that great headway has been made during the last decade in the development of illumination as a science. Units have been more accurately defined, standards of light and photometry have been changed and revised, methods of measurement have been greatly developed, the idea of luminous flux has been extended, materials of illumination have increased in number and their quality improved, new and novel shades and reflectors have been produced, and great progress in methods of exterior and interior illumination has been made. The other fact is that the general principles of the production and utilization of light have remained substantially the same. This is brought forcibly to the reader's attention when he sees that it has not been necessary to revise a large portion of the text. The book has been changed in many respects It has been entirely reset and corresponds in size and appearance to an extensive series of texts which the publishers now have on the market. The general arrangement is the same, except that the chapter on Standards of Light and Photometry has been shifted farther forward in the book to a place where it more logically belongs. This chapter together with that on Exterior Illumination have been entirely rewritten. The Index has been redrafted and the number of subjects entered about doubled A great deal of the tabulated information and the precise data, such as intrinsic brilliancies, co-efficients of reflection and diffusion, etc., have been revised and amplified. Much material has been added on gas mantles, metallized and metallic filaments, flame and luminous arcs, shades and reflectors, lighting large interiors, indirect lighting, etc. Part of the chapter on Decorative and Scenic Illumination has been rewritten; while much of the discussion on stage lighting and descriptive matter on the Nernst lamp, projectors and search lights has been omitted. The author seems to have modified his views on the indirect system of lighting, and does not seem to be as sanguine of its possibilities now as formerly. The place of this book in the literature of illumination is of course well established, and this second edition further secures its position. It has been carefully edited and is practically free from errors. However, Figs. 72 and 85 are inverted, which only goes to show how easily large mistakes may be overlooked.

C.M.D.

SYNCHRONOUS MOTORS AND CONVERTERS

By André E. Blondel, Translated from the French by C. O. Mailloux

295 Pages | **McGraw-Hill Book Co.** | **$3.00 Net**

A book dealing with the properties of the synchronous motor from a theoretical standpoint has been a long felt need. While several good works on the subject have been published in the French and German languages, this is the first work in English which covers the matter in a systematic and comprehensive way. The book should, therefore, be of great service to designing engineers, teachers and others who are desirous of making a more extensive study of the subject. Its publication is also a very timely one in view of the rapid increase which is now taking place in the general use of synchronous motors. Improved methods in the design have resulted in very stable and reliable operation; while the possibilities of these machines for improving the power-factor of power systems is now fully recognized.

The book is divided into three parts. Part I, which covers about 200 of the 300 pages, relates entirely to synchronous motors and is a translation of the author's French work, supplemented with a chapter by Prof. C. A. Adams, of Harvard University. Part II relates to synchronous converters: while Part III contains reprints of the two papers presented by Prof. Blondel at the St. Louis Electrical Congress in 1904, relating to the application of his "two-reaction" method of alternators.

The chapters on the synchronous motor begin with a treatise on the general principles of both the single-phase and polyphase type, the fundamental equations of the motor being clearly worked out. Several methods of graphical representations of the general operating conditions are shown, and a detailed study is made of the operation under normal load with both constant and varying excitation. A very valuable part of the book is the section dealing with the influence of synchronous motors on the general operation of an alternating current electrical transmission or distribution system. A number of numerical examples are given, showing the possibilities of using synchronous motors to compensate for the lagging inductive currents of asynchronous motors, transformers, etc., thus raising the power-factor of the system and improving the regulation. One chapter is devoted entirely to the actual operation of synchronous motors, the problem of hunting and methods of damping being dealt with.

The chapters on synchronous converters deal first with general diagrams which are deduced from the diagram for synchronous motors. The determination of the field excitation, involving the characteristic features of the converter, is then taken up; after which the stability of operation and the operation of synchronous converters in parallel is dealt with. The subject is concluded with a chapter by Prof Adams relating to voltage ratio, special reference being made to the split-pole or regulating pole-converter.

E.A.L.

GENERAL ELECTRIC REVIEW

Published Monthly by the
GENERAL ELECTRIC COMPANY'S PUBLICATION BUREAU

Manager, M. P. RICE   Editor, D. S. MARTIN   Associate Editor, B. M. EOFF   Assistant Editor, E. C. SANDERS

Subscription Rates: United States and Mexico, $2.00 per year; Canada, $2.25 per year. Foreign, $2.50 a year, payable in advance. Remit by post-office or express money orders, bank checks or drafts, made payable to the *General Electric Review*, Schenectady, N. Y.

Entered as second-class matter, March 26, 1912, at the post office at Schenectady, N. Y., under the Act of March 3, 1879.

VOL. XVI., No. 7 JULY, 1913

CONTENTS

HYDRAULIC MINING OF PHOSPHATE ROCK

Farmers have taken up the use of manufactured fertilizers to such an extent that the output of the United States in this direction has more than doubled in the last five years. The production of phosphate rock, which is extensively used as a base for acid phosphate fertilizer, was more than 3,050,000 tons in 1911, 80%, of which came from Florida. Where a sufficiency of cheap electric power is available, hydraulic mining is used, in which process water, at a pressure of 100 to 150 lbs., is discharged at the face of the quarry from nozzles or "guns". The mined rock is washed into the sump-hole, dredged, pumped to the washing and drying houses, and stored for shipment to the fertilizer factory. The above cut, which accompanies the article by Mr. C. B. Pentecost (page 529) on "Hydraulic Mining of Phosphate Rock," shows one of the quarries of the Prairie Pebble Phosphate Company, Mulberry, Fla. The gun can here be seen discharging at the face of the rock.

GENERAL ELECTRIC REVIEW

DEFINING THE FIELD OF THE ELECTRIC VEHICLE

In next month's REVIEW we shall publish a very interesting article by Mr. P. D. Wagoner, President of the General Vehicle Company, on the subject of motor truck adaptability and its relationship to operating efficiency.

The fact that a firm which holds such a commanding position as manufacturers of electric trucks has now decided to enter the gasolene-truck field is indicative of the broader attitude which has lately been taken up by the electrical interests in this matter. There was a time, not so long ago, when a man connected with the electric vehicle industry was considered a renegade if he were not prepared to extol the electric truck to the skies for any and every kind of road transportation service, and to deny any right of the gasolene vehicle to a place in the sun. Some are even now persisting in this policy. It is not a wise one; as it is only necessary to resort to operating data to show that, for some of the longer hauls with infrequent stops, the gasolene can put it all over the electric; and the electric man were wiser to confine his arguments to the classes of strictly urban business in which his product is known to be the best, and indeed the only, vehicle to use if economy is the desideratum.

If his own judgment does not lead him to anticipate this requirement of the market, it is safe to say that the producer of the electric vehicle will sooner or later be compelled by the stress of the commercial demand to broaden his outlook on trucking matters, to shed his prejudices, and to concede to the gasolene vehicle some of the virtues which the buying public have apparently found it to possess. If it is today realized that there are certain limitations to the scope of usefulness of the electric truck, it is equally patent that, within these limits, it can realize a degree of economy and efficiency with which no other vehicle can hope to compare; and the path of wisdom would therefore certainly seem to lie in a frank recognition of the fields of application of these two types of self-propelled truck, to the end that, with an intelligent use of the known facts in regard to the operating characteristics of each, the old-time four-legged friend of man may, with one final flourish of Jehu's whip, be speedily driven from the streets of our cities.

The sales of electrics are meanwhile growing at a very satisfactory rate, and are providing the central stations with some excellent off-peak load. There are now over 30,000* electric vehicles—for pleasure and business—in service, 10,000 of these having been built in 1912. An output of 15,000 is predicted for 1913; and by the end of 1915 there will very likely be nearly 100,000 of these machines on the streets and roads of the United States. Assuming that the average consumption of energy is of the order of five or six thousand kilowatt-hours a year, this will mean that the aggregate charging load will then be around half-a-billion kilowatt-hours a year, at least 90 per cent of which may be said to come off the peak. The effects of this accretion of load and revenue will certainly be felt in quarters some distance removed from Long Island City and the other vehicle centers, and will redound to the very considerable advantage of the whole industry.

In most foreign countries, meanwhile, very little is being done to popularize this application of electric service, mainly owing to the circumstance that it has not yet been thoroughly realized abroad that this is, first and foremost, a speculation in which united effort is imperative. The spirit which gave birth to the Electric Vehicle Association of America nationally, and to such bodies as the Electric Motor Car Club of Boston locally, is the spirit which recognizes a good thing when it sees it, which makes light of any obstacles which stand in the way of complete possession, and which realizes clearly that all the parties which stand to gain from final possession are jointly interested in smoothing out the incidental troubles, and may be depended on to provide their meed of assistance.

* This figure is taken from the Presidential Address of Mr. Arthur Williams before the Electric Vehicle Association of America. We therefore believe it to be correct, although of late many higher values have been confidently assigned to the number of electrics now in service.

THE PERSONAL EQUATION*

By Fred. M. Kimball

Manager Small Motor Department, General Electric Company

Personal equation, in its non-technical and broader sense, is defined by the author as that peculiar characteristic of an individual which causes him to act otherwise than the normal average man would be expected to act under given conditions. It is the element in his personality which determines to a great extent his qualifications, good or bad, as a salesman or commercial engineer. A favorable personal equation, exercising a prepossessing influence, is marked by health, optimism, cheerfulness and activity, and is present to the best advantage only in a perfectly sound body. Unfavorable or negative personal equation, on the other hand, is overcast by disease, moroseness, and sluggishness of mind and body. It need scarcely be added that anyone striving for success in life, whether in commercial enterprises or otherwise, should seek by every means to preserve robust health and place himself amongst agreeable surroundings.—Editor.

There is no more important factor incident to the business of buying and selling than Personal Equation. Generally speaking, personal equation, in its technical sense, may be defined as expressing the time relation between a person's perception of and response to an observed occurrence and the actual occurrence itself.

The technical personal equation of a man in normal health and possessed of normal faculties of perception and activity may be determined with reasonable accuracy and rated as a constant of fairly definite value. For illustration: An observer is placed in a darkened room into which a single beam of light penetrates. In front of the aperture through which this beam of light enters swings a pendulum, so supported and adjusted as to completely cut off the beam when at rest or in "zero" position. The observer is required to note the exact instant at which the entering beam of light is interrupted and restored by the swing of the pendulum. A chronograph is arranged to automatically record the exact time of eclipse and restoration of the light by means of an electrically actuated pen, which traces a line on the chronograph's cylinder. The instrument is also provided with another similar pen, the motion of which is controlled by a telegraph key, that will trace a second line closely parallel to the first. The observer is requested to depress the key at the instant that the light is cut off by the swinging pendulum, and to press it again at the instant that the light is restored. As the first pen records with mathematical accuracy the exact instant at which the light really is cut off and restored, and as the second pen records on a closely parallel line the exact instant when the observer signals the eclipse and restoration of the light, very accurate comparison of the two records is possible.

The perceptive faculty of some observers is anticipatory, and even if the motor impulse necessary to make the record instantly follows the sensatory impulse of vision, their records of observed eclipse and restoration of the beam of light will indicate anticipation of the actual occurrence, to a greater or less extent, and the time value of this anticipation will be shown and can be directly determined by comparing the parallel record curves on the cylinder of the chronograph.

The perceptive sense of other observers is retarded, and their records of observed occurrence will lag behind the record of the true time of occurrence, as recorded. Again, when there is sensibly no anticipation or retardation in perception, the time which elapses between the transmittal of perception of the observed eclipse or restoration of the light to the observer's brain, and the stimulation into activity of his motor nerves and the muscles thereby controlled, which depress the key, varies materially in different individuals.

In many other ways may the perceptive, nervous or muscular functions of the individual be affected and more or less imperfectly co-ordinated. Variations in normal perception and mental and muscular activity similar to the above constitute the class of phenomena ordinarily alluded to in technical language as the "personal equation."

The term "personal equation" when applied in its commercial or business sense has a much wider and more intricate meaning than when applied in its strictly technical sense. In its less restricted significance, personal equation may be defined as that peculiar characteristic of any individual which causes him to think or act otherwise than the average normal man would be expected to think or act under given conditions. In attempting to analyze this characteristic, we soon discover that the perturbing

* This is the third [illegible] prepared for the Review which [illegible] commercial end of business. The first, by Mr. [illegible] "Fundamental Principles of Commercial Engineering," [illegible] in the April issue, and the second [illegible] on "The Discovery and Development of New Business," appeared in the May number. The fourth article [illegible]

causes which lead to thought or action other than that thought or action which we might ordinarily expect in the normal individual are very much involved and complicated. Furthermore, they may arise from an almost innumerable series of internal, extraneous or inter-relating conditions of mind or body. Thus, the personal equation in its commercial sense may vary very widely from day to day or from hour to hour, thereby rendering it well nigh impossible to determine its constant in a given individual.

The art of instantly detecting, accurately analyzing and determining the character and importance of the personal equation of buyer or seller constitutes one of the most valuable and powerful instruments of bargaining which a buyer or seller can possess.

The "plus" personal equation is engendered by and tinged with health, optimism, cheerfulness, frankness and activity. The "minus" personal equation similarly reflects and is shaded by disease, doubt, depression of spirit, equivocation and sluggishness of mind and body.

The personal equation of some purchasers manifests itself by involuntarily and unconsciously dominating their consideration of a prospective bargain to an extent that no matter how fairly, completely or carefully a proposition is explained and demonstrated to them, they feel that they are being deceived, over-reached or tricked, and to deal with such people, as every salesman knows, is most unsatisfactory and difficult. The seller who can distinguish and identify the influence of a personal equation like that alluded to is forewarned, and, therefore, forearmed; can select his line of attack and the arguments he must use and the means which should be employed both in preliminary and final negotiations to combat and offset the effect of the peculiarity of the buyer referred to.

On the contrary, the personal equation of some salesmen is such that, irrespective of how much care they may exercise in presenting a proposition to a prospective customer fairly and clearly, they will almost, if not quite, unconsciously distort or modify the facts and misled the customer. In the same way as the seller may learn to detect and identify the characteristics of "personal equation" in the buyer, so the purchaser may learn to be on his guard, frame his inquiries, and conduct his negotiations in such manner as to extract the whole truth from the seller and leave no part of the transaction open to misunderstanding.

So far as the welfare or activities of humanity are directly concerned, the most potent of all forces is that of human effort. The great forces of Nature, the boundless and varied resources of the earth, are inert and valueless until they have been subjugated or developed to the use of man. The mind of man is the only known power which, acting through the intermediary of his physical organization, can put into effect the means of subjugating the forces of Nature to his service or developing the material products of the earth to his use.

It has well been said that the greatest study of mankind is man, and the mind of man is the seat of all his potential power. Of what surpassing importance, therefore, is the necessity of encouraging the activity of the mind to constructive effort. How important that human effort be directed aright and to the most useful ends, and how important that its effectiveness be additionally enhanced by cultivating the "plus" personal equation in all men.

It is a truism that a sound mind can only exist in a sound body. It is equally true that the personal equation of the individual exercises a most powerful but subtle influence on the operation of his mind, and that the characteristics of his personal equation are not only a reflex of his mental processes, but also to a great extent dependent on his bodily condition and environment.

It is most vitally important, therefore, that everyone, whether occupied in the commercial walks of life or otherwise, should seek by every means to preserve robust health and secure agreeable environment. Elbert Hubbard says that sickness is indecent, and disease a crime. In large measure I believe these statements are true; that more ill health is caused by a departure from the obvious and elementary rules of living than because of any other reason. A person suffering from even minor bodily ailment will inevitably show loss in the activity or quality of his mental processes. In other words, the value of his normal personal equation if "plus" will be minimized, and if "minus" will be augmented. On the other hand, a person of perfectly robust health will usually think and act along normal lines, and his personal equation will have a "plus" value, that is, his mind will be receptive, his reasoning powers alert and active, his imagination—which is a function of his mentality—strong and vivid, and his action direct and forceful.

The environment and conditions under which men labor have such an important influence on the character of their personal equations, as well as on the general interest, spirit and activity of their efforts, that one cannot comprehend why a more universal and urgent attempt is not made to improve the conditions under which men labor, when unlimited money and care are expended ungrudgingly to improve the efficiency of inanimate machines.

The study of the "personal equation" and the causes that determine it will compel more attention as time goes on. Its importance will be more and more emphasized, buyers and sellers alike will endeavor to recognize and interpret it as a part of the more refined and effective business training of the future; and all employers of human service will seek to augment the value of the normal or plus equation in their employees, and counteract or eliminate the causes responsible for equations prefixed by the minus sign.

OPERATING CHARACTERISTICS OF THE MODERN PASSENGER ELEVATOR

By E. F. Tweedy

Commercial Engineer of the New York Edison Co.

The first part of this article outlines the development of all the successful types of passenger elevator, viz., steam, hydraulic (water-balance, vertical and horizontal cylinder), electric (single and variable speed), and drum and traction suspensions. The merits and demerits of each type of drive and suspension are discussed. Curves are included which show the effect upon power consumption of different counterweighting, the schedule relation between number of stories and linear speed of travel, and the difference in the time-characteristic of two classes of traffic. A two-page tabulation gives complete data of representative installations. The second part of the article explains the method of arriving at the number and size of elevators which are necessary to fulfill the given requirements of a proposed building, a curve chart being used, which practically eliminates all computation. In conclusion, the construction and operation of the automatic signal-lamp system, so commonly used, are described in detail. Editor.

Vertical transportation, as exemplified in the elevator installations of our modern buildings, presents a problem of increasing importance, as the heights of our buildings tend steadily to increase and as the resultant service requirements become increasingly severe. The elevator problem of today is quite different from what it was only a comparatively few years ago, when our tallest buildings were confined to a height of some twenty-odd stories. That the towering structures of today stand as monuments to the successful solution of this elevator problem, hardly needs to be said, for it can readily be seen that it is as a result of the development of the modern passenger elevator, that the erection of the modern "skyscraper" has been made commercially possible.

Upon the Island of Manhattan, where vertical transportation has undergone its greatest development, there are, at the present time, about 120,000 buildings. Of this total number, approximately 1 per cent, or some 1200 are ten stories or more in height. Of these latter, some fifty-odd are between 20 and 30 stories in height, six range between 30 and 40 stories, and three are in excess of 40 stories, including one which towers to a height of 55 stories above the ground.

The total number of passenger elevators upon Manhattan Island at the present time is approximately 10,000 which is about double the number that was in use 10 years ago. If we assume a daily travel of only 10 miles for each of these elevators, the total daily mileage amounts to 100,000 miles, or four times the circumference of the earth. The five largest office buildings of Greater New York including two buildings which are now nearing completion will have a combined equipment of approximately 150 elevators, and the aggregate yearly mileage of the elevators in these five buildings will probably exceed one million miles.

The mechanical or electrical features of the different types of elevators will be dealt with to only a slight extent in the following, as many articles have been written upon this phase of the subject. This article will be confined largely to a study of the operation of the passenger elevator in its relations to the building in which such operation occurs. Before taking up this phase of the subject, however, the development of the passenger elevator, from its early beginnings to the present time, will be very briefly reviewed and the more important characteristics of the several types of passenger elevators, that are now available for use, will be briefly compared.

The first type of passenger elevator to be used in this country was operated by means of steam. This type of elevator was first introduced some 50 or more years ago, at a time when buildings consisted of only three of four stories, but it was afterward used in several buildings of considerable height, although later replaced by the faster and more reliable hydraulic elevator.

One of the earliest forms of hydraulic elevator was known as the "water-balance" type. In this type, an iron bucket, which was free to move in a vertical iron pipe, was connected to the car by means of cables, which passed over sheaves located at the top of the elevator shaft. By means of a rope which passed through the car, the operator could admit water to or discharge it from the bucket, and thus cause the car—which always weighed more than the empty bucket—to ascend or descend. The speed of the car was controlled by means of brakes, which gripped the guide strips. This type of elevator was capable of high speed, but it proved decidedly dangerous in operation, and its use was soon discontinued, although an elevator of this type was in operation in the Western Union Building in New York City, until this building was partially destroyed by fire in the early nineties.

The vertical-cylinder type of hydraulic elevator was first installed in New York City in 1878, and, except for some improvement in detail, it remains practically the same today as when first introduced. It has had a more extensive use than any other type of hydraulic elevator in buildings of 20 stories and under. This type of elevator has a vertical cylinder located along one side of the elevator shaft, and this vertical cylinder contains a piston which is connected by rods to a travelling frame in which sheaves are mounted. At a distance sufficiently high above the top of the cylinder to accommodate the piston stroke, fixed sheaves are located, and the cables which support the car, after passing over the sheaves located at the top of the elevator shaft, pass back and forth between the fixed and travelling sheaves so as to form a tackle, which multiplies the stroke of the piston by an amount equal to twice the number of travelling sheaves. The ratio of car travel to piston travel is termed the "gear."

The horizontal-cylinder type of hydraulic elevator, which is similar in principle to the vertical-cylinder type, is found in two separate forms, known as the "pushing" and "pulling" types. The latter is practically the same as the vertical-cylinder machine laid upon its side. While this type of elevator has found considerable favor, it has not been used to anywhere near such an extent as has the vertical-cylinder machine.

The first elevator to be operated by an electric motor was installed in a building in Baltimore in the year 1887. This elevator was of the worm-gear, drum type, with a series-wound motor operated from a constant current circuit. In 1889, two electric elevators of the drum type, with compound-wound motors, operated at constant potential, were installed in a building on Fifth Avenue, New York City. These elevators proving decidedly successful, other installations soon followed, and all electric elevators installed during the next five years were of this type. The drum-type elevator is unsuitable for very high buildings on account of the excessive size of drum that is required, and it is rarely used for speeds exceeding 350 to 400 feet per minute. This type of elevator has been used very extensively in buildings up to 20 stories in height; but in buildings of 20 stories and over, the width of the drum face and the horizontal travel of the cables when winding makes its use undesirable.

The first drum-type elevators were one-speed machines. Attempts were soon made to secure variable speed, and the Ward-Leonard system was developed. This system requires a separate generator for supplying current to the armature of each elevator motor, the shunt fields of both the generator and the motor being supplied with energy from a separate source. By varying the shunt field of the generator, the current supplied to the motor armature can be very effectively controlled without incurring the heavy rheostatic losses which result from direct armature control. While this system of control has been used in some notable elevator installations, it adds considerable complication and increases the cost of installation materially. The magnet system of control was developed in 1897, and it has been used very extensively since that time.

This system of control depends upon the counter e.m.f. developed by the motor as its speed increases, the resistance in series with the motor armature and finally that in series with the field being gradually cut out by means of a series of magnets.

In 1894 the screw-type electric elevator, with pilot motor control, was developed as a substitute for the drum-type electric elevator for high-rise work. This type of elevator was installed in a number of prominent buildings in New York City and elsewhere, but it proved somewhat costly to maintain and to operate. It is not being manufactured at the present time, although a considerable number of these elevators are still in use. The thirty-two-story Park Row Building in New York City, which was erected in the late nineties, was equipped with 10 of these elevators, each rising to a height of 26 stories.

Before following the development of the electric elevator further, and in order to preserve the chronological order of elevator development, we will turn for a moment to the plunger type of hydraulic elevator, which became prominent for high-rise work about 1899. This type of elevator was by no means new at that time, as it had been used extensively in Europe for a number of years in buildings of moderate height and also to some extent in this country, particularly for freight service. Its adoption for high-rise passenger work at this time was made possible as a result of improved methods of installation, which resulted in a considerable reduction in the initial cost. For several years this type of elevator enjoyed a considerable degree of popularity, and it was installed in a number of very high office buildings in New York City and elsewhere. It has found considerable favor for hotel and department store service, for which uses it still has many advocates. For high-rise office building work, where high speeds are involved, this type of elevator has now been practically superseded, so far as new installations are concerned, by the traction type of electric elevator.

The chief claim made for the plunger type of elevator is that of safety in operation. For handling heavy loads at low speeds this claim is probably justified. For high-rise, high-speed service, it is a question whether this elevator possesses any greater degree of safety than the traction type of electric elevator. As the plunger elevator, in common with all elevators of the hydraulic type, depends upon gravity to effect retardation upon the up trip and to cause the car to descend, the car must be sufficiently under-counterweighted to effect a stop when the car is ascending, with the operator alone, within a reasonable distance, and to cause the car to descend, under the same load conditions, at a proper rate of speed. As the operating speeds become greater, the difficulty of effecting proper retardation by means of gravity is greatly increased, and in the case of the plunger type of elevator the weight of the moving parts becomes so great, in a high-rise installation, as to make it difficult or impossible to make stops with precision when operating at high speed. This difficulty materially lessens the service speed obtainable with this type of elevator. The cost of the plunger type of elevator, including the necessary pumping plant, is usually from 30 to 40 per cent greater than the cost of an electric elevator of the traction type designed for the same service.

The traction type of elevator was developed about eight years ago, and is now being used almost exclusively for high-rise, high-speed work. This elevator is extremely simple in its mechanical construction, consisting of a slow-speed motor direct-connected to a driving sheave, above or below which, according to whether the motor is located at the bottom or top of the shaft, is placed an idler sheave. The cables which connect the car and counterweight form a loop around these two sheaves. The weight of the car and counterbalance produce sufficient adhesion between the cables and the driving sheave to cause the former to move with the latter at its circumferential speed. As compared with the drum-type machine, the traction elevator has the advantage that the ropes are always in a vertical position and that there is no danger of the car over-running at the top or bottom of the shaft. If the motor should continue to revolve after the car had reached the end of its up-travel, the counterweight would have reached the end of its down-travel and the cables would slacken and allow the motor to revolve without any further movement of the car. At the end of the down-travel, the same conditions would result when the car reached the bottom of the shaft. This type of elevator requires a motor of very slow speed—about 63 r.p.m. for an elevator speed of 600 feet per minute with a wheel three feet in diameter. For speeds of 400 feet per minute and under, the geared-type traction machine is used. This machine permits of the use of a motor of standard speed, which results in a somewhat lower motor cost. In certain recent installations, the advantages of the gearless drive have been retained for medium operating speeds by means of a ratio of 2:1 roping, which requires two additional idler sheaves, one being placed on top of the car and the other on top of the counterweight. In this type of machine the speed of the car is one-half the peripheral speed of the driving sheave.

In what has preceded, an attempt has been made to cover very briefly the development of the passenger elevator from its early beginnings up to the present time. Only those types of elevators have been mentioned which have proven successful in operation, and no reference has been made to a number of other types that have been tried, but, for one reason or another, have not proven commercially successful. As the matter stands today, the electric type of elevator—as represented by the drum-type machine for buildings of medium height, and by the traction machine for high-rise installations—possesses several advantages over the hydraulic type of elevator. It is cheaper to install and, in the great majority of cases, it is cheaper to operate. So far as the question of safety is concerned, there is little to choose between the two types at the present time, if both are properly installed and carefully maintained, particularly if the traction instead of the drum type of electric elevator is selected for comparison in the case of high-rise, high-speed work.

The drum type of elevator usually has two and sometimes three separate counterweights; other types of elevators have one and sometimes two. One counterweight of the drum-type machine is usually designed to balance about two-thirds of the weight of the empty car, and this counterweight is attached directly to the car by means of cables which pass over the overhead sheaves. The second counterweight is attached to the drum in a similar manner, and it balances the remainder of the empty car's weight, together with a portion of the live load that the car is to carry. The amount of this live load counterbalance is usually from 20 to 40 per cent of the maximum carrying capacity of the car, although it is occasionally increased to 50 per cent in order to keep the starting current at a minimum, when the car starts with a full load. This is sometimes necessary when an elevator is supplied with current from a private plant, which also furnishes current for lighting from the same generators.

The amount of live load counterbalance provided with the 1:1 traction machine is generally about 40 per cent of the duty load, which is usually about 80 per cent of the rated maximum capacity.

The third form of counterweight with the drum-type machine, and the second with other types of elevators, usually consists of a chain with one end attached to the bottom of the car and the other end fastened to the bottom of the regular counterweight. The purpose of this flexible counterweight is to compensate for the variations in the weight of the cables upon the two sides of the overhead sheaves. The weight of this chain is usually made somewhat greater than the weight of the cables, for the reason that the live load is at a maximum when the car is at the bottom of the shaft but becomes progressively less as the car ascends and discharges its passengers.

As already mentioned, the hydraulic elevator must be sufficiently under-counterweighted to bring the car to rest on the up-trip within a reasonable distance, when running at full speed under conditions of light load. This usually means that the counterweight can only be about two-thirds of the weight of the empty car. As the full weight of the car, together with a large part or all of the live load, can be counter-balanced in the electric type of elevator, the amount of power required to operate the latter for a given weight of car and live load is very much less than that required by an elevator of the hydraulic type. The hydraulic elevator uses power, of course, only on the up-trip, while the electric elevator consumes power when moving in both directions, unless there is an excessive amount of unbalance. In this event, the motor usually generates current when the car is moving in one direction and absorbs an abnormal amount during the reverse movement. Theoretically, the amount of energy consumed by an electric elevator per car mile should not be materially affected by the amount of this unbalance, as the additional amount of energy required to raise the car—if insufficiently counterbalanced—should be offset by the less amount of energy required on the down-trip, when energy might even be returned to the line. Practically, however, the energy consumed in lifting the excess weight—either in the form of live load or counterbalance—is not fully recoverable, and it will be found that the minimum consumption occurs, for any given number of stops per car-mile, under conditions of practically balanced load.

The number of kilowatt-hours consumed per car-mile does not afford an altogether satisfactory unit for comparing the operating efficiency of electric elevators under different service conditions, as the amount of electrical energy consumed per car-mile depends upon a number of factors, such as the speed and load conditions, the number of stops, the amount of unbalanced load that is being carried, and upon several other factors of somewhat less importance.

Fig. 1 shows the results of a test that was recently made upon a drum-type electric elevator in a sixteen-story office building.

The amount of live load counterbalance provided for this car is approximately 750 lb., which is 30 per cent of the carrying capacity of the car. Different numbers of stops per trip were made while carrying different amounts of live load, and the kilowatt-hours per car-mile were obtained under these different operating conditions. While the results of this test may be subject to some errors of measurement or calculation, they show very

express elevators make their first stop at the 13th floor, between which and the 35th floor they operate as locals. The average round trip running time of these express cars—excluding the time spent at the ground floor, which varies according to the traffic requirements—is about $2\frac{3}{4}$ minutes, which is equivalent to an average speed of approximately 300 feet per minute or one-half the rated running speed.

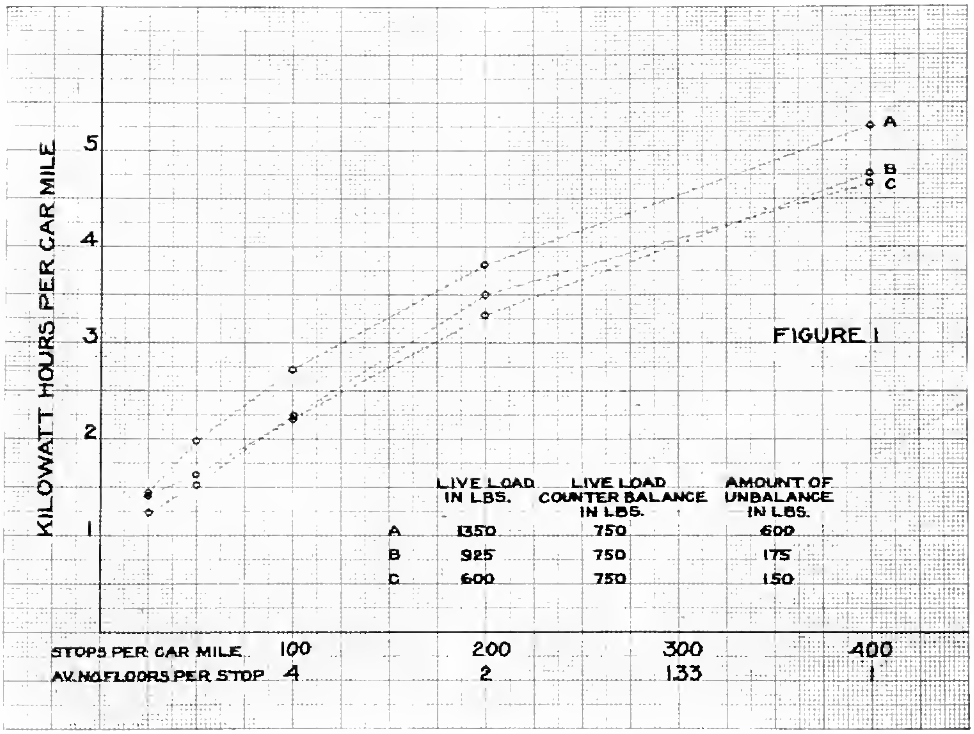


Fig. 1. Curves Showing the Kilowatt Hour Consumption of a Drum-Type Electric Elevator having a Counterbalance Weight Equal to 30 Per Cent of the Carrying Capacity of the Car. Various Live-Loads Carried and Various Stops Made Per Car-Mile

clearly what a tremendous effect the number of stops has upon the consumption of electrical energy per car mile. For this particular elevator, the consumption of energy seems to vary approximately as the square root of the number of stops per car mile.

Fig. 2 shows the average round trip time and the average speed, including all stops, of the passenger elevators in a number of office buildings of different heights. It will be observed how both the round trip time and the speed increase with the number of stories above the ground. In the case of the building having 34 stories above the ground floor, the

In buildings having 10 stories above the ground floor, the average round trip time, including all stops, is usually about $1\frac{3}{4}$ minutes; in buildings having 15 stories above the ground floor, it generally ranges from $2\frac{1}{4}$ to $2\frac{1}{2}$ minutes. When a building has more than 15 stories above the ground floor, express service is usually resorted to for serving the upper floors. This, together with higher running speeds, tends to prevent the round trip time from exceeding some three minutes in buildings as high as 25 or 30 stories. In buildings of greater height than this, still greater running speeds are employed, but the round trip time necessarily becomes somewhat more extended, although rarely beyond $3\frac{1}{2}$ minutes. If the round trip time becomes too extended, it places the upper floors at a disadvantage from a rental standpoint, in spite of the superior advantages possessed by these floors as regards light and air. In one particular office building in New York City, 26 stories are served by local elevators with the result that the average round trip time is nearly 4 minutes, which does not provide satisfactory service so far as the upper floors of this building are concerned.

Fig. 3 shows the variations in traffic over half hourly periods throughout the day in two office buildings of different types. The upper diagram represents the elevator traffic in a high-class office building in a financial district. This building is occupied largely by bankers, brokers, lawyers, etc. The lower diagram shows the elevator traffic in a modern mercantile building containing offices and lofts, the latter being used principally for sales purposes and only to a slight extent for manufacturing. In the former building, the arrival of the occupants—of which there are approximately 1000, occupying a net rentable area of a trifle over 100,000 square feet—is spread over one hour, while in the mercantile building the arrival of the occupants largely takes place within a period of one-half hour. The elevator traffic in the financial building is seen to be quite uniform throughout the day, while in the mercantile building there are very pronounced morning and evening "peaks" and a considerable increase in traffic between the hours of 12 and 2. The traffic in the latter building more typically represents that of the ordinary office or commercial building than does that of the former, in which, from the nature of its occupancy, the traffic throughout the day is exceptionally heavy.

In New York City, the speed of passenger elevators is limited, under the regulations of the Bureau of Buildings, to 500 feet per minute, although express elevators are allowed to operate at a speed of 700 feet per minute

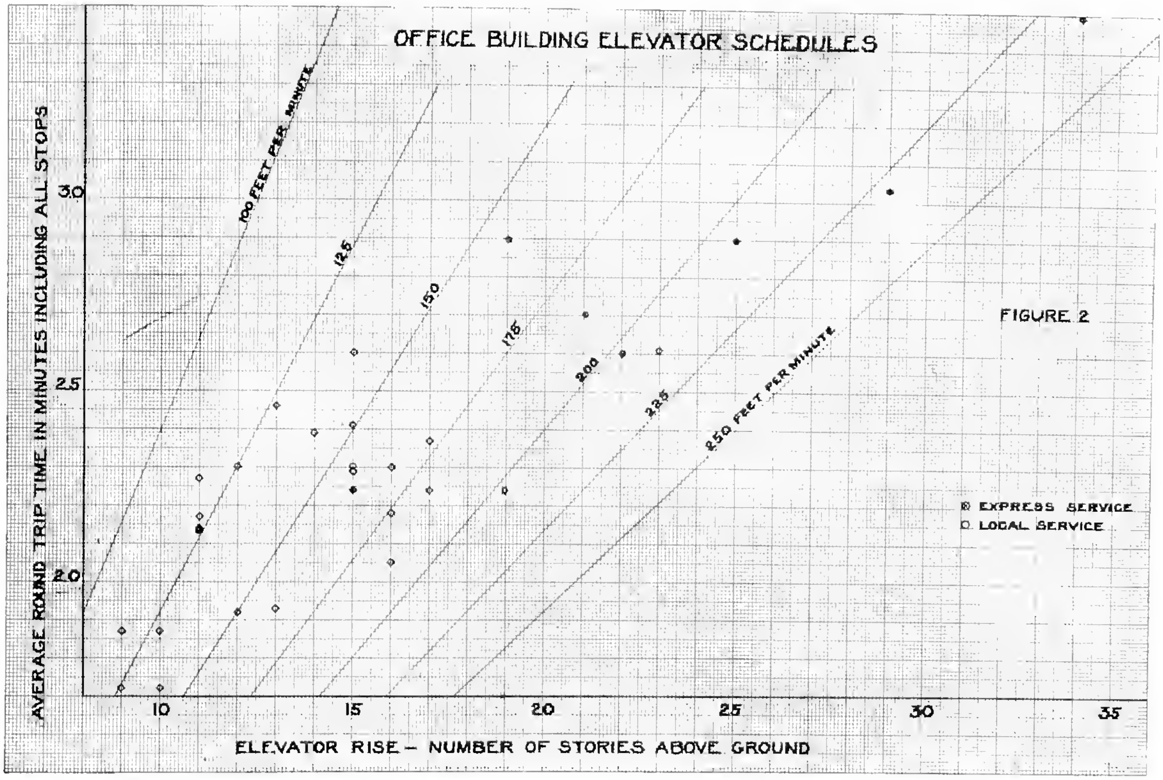


Fig. 2. Curves Showing the Average Round-Trip Time and the Average Speed, including all Stops, of Elevators in Office Buildings of Different Heights

OFFICE BUILDING ELEVATOR DATA

No.	Net Rentable Area Above Ground Floor	No. of Floors above Ground Floor	No. of Elevators and Floors Served: Local No.	Local Floors Served	Express No.	Express Floors Served	Net Rentable Floor Area Above Ground Floor: Per Elevator	Per Elevator Per Floor	Dimensions of Cars	Floor Area of Each Car Sq. Ft.	Total Car Area in Sq. Ft.	Sq. Ft. of Rentable Floor Area Per Sq. Ft. of Car Area	Rated Capacity of Elevator in Lb.	Type of Elevator	Rating of Elevator Motor: R.P.M.	Volts	Amp.	Average Miles Traveled per Day (excluding Saturdays and Holidays)	Ave. Kw-Hr. per Car Mile
1	32,030	10	3	All			10,676	1067	5 ft. 2 in. x 5 ft. 10 in.	30.00	90.00	356	1500	Electric drum	750	230	80	14.60	2.34
2	13,600	17	3	All			4,533	266	4 ft. 0 in. x 3 ft. 8 in.	14.70	44.10	309	1500	Electric traction 1:1	60	220	100	19.56	3.53
3	89,200	15	5	All			17,840	1190	5 ft. 4 in. x 5 ft. 7 in.	30.00	150.00	595		Vertical hydraulic				17.80	
4	57,313	19		1 to 8 2 to 20	1	8–20	14,310	754	(2) 5 ft. 1 in. x 5 ft. 6 in. (2) 5 ft. 1 in. x 5 ft. 2 in.	27.90 26.20	108.20	529	2000	Electric drum	800	220	145 125	(L)21.10 (E)28.05	4.01 3.26
5	25,528	11	3	All			8,509	773	5 ft. 0 in. x 4 ft. 5 in.	22.00	66.00	387		Vertical hydraulic				13.99	
6	30,250	9	3	All			10,083	1120	4 ft. 6 in. x 6 ft. 0 in.	27.00	81.00	373	2000	Electric drum	800	230	100	14.28	2.38
7	29,986	11	3	All			9,995	909	6 ft. 6 in. x 5 ft. 4 in.	34.60	103.80	288		Electric drum	825	240	130	13.90	3.07
8	38,700	15	3	All			12,900	860	5 ft. 10 in. x 6 ft. 6 in.	37.90	113.70	340	3000	Electric drum	800	220	145	15.69	1.44
9	155,650	16	10	All			15,560	972		23.70	237.00	657						18.94	
10	60,492	19	4	All			15,123	796	5 ft. 11 in. x 4 ft. 8 in. 4 ft. 8 in. 5 ft. 8 in. 5 ft. 1 in.	(2) 27.70 33.50 30.30	119.20	507	2500	Vertical hydraulic				23.20	
11	51,020	17	3	All			17,006	1000	4 ft. 1 in. x 6 ft. 5 in.	25.70	77.10	662	2000	Electric drum	850	220	60	20.78	1.45
12	224,500	15	6	All	2	10–16	28,100	1871	(L) 5 ft. 1 in. x 5 ft. 8 in. (E) 4 ft. 6 in. x 5 ft. 8 in.	28.80 25.50	223.80	1005		Vertical hydraulic				(L)17.00 (E)18.25	2.11 2.21
13	86,200	20	2	1–10	(2) 3	9–21 (1) 9–20	17,220	861	(L) 4 ft. 2 in. x 6 ft. 3 in. 4 ft. 4 in. x 6 ft. 3 in. (E) 4 ft. 2 in. x 6 ft. 0 in. 4 ft. 2 in. x 6 ft. 3 in. 4 ft. 3 in. x 6 ft. 4 in.	26.00 27.00 25.00 26.00 26.90	130.90	660		Vertical hydraulic					

14	113,700	29		2 to 15	3	15	30	22,700	783	(L) (E)	5 ft. 0 in. x 6 ft. 0 in. 5 ft. 0 in. x 6 ft. 0 in. 4 ft. 10 in. x 6 ft. 1 in. 4 ft. 11 in. x 6 ft. 1 in. 5 ft. 2 in. x 6 ft. 1 in.	30 00 30 00 29 40 29 90 31 40	150 70	734		(L) Electric drum (E) Electric traction 1:1	800 63	220 220	115 125	(L)16 00 (E)26 10	4 94 4 45
15	202,000	16	5 5*	All				20,200	1260		6 ft. 0 in. x 5 ft. 6 in. 8 ft. 0 in. x 5 ft. 10 in.*	33 00 46 60	398 00	507	3000	Electric drum	775 825	230	120 100	20 00	3 46 3*93
16	10[illegible],641	13	5	1-14	1	11	14	17,250	1328	(2)	4 ft. 2 in. x 6 ft. 10 in. 4 ft. 3 in. x 6 ft. 9 in. 4 ft. 2 in. x 6 ft. 8 in. 4 ft. 9 in. x 6 ft. 4 in. 4 ft. 7 in. x 5 ft. 0 in.	28 40 28 70 27 70 30 10 22 90	137 80	752		(2) Elec. traction 1:1 (1) Elec. screw	63	240	125	22 80 16 30	4 64 5 00
17	25,330	11	3	All				8,443	767	(2) (1)	4 ft. 2 in. x 5 ft. 5 in. 4 ft 4 in. x 5 ft. 4 in.	22 60 23 00	68 2	371	1800	Electric drum	800	220	265 110	13 80	2 10 3 81
18	80,400	16	6	All				13,400	837		4 ft. 8 in. x 5 ft. 9 in.	26 80	160 8	500	2500	Hydraulic				21 20	
19	53,030	14	4	B-14 All				13,260	947		4 ft. 8 in. x 5 ft. 11 in.	27 60	110 4	480	2200	Vertical hydraulic				21 40	
20	162,090	15	4 3	All				23,156	1544		5 ft. 11 in. x 5 ft 5 in. *6 ft. 0 in. x 6 ft. 0 in.	32 00 36 00	236 0	686	2500 3500	Electric drum	800	240	115	17 78 *11 91	3 46 3 93
21	48,484	10	3	All				16,161	1616						2750	Electric drum		230	115	15 80	4 30
22	34,262	11	3	All				11,421	1038							Plunger hydraulic				13 20	
23	79,100	15	4	All				19,750	1520		4 ft. 4 in. x 5 ft. 9 in.	24 90	99 6	795		Vertical hydraulic				14 35	
24	67,000	12	4	All				16,750	1396			29 00	116 0	578						17 04	
25	102,700	22		4 to 12	2 1 1	10 10 10	20 22 23	12,810	583		5 ft. 8 in. x 6 ft. 4 in.	35 80	286 4	358	3000	Electric tract. 1:1	63	240	150	(L)18 0 (E)28 0	5 09 4 62
26	323,400	23		6 to 14	6	14	24	26,900	1170		5 ft. 10 in. x 6 ft. 7 in.	38 40	461 0	701	2750	Electric tract. 1:1	63	240	150	(L)18 4 (E)24 0	4 76 4 09

(L) Local. (E) Express. *Passenger and Freight Service.

over that portion of the shaft in which no intermediate stops are made.

When the elevator requirements of a building are based upon furnishing transportation for all of the occupants above the ground floor within a specified time of arrival, more elevator capacity is required with the hydraulic type of elevator than with the electric traction type, when both are designed for the same average speed under normal traffic conditions. Under the traffic demands that are usually present in an office building in the early morning, as a result of the occupants of the building arriving and requiring transportation within a comparatively short period of time, the hydraulic elevator, ascending heavily loaded and descending practically without load, is at a decided disadvantage as compared with the traction machine with its ability to accelerate rapidly and to carry heavy loads at approximately rated speed.

The table on pages 480 and 481 contains data upon the elevator installations of a considerable number of office buildings. A study of this table will disclose a remarkable amount of variation in the relation between these different elevator installations and the buildings which they serve. Some of these buildings are unquestionably "over-elevatored," while in others the elevator installations are inadequate to provide satisfactory service.

Reference has already been made to the time within which the occupants of a building arrive and require transportation, as an element in determining the elevator requirements of a given building. In addition to this, there is the necessity of quickly removing the occupants in the event of fire. As the stairways would ordinarily help out the elevators very materially at such a time, particularly as regards the lower floors, a building could ordinarily be cleared of its occupants in a considerably less period of time in an emergency than that required to transport all of the occupants of the building one way under normal conditions.

In Fig. 4 a chart is shown by means of which the necessary number of square feet of elevator car area may be obtained for a proposed building, having a given number of square feet of rentable area, after assuming a maximum period of time for transporting all

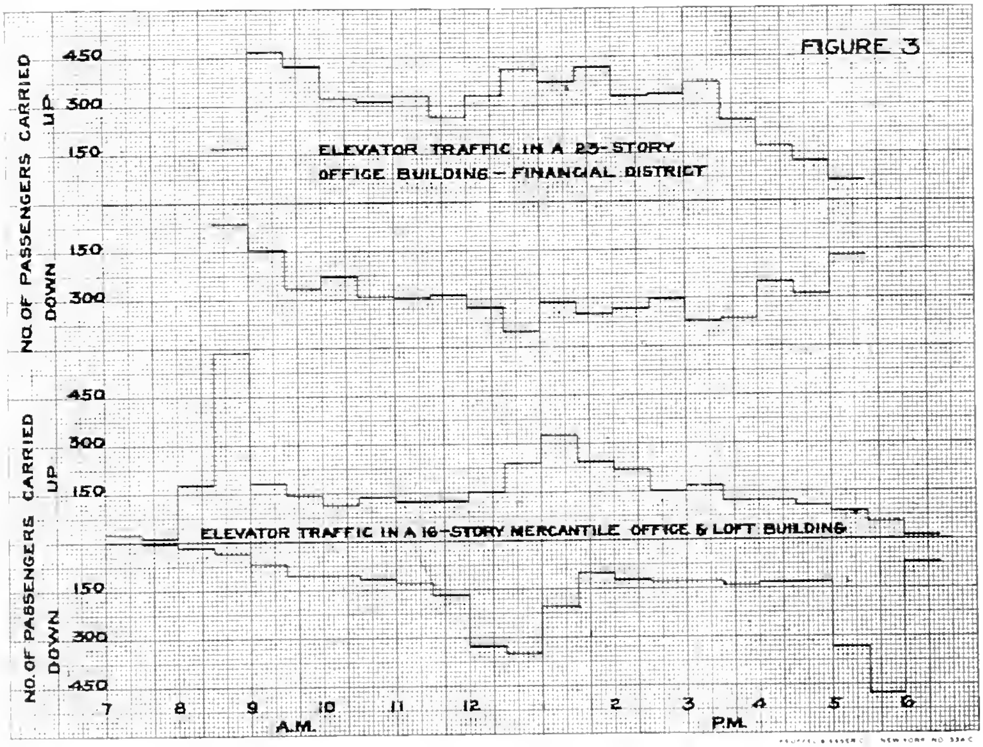


Fig. 3. Curves Showing the Difference in the Class of Elevator Passenger Traffic, Throughout the Day, in the Two Usual Types of Office Buildings Financial and Mercantile

of the occupants of the building in one direction. This chart is based upon an allowance of $2\frac{1}{4}$ square feet of car area per passenger, exclusive of the car operator, which is approximately the maximum carrying capacity of an elevator without excessive crowding. In order to show the method of using this chart, the requisite elevator equipment for a proposed building will be worked out in detail.

number of stops per round trip during this period will be somewhat greater than the average throughout the day, the wait-over at the ground floor will be shorter than the average for the day. We will assume that the elevators in this proposed building are to be capable of transporting all of the occupants one way in one-half hour under conditions of maximum traffic.

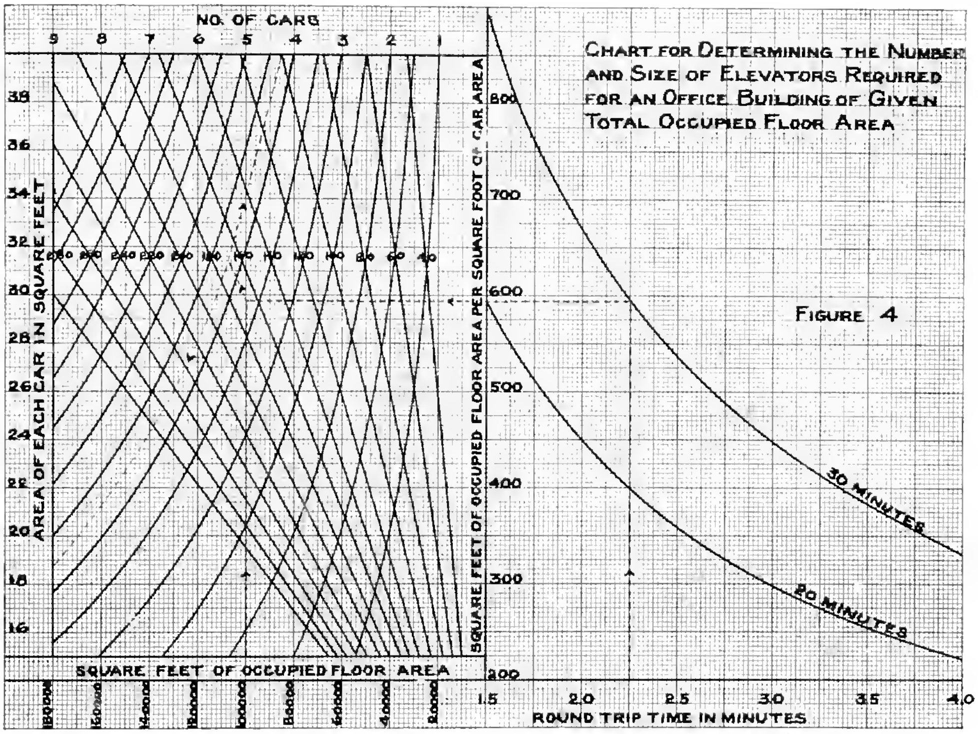


Fig. 4. Chart for Determining the Number and Size of Elevators Required for Office Buildings of Given Total Occupied Floor Area

For convenience, we will assume a building requiring local elevators only, although the chart is equally applicable to a building requiring both local and express service, if each class of service is considered separately in relation to the portion of the building which it is to serve.

We will assume that our building is to have 15 stories above the ground floor and is to have a total occupied area of 100,000 square feet. Referring to Fig. 2, we can safely assume an average round trip time throughout the day of about $2\frac{1}{4}$ minutes for a building of this type. It will also be safe to assume that this round trip time will not be exceeded even during the morning rush, for while the

If we erect a perpendicular at $2\frac{1}{4}$ minutes on the horizontal scale of "round trip time in minutes," until it intersects the curve marked "30 minutes," and then draw a horizontal line to the left until it intersects a perpendicular erected at 100,000 on the scale of "square feet of occupied floor area," we obtain a point located midway between the diagonal lines passing through 160 and 180, which means that we must provide a total car area of 170 square feet. Following a diagonal drawn midway between 160 and 180 until it intersects the corresponding curve, and then following this curve, we have the various combinations of number of cars and car sizes, that will produce a total car area of 170 square feet. We shall require five cars of 34 square feet each, six cars of a little over 28 square feet each, or seven cars of a trifle over 24 square feet each. The proper size of car to select would, of course, be governed by the dimensions of the space available for the elevators, and by certain other conditions of a practical nature.

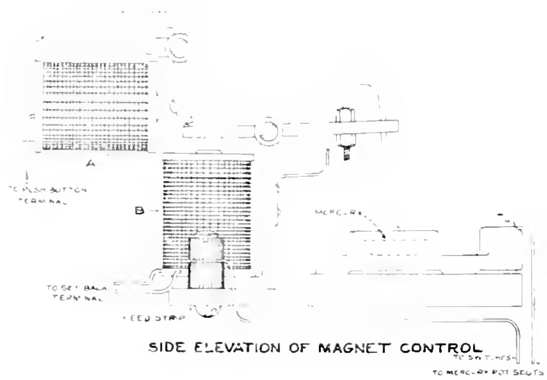


Fig. 5 Control Magnet Mechanism for an Elevator Automatic Signal-Lamp System

While the chart is based upon a density of occupancy of 100 square feet per person, it may be used just as readily for any other density of occupancy. For instance, if we were to allow 125 square feet per person, we would select a point on the scale of "square feet of occupied floor area per square foot of car area" 25 per cent above that determined by the intersection of the horizontal line drawn from the "30 minutes" curve, and we would then draw a horizontal line to the left from this new point until it met a perpendicular erected at the number of square feet of occupied area.

By means of this chart, the number and the size of the elevators required to meet any given operating requirements in a proposed building may be determined, and the elevator builder should then be required to guarantee the fulfillment of the operating schedule as specified, under the conditions of maximum traffic that are assumed.

The system of automatic signals, required in connection with the elevator installation of a large office building, is necessarily quite complicated in its details. The subject will therefore be dealt with only to such an extent as will convey some idea of the signalling methods that are usually employed.

It is customary to place two signal lamps in front of each elevator on each floor of an office building, with the exception of the top and bottom floors, where only a single lamp is provided. These two lamps are usually placed one above the other, the upper one flashing white as an ascending car approaches, and the lower one flashing red as a car approaches in the reverse direction, provided the signal has been set for a stop at the floor upon which the lamp is located. There are two push buttons—an "up" and a "down"—on each floor, with the exception of the top and bottom floors, by means of which a person waiting on any floor may stop an approaching car by lighting the signal lamp located within the car. In addition to the foregoing, signals are generally provided which enable the elevator starter to notify the operator of any car to bring his car from any position of its travel to the starting floor.

Current for lighting the signal lamps and for operating the control magnets is usually supplied from a motor-generator set, the voltage of the generator being about 10 volts. Fig. 5 shows the form of magnet control that is usually employed. Two sets of these magnets—one for operating the "up" lights and the other for operating the "down" lights—are provided for each floor, with the exception of the top and bottom floors. When a button on any floor is pressed, current from the generator energizes magnet *A* of either the "up" or "down" set of magnets corresponding to the floor upon which the button is pressed. By energizing magnet *A*, the contact point at the right is made to dip into the mercury cup, thereby connecting the generator with certain segments over which brushes travel in accordance with the movement of the car. As the car approaches the floor from which the stop signal has been given, a circuit is completed through these segments and brushes and the proper lamp is lighted on this floor to warn the person who is waiting of the car's approach. Other segments then complete a circuit which lights the operator's signal lamp within the car. As the car leaves the floor, another set of segments completes a circuit which energizes magnet *B*, resulting in the contact point being lifted out of the mercury cup. Should a car be filled with passengers and the operator desire to transfer the stop signal to the car following, he may do so by opening a "transfer" switch, located within the car, and thus prevent magnet *B* from becoming energized. This operation automatically transfers the stop signal to the next car.

THE EXTRACTION OF STEAM FROM CURTIS TURBINES

By R. H. Rice

Engineer, Steam Turbine Department, Lynn Works, General Electric Company

This article describes two mechanisms that have been perfected for the extraction of low pressure steam from Curtis turbines, one a very efficient device intended for continuous use or for those cases where the maximum obtainable efficiency is desired, and the other a simpler and somewhat less efficient arrangement intended for use at irregular intervals or during certain portions of the year only. When compared with methods that are necessary in turbines of other designs for accomplishing the extraction of low pressure steam, the first of these mechanisms possesses the great advantage that only a portion of the steam passing to the low pressure section of the turbine is throttled, and that there are no losses from friction occasioned by the flow of steam through tortuous passages.—Editor.

Extraction turbines are applicable for all cases where a limited amount of steam is required for mechanical or heating purposes and where for a part of the year such steam is not needed, and are particularly valuable where the demand for low pressure steam is variable.

The term "extraction turbine" covers those turbines which, while designed to operate as high pressure condensing units, are also provided with means for permitting steam at some pressure above atmosphere, say 5 or 10 pounds per sq. in., to be withdrawn from the turbine, and in any quantity desired up to the capacity of the turbine as determined by load conditions.

In order to permit steam to be withdrawn at any desired time, it becomes necessary to provide such turbines with regulating device which will ensure the maintenance of a pressure in the region from which the steam is supplied sufficient to cause the steam to flow into the mains; and in order to avoid fluctuating conditions in the low pressure steam system it is desirable that the pressure in this region be kept reasonably constant.

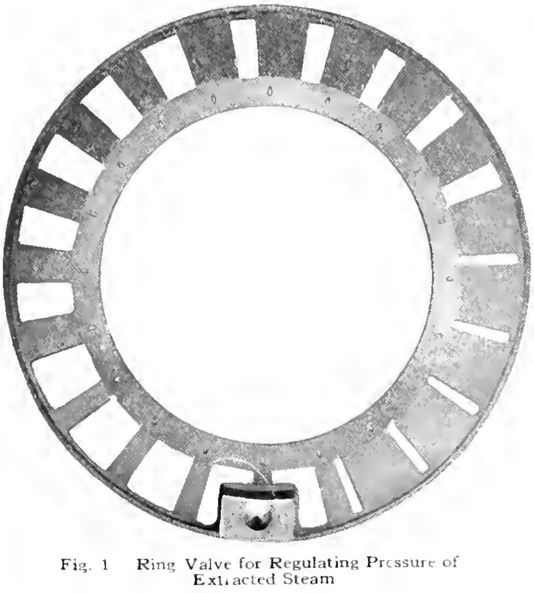


Fig. 1 Ring Valve for Regulating Pressure of Extracted Steam

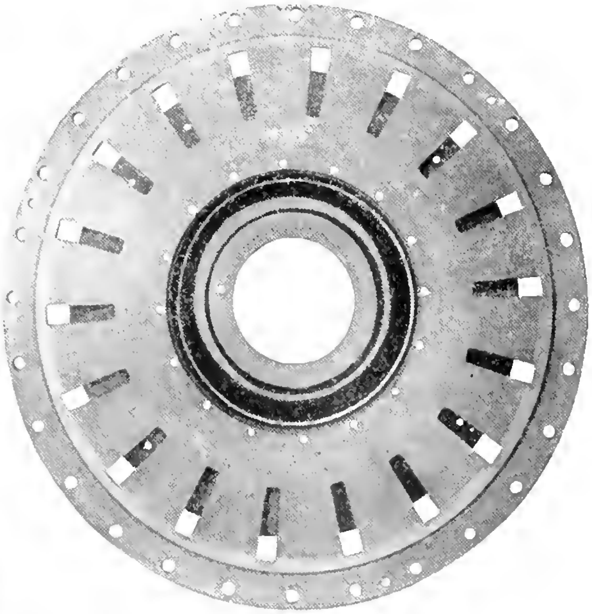


Fig. 2. Diaphragm with Ports, on which Rests the Ring Valve Shown in Fig. 1

In order to effect this result in reaction machines it is usual to separate the high and low pressure parts of the turbine by a partition in such a manner that all the steam from the high pressure part is caused to flow into a suitable passage, from which it passes into either the low pressure mains, or, in case of surplus steam not needed for mill purposes, through a throttling valve into the low pressure part of the turbine, where it does work, and thence to the condenser. The office of the valve is to so throttle the steam as to maintain sufficient pressure in the passage to cause the desired flow into the mains; and in such machines all the steam going to the low pressure part of the turbine is throttled.

The same general construction is necessary in turbines of the impulse type having two

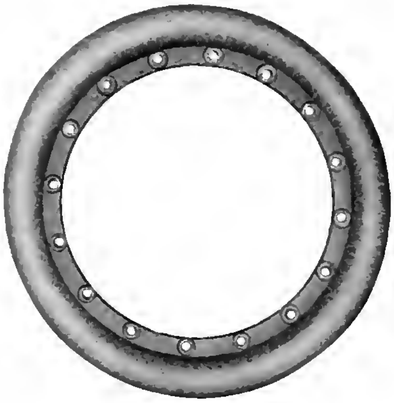


Fig. 3. Balancer Plate for Ring Valve

drums, one for the high pressure turbine and one for the low pressure.

In the Curtis turbine it is unnecessary to divide the turbine into two parts in order to effect adaption for extracting low pressure steam. It is only necessary to place a valve over the bowls of the nozzles leading from the stage to be bled, and to control the movements of this valve by a mechanism responsive to the pressure in the stage in such manner that the valve shall automatically throttle the steam passing into the nozzle bowls sufficiently to maintain constant stage pressure.

Two advantages arise from this construction, viz.: no losses from friction are experienced, as is the case when the steam has to pass through tortuous passages; and it is possible and usual to throttle the nozzles in groups so that only one group, or say one-fourth of the nozzles, are undergoing throttling at any one time, the others being either wide open, and therefore unthrottled, or else completely closed off.

The illustrations show how this valve is constructed and operated. Fig. 1 is a view of the ring valve, and Fig. 2 shows the diaphragm, with ports, on which the ring valve is seated. On the other side of this diaphragm the nozzles are bolted in position,

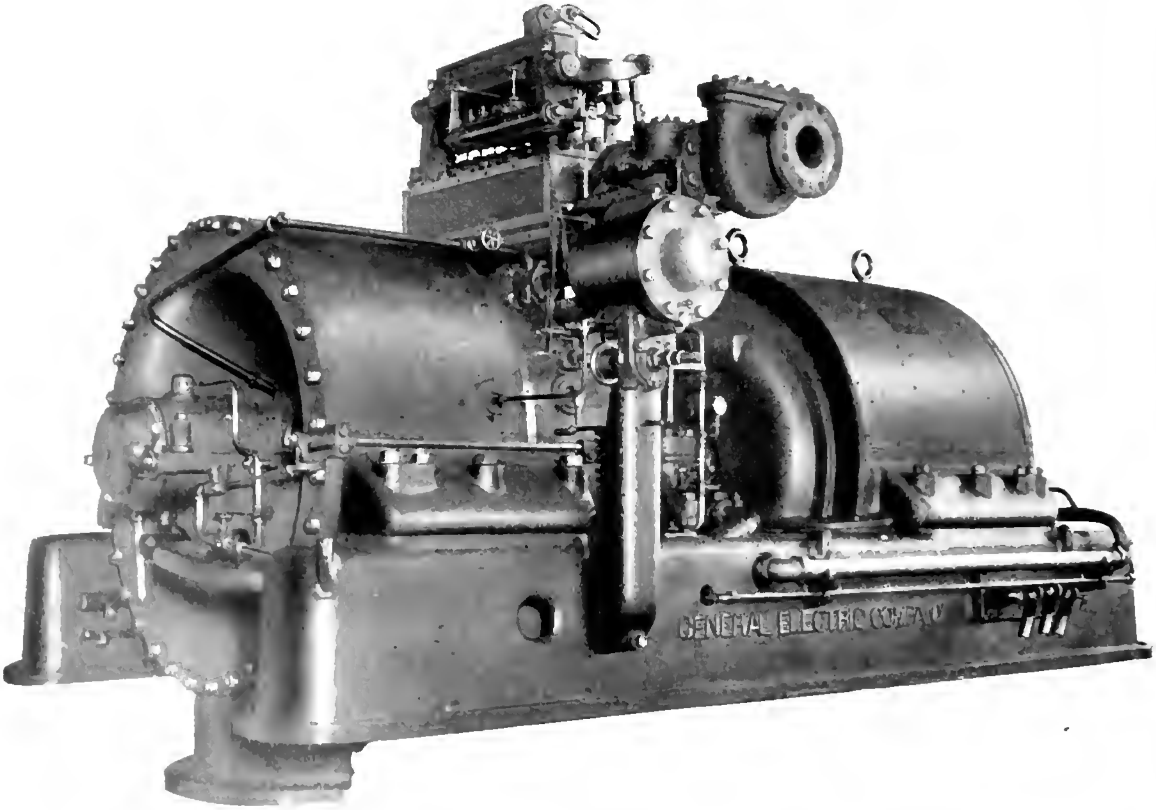


Fig. 4 750 Kw Curtis Turbine Fitted with Ring Valve and Controlling Mechanism for the Extraction of Steam but they are not shown in this view. Fig. 3 shows the balance plate which is put on top of the ring valve and which has the effect of equalizing the pressure on the two sides of the valve, thus greatly reducing the resistance of the valve to movement. Fig. 4 shows a 750 kw. turbo-generator set with this mechanism attached. The valve is operated by a steam (or oil) cylinder shown on the front side of the set, while directly below this cylinder is a diaphragm responsive to pressure variations in the stage of the turbine from which steam is extracted, the function of this diaphragm being to ensure that the valve (Fig. 1) will always be in such a position as to give the requisite amount of throttling between this stage and the one next following it to maintain the pressure desired in the former stage.

Fig. 5 shows a cross-sectional view of the mechanism which actuates the valve. In this figure the valve is controlled by a cross head (1) connected with a piston rod (2), which is actuated by a steam or oil cylinder (13). Movements of the piston are effected by means of the pilot valve (22), which is in turn actuated by the diaphragm (30), which is responsive to

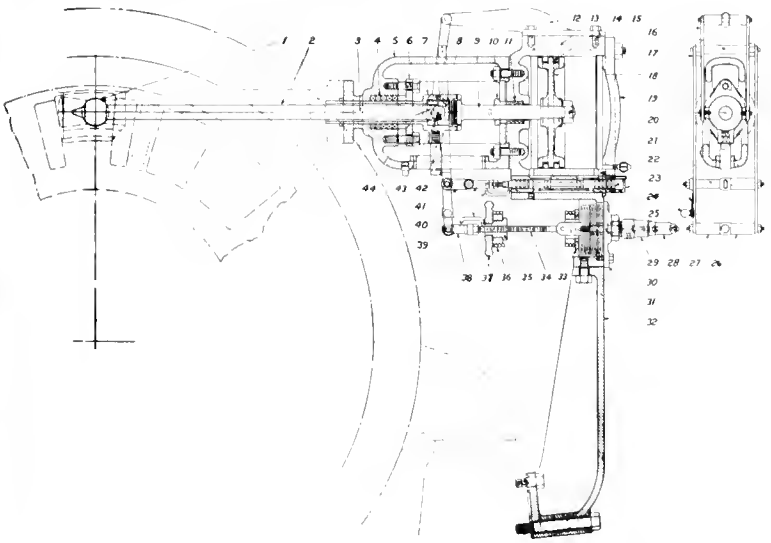


Fig. 5. Cross Section of Mechanism for Operating Ring Valve

pressure in the stages; the movements of the diaphragm being opposed by spring (36), which is set so as to preserve any desired pressure in the stage.

Referring to Fig. 1, it will be seen that the ports are of progressively increasing width around the circumference, from the narrowest to the largest. The narrow ports begin

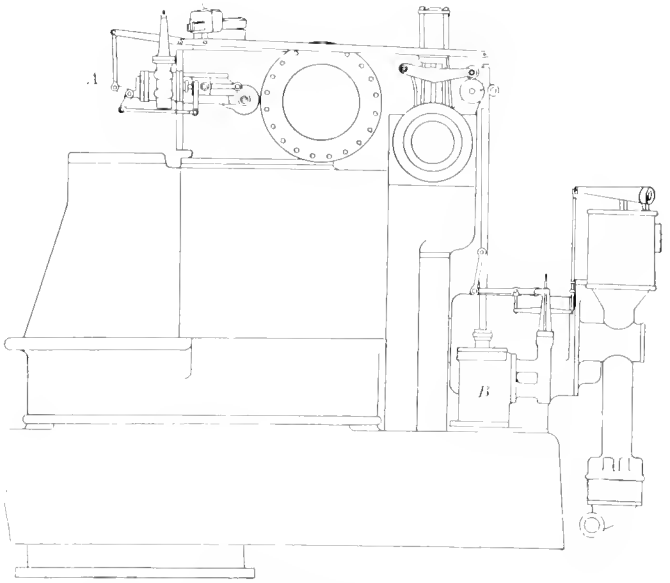


Fig. 6. A Simpler Mechanism for Controlling the Extraction of Steam from Curtis Turbines

throttling on the first movements of the valves. Successive groups (in this case four) gradually take up the throttling. At the time when any one group begins throttling, all the others are either fully opened or fully closed. The effect of this nozzle control by groups is to increase the efficiency of the turbine when a given amount of steam is being extracted, or in other words, to diminish the total steam consumption of the set. The amount of steam which can be extracted varies with the electrical load which the turbo-generator set is carrying.

In cases where it is not necessary to realize the last degree of refinement in efficiency of the set at any time, or for portions of the year only, it is possible to use a simpler mechanism, such as that shown in Figs. 6 and 7. This arrangement was designed for a 3500 kw. machine. The steam flow from the turbine is regulated by a butterfly controlling valve placed in a chest on top of the turbine, this valve being controlled by the hydraulic cylinder *A*, acting in unison with the hydraulic cylinder *B* which controls the main valves. This mechanism is so constructed that every movement of the piston and piston rod of cylinder *B* is followed by a movement on the part of cylinder *A*. This compensates for the changes in the amount of steam admitted to the turbine by the main controlling valves. The pressure in the chest is held constant by a diaphragm located at (8) in Fig. 7. The controlling levers are so arranged that an increase of pressure in the chest causes the cylinder *A* to move in such a manner as to open the throttling valve and thus give less

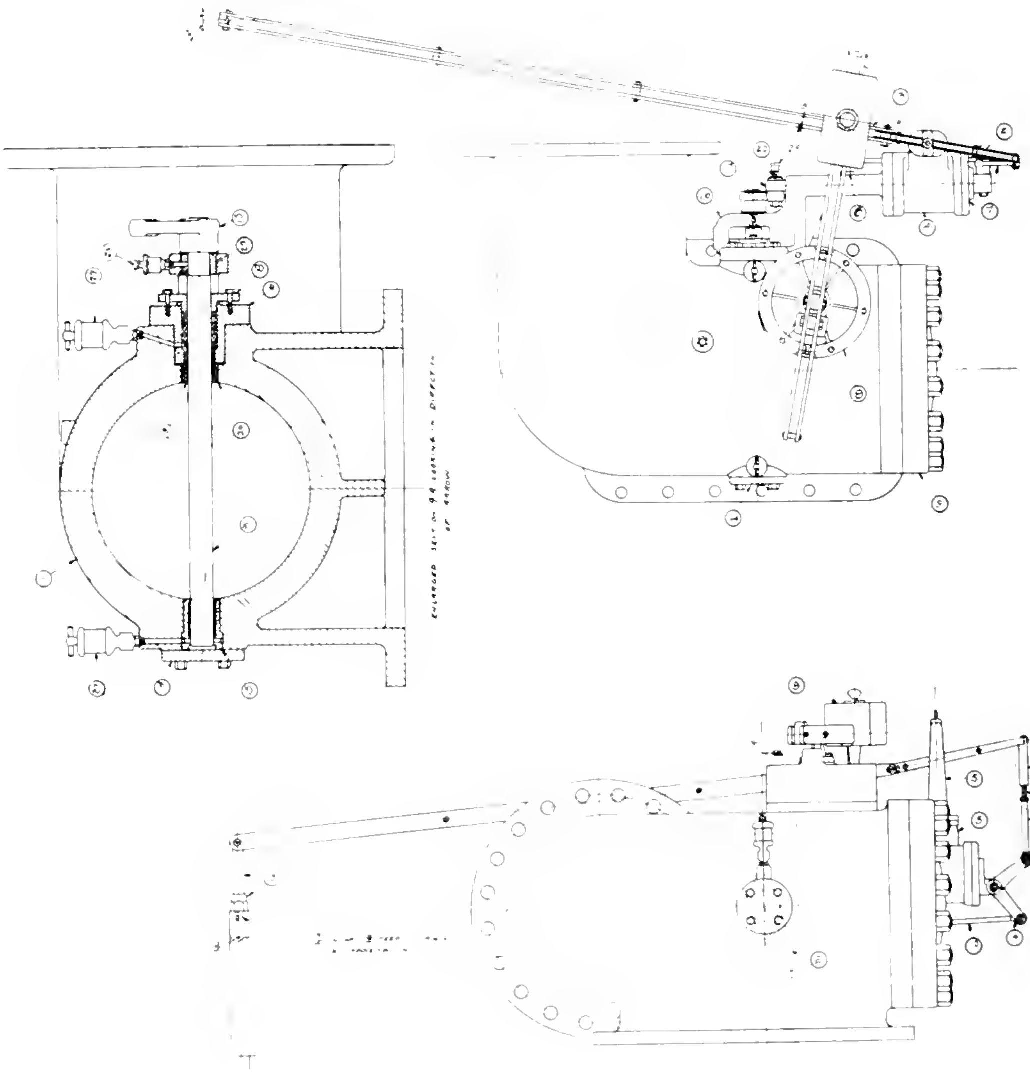


Fig. 7. Details of the Mechanism Shown in Fig. 6

throttling. Decrease in pressure produces the contrary effect. The mechanism is therefore so arranged that the butterfly or throttling valve is controlled both by pressure and by the quantity of steam flowing into the machine.

Mechanisms such as those described are readily adaptable to service on mixed pressure turbines, so that we may have the case of a machine giving out steam to the mill or factory at one period of its operation, and at another time taking in surplus low pressure steam and utilizing it in the low pressure ranges. In this way turbines can be built for a wide range of use in connection with low pressure steam.

THE STRUCTURE OF THE ATOM

By Professor R. A. Millikan

Department of Physics, University of Chicago

This article is based upon an address to the Schenectady members of the American Chemical Society, and has been specially written by the author for the Review. Professor Millikan has won renown in the field of science by virtue of the valuable work he has performed in the study of the structure of matter and the irrefutable proof he has given us of the atomic nature of the electrical charge. A description of his classic experiment, by means of which he succeeded in proving the atomic nature of electricity and determined the value of the unit charge, serves as an introduction to a very interesting discussion of the probable nature of energy radiations, mainly x-rays and alpha rays. The behavior of the latter has blasted our old theory of the impenetrability of matter, while certain characteristics common to both have led to the formulation of a corpuscular theory as to their nature, which for x-rays has since been refuted by the experiments of other investigators. Our scientists have wrested many secrets from Nature in recent years, and it would seem that we were shortly to know a vast deal more about the insides of the atom and the different forms of energy.—Editor.

The very fact that a paper on such a subject as the structure of the atom is possible shows how far we have progressed scientifically in the past twenty years; for twenty years ago anyone who would have attempted to tell an audience about the insides of the atom would have been either a knave or a fool. Today he may be a knave, but he is not necessarily a fool, for nowadays a man may *know* something about the insides of an atom, if he wants to. In fact, there is nothing more characteristic about the remarkable advances of physics in the last twenty years than the way in which our atomic and molecular hypotheses have swept the field in almost every domain. Today I think it is perfectly safe to say that we are counting the number of atoms or molecules in a given amount of substance with just as much accuracy as we count the inhabitants of a city. No census is correct to more than one or two parts in a thousand, and this represents about the degree of accuracy with which we know the number of molecules in a given volume of gas under given conditions.

Furthermore, today we have conclusive *experimental* evidence for the correctness of the fundamental conceptions of the kinetic theory of matter, which pictures the molecules of gases as darting hither and thither with the speed of a rifle bullet. Indeed, if we wish to, we can almost see the motions of the molecules of a gas; or if not quite that, we can at least see the immediate effects of these motions in imparting a very lively agitation to oil drops and other small particles suspended in the gas. And further, when the pressure of the gas is reduced more and more, we can see this agitation become more and more violent, just as it ought if it is due to molecular bombardment, and for the same reason that a football makes farther and farther flights the sparser becomes the crowd of boys which is surrounding it and kicking at it.

Then again, on top of these old atomic and kinetic theories of matter, we have superposed in recent years an atomic theory of electricity and have brought forward most irrefutable proof that electricity is granular or atomic in structure—that every electrical charge consists of an exact number of exceedingly minute electrical units or atoms which are scattered over the surface of the charged body. We have also learned how to measure the value of one of these charges with an accuracy of something like one or two parts in a thousand. In addition to this, we have learned that these electrical atoms are constituents of all ordinary atoms. That does not mean that we know that all matter is built up solely of electrical charges, but we do know that all matter contains as constituents some of these minute charges. So you see we do know something at least about the insides of the atoms.

Finally, within very recent time this atomic conception has also been extended, as a tentative speculation, to radiant phenomena, and there are some indications that we shall have to modify our points of view in regard to heat, light, and X-rays, and possibly come nearer to an atomic picture of radiant energy than we have ever been before.

Thus far I have merely made assertions. Let me now attempt to outline some of the types of experiments which have led to the possibility of making such assertions. I will begin with a brief outline of experiments which show the atomic nature of the electrical charge, and since most of you are more or less familiar with them, I will run over them rapidly. Just one more assertion by way of introduction to these experiments: we now know that there are about 27×10^{18} molecules in one cubic centimeter of air under standard conditions of temperature and pressure. Of this inconceivably large number of molecules, there are only perhaps from 5 to 20 per second, depending upon conditions, that normally split into ions. We conceive this process of ionization to consist in the detachment from a neutral molecule of a negatively charged particle (now called an electron) of infinitesimally small mass, so that the molecule, after it has lost one such electron, has a free charge of positive electricity and therefore may be attracted by a negatively charged body. If, now, we let X-rays or rays from some other ionizing agent fall upon the gas, the number of ions formed per second is enormously increased. It is probable that the ions normally present in the atmosphere are formed not because of any tendency of the molecules to throw off electrons, but because of rays emitted by traces of radio-active substances which are universally present.

But however these atmospheric ions are formed, the problem which we set ourselves was to catch one of them upon an oil drop and measure the charge carried by it. We accomplished this result as follows: we blew an oil spray by means of an ordinary atomizer, and got one of the minute droplets into the space between two circular metal plates one and a half inches apart. We illuminated the oil drop by means of a beam of light from an arc lamp. The drop falls under the action of gravity towards the lower plate but before it reaches this plate an electrical field of strength between 3000 volts and 8000 volts per centimeter is created between the plates, and if the droplet has received an electric charge in the atomizing process, as is generally the case, it is pulled up by this field (applied in the proper direction) against gravity, toward the upper plate. By throwing the field off and on, the oil drop can be kept moving up and down between the plates. If now the oil drop was at first positive and then caught a positive ion from the air, it should go faster in a given electrical field. If it was at first negative and got a positive ion, it should go slower. The experimental results were just what we expected them to be. The oil drops did indeed undergo sudden changes in speed, and it comes out that the charge on an ion is proportional to the amount of change in speed which it produces when it attaches itself to the drop. This may be seen as follows:

If we denote the apparent mass of the drop by m,* the electrical charge carried by E_n, its speed under gravity by V_1, and its speed under the resultant influence of the electrical field of strength F and gravity by V_2, the following relation holds true:

$$\frac{V_1}{V_2} = \frac{mg}{FE_n - mg} \text{ or } E_n = \frac{mg}{F}\left(\frac{V_1 + V_2}{V_1}\right) \qquad (1)$$

where g is the gravitational constant.

This equation shows that the change in velocity of the oil drop $(v_1 + v_2)$ due to loss or gain of ions measures the electrical charge captured by the oil drop from the ion. If electricity is atomic in structure there will evidently exist a greatest common divisor for all the observed values of this quantity $(v_1 + v_2)$, and this will correspond to the value of $v_1 + v_2$, which represents one elementary unit of electricity (E). The values of this unit obtained by this method agree among themselves with the greatest accuracy.†

* The term apparent mass is used to denote the difference between the actual mass and the buoyancy of the air.

† Editor's Note.—The following results, taken from Prof. Millikan's published results, illustrate this point well:

In one case the oil drop under observation fell the distance between the two cross hairs of the telescope field (actual distance 0.522 cm.) in 13.595 seconds. A difference of potential of 5.05 volts was then applied to the plates and the intervals of time taken by the drop to fall the half centimeter varied from 12.5, 21.8, and 34.8 to 84.5 seconds. The change in the sum $(V_1 + V_2)$ produced by the capture of an ion which caused the time to vary from 34.8 to 84.5 seconds was 0.00891 cm. per second, and the successive values of this sum arranged in order of magnitude were 0.01456, 0.05347, 0.07106, 0.08038. If now, electricity is atomic in structure, all the different charges appearing in this experiment, those on the ions and those on the drop, should be

Here is the most irrefutable proof we have of the atomic structure of electrical charges. On any other theory there is no reason at all why the results should come out this way. We simply find, as a matter of fact, that the sum of these speeds, which is proportional to the electrical charge, always comes out a multiple of a definite unit, which, by definition, is an atom of electricity or an electron. All the charges that that drop can take on, whether they are produced by the frictional process or whether they come to it from outside ionizing agents, all are found to be built up as multiples of this unit charge.

These experiments have been carried on with all sorts of substances, some of which were conductors, like mercury, some semi-conductors, like glycerine, some non-conductors like oil, and the above relationship has been found in every single case. This means that the charges on these bodies are built up of the same kind of units.

So much for the proof of the atomic structure of electricity. Let us next see how the exact value of this unity is actually determined.

Equation (1) involves no assumption whatever, save that the speed of the drop is proportional to the force acting upon it, an assumption which has been fully and accurately tested by a large number of experiments. However, in order to evaluate E_1 it is necessary to determine M. The other quantities occurring in the equation are determined directly from the observations made during the experiments.

Now we cannot weigh these drops, because they are too small. The average diameter of the drops is two or three times the wave length of sodium light, say 0.001 millimeter. We can indeed compute the mass m from Stoke's law, but it must be remembered that the latter involves the assumption that we are dealing with a homogeneous medium and is therefore not valid under all conditions.

Stoke's law in its simplest form states that if μ is the coefficient of viscosity of the medium, x the force acting upon a spherical drop of radius a, and v the velocity with which the drop moves under the influence of the force, then

$$x = 6\pi\mu a v \qquad (2)$$

The substitution in this equation of mg for x enables us, therefore, to calculate E in absolute units.

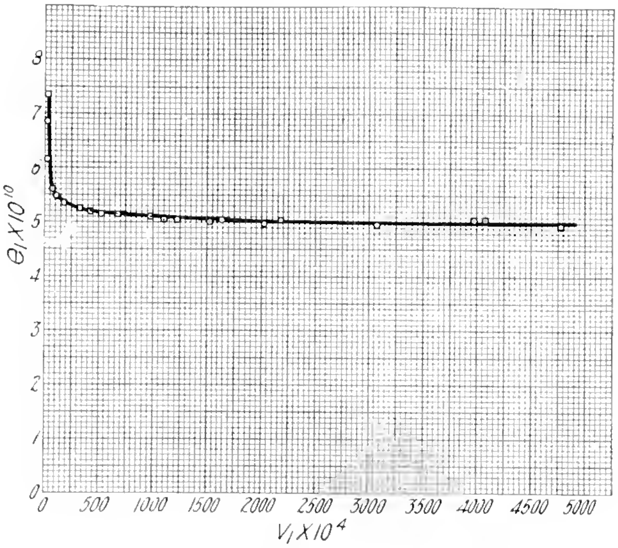


Fig. 1. Curve Showing Relation Between Charge (E_1) and Velocity of the Drop (V_1) Obtained by Applying the Equation (2)

As a matter of fact, we attempted to do that, and what we found was that although we always got the above mentioned multiple relation so long as we were working with a given drop, nevertheless the values of the greatest common divisor E_1 of all the E_n's obtained with a given drop came out differently for drops of different sizes, and the smaller the drop the higher the value of E_1. In the original experiments, the variations were not large, but when the sizes of the drops were varied more and more, the discrepancies in the values of E_1 became greater and greater. For example, in one case, E_1 came out 4.99×10^{-10}; for drops one twentieth that size, the size being roughly estimated by the speed, E_1 came out 5.67×10^{-10}, or about that value (See Fig. 2.) All this obviously meant that the assumption we made at the start that the medium is homogeneous is not correct.

Well, then, the problem was how to find the true value of the charge in spite of the error in this law of Stokes. The trouble with this law is that it is set up on the assumption of a homogeneous medium, but as the drops

exact multiples of the elementary unit of charge, which means that all of the numbers given above should be exact multiples of something. Dividing the above five numbers by 5, 6, 7, 8, and 9, respectively gives 0.008912, 0.008911, 0.008903, 0.008883 and 0.008931, which are all seen to be within one-fifth of one per cent of the value of the change in the sum of the speeds produced by the capture of the ion which caused the velocity to change from 34.8 to 84.5. *Hence the charge carried by this ion was itself the elementary unit out of which all of the other charges which appeared in the experiment were built up.*

become smaller in size and more nearly approach the size of molecules, the medium can evidently no longer be considered as homogeneous. Instead, we must regard it as full of holes, and we may think of the drops as they become smaller and smaller as falling freely through the holes between the molecules.

There are two ways of getting around this defect in the equation: one way is to increase the size of the drops; the other is to compress the medium; i.e., to squeeze the holes together. Experimentally, the trouble with the first is that as soon as we have larger drops, they fall too rapidly out of the field of vision. Compressing the medium has equally objectionable features, for the disturbances due to convection become greater and greater the higher the pressure is carried. Accordingly we modified the equation as follows: we added a correction term of the form shown in (3) and then wrote the modified Stokes equation thus:

$$x = 6\pi\ \mu a v_1 \left(1 + \frac{Al}{a}\right)^{-1} \qquad (3)$$

where A is a constant for the medium and l is the mean free path of the molecule of the gas constituting the medium.

Using this form of equation to combine with (1), the absolute values of E have been determined with an accuracy of 0.1 to 0.2 per cent to be 4.77×10^{-10} electrostatic units.

Now perhaps I can go over to something that looks more interesting because it has larger bearings.

I have presented so far the type of experiments which prove the atomic structure of electricity, and I have attempted to show how we go to work to measure the magnitude of the elementary electrical charge. Now it can be shown that every kind of matter contains these electrical units. They can be driven out of conductors and non-conductors. Ordinary atoms of air certainly have them as constituents, since they can be produced from these atoms by any kind of ionizing agent.

As to how many electrons there are in an atom, I shall have to be content with mere assertions. All the evidence we have seems to show that there are at least as many as three or four times the number which represents the atomic weight.

If we were to consider the mass of an atom of matter as built up entirely out of electrons, then we should have to have 1,760 electrons inside a hydrogen atom.

In the next few years we shall probably have this interesting question settled, but at present we can go only this far and show that the process of ionization, by any of the ordinary ionizing agents, as for instance X-rays, ultra violet rays, or radiations from radium, consists in knocking out just one electron from the molecule that is ionized. We prove this as follows: it is evident, from the above considerations, that if, in the process of ionization more than one electron were ejected, then the velocity of the oil drops would change by an amount corresponding to the addition or subtraction of more than one unit of charge. Our observations lead us to the conclusion that such a change never happens, at least with such ionizing agents as we have thus far tried. There may possibly be other kinds of agents which detach more than one electron. I have not yet been able to try to determine whether alpha rays of radium detach more than one, but X, beta and gamma rays certainly do not.

Some very recent work by C. T. R. Wilson confirms this conclusion even in the case of the alpha rays, although his experiments have not gone quite far enough to make the result certain.

Wilson has succeeded in actually photographing the tracks of the alpha and beta particles as they shoot through the air, and also the tracks of electrons ejected by X-rays from air molecules.*

His results help to throw a good deal of new light on this subject. The alpha particle is a big thing, four times the mass of the hydrogen atom; it drives through 7 centimeters of air before it is brought to rest, and will even drive through 0.002 or 0.003 mm. of glass and come right through without making a hole in the glass. The photographs show that the alpha particles produce an enormous number of ions in their path. These experiments are new, although other experiments like them are several years old.

What do they show? They show that what we call an atom of helium is able to push right through the inner spaces of other atoms. It does not sweep them aside. If alpha particles were merely sweeping aside the molecules, then their retardation, as they come through the gas, ought to be greater

* The method used by Wilson consisted essentially in photographing the clouds produced in dust-free air by the condensation of moisture around ions when air saturated with water vapor is expanded. The illumination is produced by means of a spark discharge from a Leyden jar, through mercury vapor at atmospheric pressure. Fig. 2 is a photograph of the tracks of alpha particles through air, while Fig. 3 shows the ionization produced by X-rays.

at the start, just as in the case of a bullet. Instead of that, the retardation of the alpha particles is least when they are going fast and greatest as they are slowing down—just what it ought to be if the alpha particle plunges right through the molecules. We must suppose, therefore, that an atom has a loose structure of some kind. It resembles the solar system, with probably a very powerful nucleus at the center, and some satellites around it.

Now what is to be expected if two atoms shoot through one another in this fashion? It is to be expected that the resistance which the gas opposes to the motion will increase as the atom slows down, just as in fact it does; second, that the ionizing power of the particle would increase as the speed decreases, because the two atoms are then under one another's influence for a longer time. This is just what does happen. We have then strong evidence that one atom shoots right through another atom, and in the case of the high speed atom, the alpha particle, there

Fig. 2. Photograph of the Tracks of Alpha Particles Through Air

is but little deviation from a straight line path, as the photographs show, and yet you will notice that there is almost always a sharp bend near the further end. This shows that there must be a powerful and a very small center of force inside the atom.

These experiments of Wilson then make it practically certain that we will no longer be able to consider an atom as consisting of a positive sphere of electrification uniformly distributed over the space occupied by the atom, while electrons revolve inside this

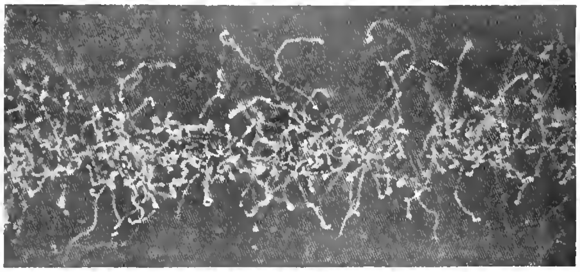


Fig. 3. Ionization of Air by X-rays

sphere. We must go back to some sort of a Saturnian atom. The actual space, however, occupied by the constituents of the atom must be exceedingly minute, probably more minute than the space occupied by the constituents of the solar system in comparison with the volume of this system. These photographs show, too, that the notion that one atom can squat on a certain portion of space to the complete exclusion of other atoms, must go. When we are dealing with sufficiently high speeds, matter possesses no such property as *impenetrability*.

Now we come to X-rays and the evidence they furnish in this field. It is evidence not so much as to the structure of the atom as to the character of the electro-magnetic radiations emitted by the atom. The photographs by Wilson show clearly that when an X-ray goes through a gas, its only effect is to throw out electrons from the molecules. The rays unquestionably pass over all but an exceedingly minute fraction of the atoms contained in the space traversed without spending any energy upon them or influencing them in any observable way. But here and there they find an atom from which they hurl an electron with enormous speed—a speed sufficient to produce ionization by collision. This is the most interesting and most significant characteristic of the X-rays, and one which distinguishes them from alpha and beta rays just as sharply as does the property of non-deviability in a magnetic field; for neither alpha nor beta rays ever eject electrons from the matter through which they pass with ionizing speeds.

Now one of the most interesting of recent developments is found in the discovery that the electrons shot out by the X-rays have the same speed, no matter whether the gas they act on is a half meter from the X-ray source or 40 meters from it. The same is true of gamma rays. This means that the energy which the X-ray or gamma ray imparts to its chosen electron is altogether independent of the intensity of the X-rays or gamma rays. It is also found to be independent of the character of the atom from which the electron is hurled. *This energy depends solely upon the penetrating power, or hardness, of the X-ray.* In fact, there is strong evidence now for the statement that, although only a thousandth part of the energy of the cathode ray beam in an X-ray tube is transformed into X-rays at the anti-cathode, yet when these same X-rays, weak in energy as a whole, fall upon matter outside the tube, they eject electrons from it with energies as great, or nearly as great, as those of the individual electron of the original cathode rays. It is as though the same energy were passed on in new form whenever an X-ray produces a beta ray, or a cathode ray produces an X-ray. These facts are among the interesting that have been discovered in the last four or five years. They seem to be completely inexplicable on any sort of a spreading wave theory.

Now why should this energy of electronic emission be always the same, no matter what the distance from the source? That fact can be accounted for in one of two ways: it can be assumed that for some reason the energy with which the X-rays are ejecting electrons is a trigger effect. That was, in fact, the first assumption made. The trouble with it is that, if correct, the velocity of the electron ought to be a property of the atom and independent of the hardness of the X-rays, provided only that the hardness is sufficient to set off the electron. That is, if the speed of the electron is a trigger effect, it ought not to vary with anything in the X-ray tube, but should be a specific property of the atom which shoots out the electron. As the speed of ejection does depend upon the hardness of the initial X-ray, it must be assumed that the energy comes out of the initial X-ray and not out of the atom.

Let us assume, then, that the energy comes out of the X-ray and that the ejection of the electron is not due to a trigger effect at all. How can this effect be then accounted for? The assumption may be made either that the atom acts as a store house of energy and keeps on absorbing it without giving any out until this stored up energy reaches a certain value, when it is suddenly released, or, on the other hand, that as the energy is radiated from the source it travels in bundles, the individual bundles losing nothing in intensity as they get further from the source. But when we study these two assumptions carefully we find that the assumption of a continuous absorption of X-ray energy by an atom until it accumulates a sufficient store to eject an electron with the observed speed is completely untenable, for the time required for it to do this, according to the spreading pulse theory, would be longer than the life of any X-ray bulb; yet as a matter of fact this ejection begins the instant the X-ray bulb is started. Precisely the same argument holds for gamma rays, for these are found to eject electrons from matter through which they pass with a velocity 0.9 that of light. This corresponds to an energy of 7×10^{-7} ergs. According to Rutherford, the total energy of the gamma rays per gram of radium, is 4.7×10^{-4} ergs, and if we assume that the number of gamma rays pulses is the same as the number of beta rays emitted, namely, 7×10^{10}, then the whole energy in a gamma ray is very nearly 7×10^{-7} ergs. That is, it is precisely the same as the energy communicated by the gamma rays to the ejected electron, even though this ejection may happen at a distance of 50 or 100 meters from the source. There is then no escape from the conclusion, in the case of gamma or X-rays, that the emitted energy keeps together as an entity, or quantum, which may be transformed back and forth between a beta ray and an X or gamma ray. This energy is slowly dissipated into heat in its passage through matter while it is in the form of a beta ray, but apparently not at all while it is in the form of an X or gamma ray.

In order to account for these phenomena, Professor Bragg advanced a frankly corpuscular theory of X and gamma rays, and his argument is so close to the undeniable experimental facts, at least as they now stand, that if X and gamma rays stood by themselves it is probable that there would be few opponents to his theory as to the corpuscular nature of these rays.

Some recent work, however, performed by Laue at Munich, shows that all the ordinary diffraction phenomena of light can be exhibited by X-rays. If the X-rays are radiations of the same nature as light, but of very short wave length, it is evident that in order to obtain diffraction phenomena with such extremely short wave lengths, diffraction gratings would have to be used with much closer ruling than it is possible to obtain at present.

Remembering that a crystalline body has a perfectly geometrical arrangement of its molecules and that the distance between these molecules is about 0.001 microns or 10^{-9} cm., Laue thought of the ingenious experiment of using the molecules themselves as a grating, and obtained beautifully sharp photographic patterns, which resembled very closely ordinary diffraction patterns. The wave length of the X-rays computed from the assumed intermolecular distances are about 0.0001 that of the shortest known ultra violet rays. These experiments seem to show that we cannot have a corpuscular theory of X-rays unless we have also a corpuscular theory of light.

There are also other respects in which there is a marked parallelism between optical and X-ray effects. Thus:

(1) Ultra-violet light, like X-rays, ejects electrons with speeds which have been repeatedly shown to be completely independent of the intensity of the source. I have myself raised a doubt about this conclusion, but have recently shown that the doubt is unjustified, and that the conclusion holds even when the intensity varies in the ratio 1000 to 1.

(2) In the normal photo-electric effect, which has none of the earmarks of a resonance phenomenon, all observers now agree that the speeds of the ejected electrons increase regularly with the frequency of the light, just as the speeds of electrons ejected by non-homogeneous X-rays increase with the hardness of the rays. Apparently, too, the law of increase is the same in each case.

(3) There is a selective photo-electric effect characterized by the emission at a particular frequency of the exciting rays of an abnormal number of electrons. This emission can not be excited until the frequency of the incident light reaches a definite value which is characteristic of the illuminated substance. This selective effect bears all the earmarks of an absorption band. Precisely similar, there is a selective X-ray effect characterized by the emission at a given hardness of an abnormal number of electrons, and also by the excitation of a new type of X-ray radiation, which differs from the ordinary or scattered X-ray in being homogeneous, symmetrical about the origin, and having a penetrating power which is characteristic of the emitting substance instead of the quality of the exciting X-ray. This so-called homogeneous or characteristic X-radiation can not in general be excited until the hardness of the exciting ray exceeds a definite value. This critical value is nearly proportional to the atomic weight of the excited substance. The exciting rays experience absorption at the hardness at which the new increase in beta rays emission occurs. In other words, this selective X-ray effect, like the selective photo-electric effect, bears all the earmarks of an absorption band.

We must therefore devise a theory which makes the X-rays keep together in a bundle and yet allows them to possess the properties of light waves. So we must begin to experiment in our theorizing with a structure in the ether which will permit both of these things to happen.

One other line of investigation which is exceedingly interesting I should like to mention very briefly. Let me start from the effect that I mentioned regarding characteristic X-rays. I have mentioned the fact that these characteristic secondary rays are for some reason or other not given off, not excited at all, until the incident X-ray energy comes to them in a certain intensity. It takes a certain hardness of X-ray to set up characteristic secondary rays. When we come to the ultra-violet light experiment, we find that it takes a certain frequency of light before we get any electrons detached from the illuminated metal. This frequency depends upon the nature of the metal.

These are analogous effects, and there is evidence that the same factor that converts the frequency of ultra-violet light into the kinetic energy of the electron emitted from the illuminated surface also holds for the emission of corpuscles by X-rays. That is, the amount of energy absorbed by the ejected electron is, in each case, given by a product $h\omega$ where ω is the frequency of the ultra-violet or characteristic X-rays and h is a universal constant. We are thus led to the notion of a quantum hypothesis, that is, an atomic theory of energy. Planck, who first formulated this theory, has also indicated the conclusions to be derived from it. It predicts that the energy of emissions of electrons under the influence of ultra-violet light is proportional to the frequency. We are pretty sure that the energy of emission of X-rays is proportional to the hardness, and the identification of hardness and frequency is logical.

But here is another striking fact; not only in these two fields of optical and X-rays effects does there arise the logical necessity for some kind of quantum hypothesis, but the theory has also received a great deal of support from results obtained in a totally different field. I refer to the recent developments brought about by the study of specific heats of solids at high and low temperatures.

One of the most interesting of the hitherto unexplained laws of physics is the Dulong and Petit relation between atomic weight and specific heat. According to this law, the product of these two quantities is approximately constant and equal to 6; that is, a given number of atoms of any kind absorb just the same amount of energy per degree rise in temperature. But we have known for a long while that there are some exceptions to that rule. Thus the light atoms of carbon, boron and silicon, absorb much less energy per degree rise of temperature. Then the next thing was to find out how temperature affects these atomic heats, and twenty years ago experiments with boron and silicon showed that they obeyed the Dulong and Petit law at higher temperatures. Now the recent work of a number of experimenters, notably of Nernst and his pupils, shows that at sufficiently low temperatures, all substances show abnormally low atomic heats, and that, in general, the lower the atomic weight, the higher the temperature at which the abnormality begins to appear. This means that if a degree of rise in temperature means a given increase in the energy vibration of the atoms of any substance, then at low enough temperatures only a fraction of the atoms take on a normal energy load. But this is precisely what the quantum theory demands. No atom can take on any energy at all until the impact of the molecules of the surrounding gas possess an energy as high as $h\omega$, and hence the higher ω the higher the temperature at which energy can begin to be absorbed. Further, the smaller the atomic weight the higher ω and hence the sooner should atomic heats lower than 6 calories begin to appear with decreasing temperature.

The curves expressing the relation between atomic heat and temperature are similar for all the elements, but the curves for elements of lower atomic weight begin to curve down at higher temperatures than those of higher atomic weight, and the order in which they run off is the same as that of the vibration frequencies of the atom in the solid state. This means that when energy flows into any substance, it is not absorbed (that is, the substance is transparent to the energy) until the intensity of the energy reaches a definite value, which depends upon the temperature. Each substance thus has a characteristic temperature at which the energy begins to be absorbed.

It is thus seen that the same factor h that is so serviceable in connecting frequency of ultra-violet light or of X-rays with energy of electron emission, also has to be considered in the field of specific heat determinations; that is, in all cases where we are dealing with extremely small quantities of energy at high frequency, we find that we are led to some form of quantum theory. But the wave theory of light at present seems to be incompatible with any other forms of quantum theory so far devised. That a corpuscular theory of radiation will ever supersede the wave theory is to me quite unthinkable. The facts of the static field and of alternating currents of high and low frequency seem to preclude such a possibility. But I see no reason *a priori* for denying the possibility of assigning such a structure to the ether as will permit of a localization of radiant energy in space, or of its emission in exact multiples of something if necessary, without violating the laws of interference. That no one has yet been able to do this can scarcely be taken as a demonstration that it cannot be done. Fifty years ago we knew that such a thing as an atom existed, but we knew absolutely nothing about its structure, and it was customary to assume that it had none. To-day, we know a great deal about the structure of the atom, but the position formerly occupied by it has been assumed by that thing which we call the ether. We know that there is a vehicle for the transmission of electromagnetic energy, but we know nothing whatever about its structure, and it has been customary to assume that it has none. To deny the existence of this vehicle, which we have been in the habit of calling the ether, and to use the word "vacuum" to denote all the properties heretofore assigned to it by the experimentalists, namely, those of transmitting electromagnetic disturbances, is a bit of sophistry in which he is little interested. We seem to be on the eve of learning something more about the properties of this vehicle, call it by what name you will, than we have known heretofore. Certainly there has never been a time when physics offered such task to its followers as now, nor ever a time when it needed more and better brains applied to these tasks.

ARCS AND ELECTRODES

By S. H. Blake and L. H. Couchey
Engineers, Arc Lamp Department, Pittsfield Works, General Electric Company

Electric arcs are of two kinds, those that owe their light-giving properties to incandescence of the electrodes, and those that give light by reason of the luminosity of their arc streams. Under the heading of the first come the old open and enclosed carbon arcs of both direct and alternating current, while classified under the latter we find the mercury vapor arc and the modern "luminous" and flame arcs; the distinction between the last two lying almost wholly in the manner in which the light-giving material is introduced into the arc stream, whether by electro-conduction or by heat evaporation. Equally as difficult as determining the proper substance to use for the light-giving elements, or designing the lamp mechanism, has been the production of satisfactory electrodes, even for the original open carbon arcs. The electrodes that were suitable for the open arc were too impure and imperfectly formed for the enclosed lamp: and so it has been in each instance of the development of a new arc—new substance for the electrodes, new structure, new diameter and length. An article on "The Composition and Preparation of Electrodes for Luminous Arc Lamps," by E. R. Berry, will be found in the issue for December, 1911.—Editor.

Characteristics of Carbon Arcs

An electric arc consists of the arc terminals and the arc stream, that is, the vapor conductor which carries the current across the space between the terminals. Light may be given by the arc terminals, or by the arc stream, or by both. For instance, in the mercury arc all the light is given by the arc stream, and none by the terminals because of their low temperature. In the plain carbon arc practically all the light is given by the terminals, and hardly any by the stream. Flame arcs usually give light from the terminals as well as from the stream.

The light given by the terminals depends upon their temperature, and follows the general law of temperature radiation, i.e., light production from *incandescence*; and with increasing temperature the light changes from red to orange, yellow, yellowish white, to white increasing in intensity. For producing good efficiency the highest possible temperature of the terminals is required. As carbon is the most refractory material known, i.e., stands the highest temperature, it is exclusively used where light is to be produced by the arc terminals. This gives us the plain carbon arc which has been used for many years. As even with carbon the temperature is limited, the efficiency of the plain carbon arc is also limited, and probably does not greatly exceed one watt per candle.

The light from the arc stream does not depend directly upon the temperature, but is essentially dependent upon the chemical nature of the material of which the arc vapor is composed. That is, just as for instance gold is yellow, copper red, and silver white in color, for no particular reason except that this is just the nature of these materials, so mercury gives an intensely green light, iron a white light, and carbon a purple light of very low intensity.

Therefore, to produce high efficiency and the desired color of light from the arc stream, it is necessary to search amongst all chemical substances to find the one or ones which just happen to have the desired properties. The temperature has nothing directly to do with this phenomenon. For example, carbon, which produces the hottest arc because of its extremely high boiling point, gives very little light; iron, which boils at a much lower temperature and thus has a correspondingly lower temperature arc stream than carbon, gives a bright white arc; mercury, with an extremely low boiling point and therefore very low temperature of the arc stream, gives a remarkably efficient green light; while titanium, with a fairly high boiling point, gives a still more efficient white arc.

In the order of their efficiency as producers of light in the arc stream, materials arrange themselves about as follows:

Material	Color of Arc Stream	Remarks
Titanium	White	Most efficient
Calcium	Yellow	
Mercury	Green	
Cerium and other rare earths	White	
Iron	White	
Barium	Greenish white	
Magnesium	White	
Zinc	Bluish green	
Copper	Green	
Aluminum	White	
Boron	Green	
Carbon	Purple	Least efficient

The efficiency of light production by the arc streams of the most efficient light-giving materials, such as titanium, calcium, and mercury, is much higher than the efficiency of light production by incandescent arc terminals even at the highest available temperature, that of the carbon arc, and such *luminescent* arcs therefore are much more efficient that the plain carbon arc of old. The efficiency of arc lighting was, therefore, greatly increased by abandoning the plain carbon arc and introducing materials in the arc stream which would make it luminous. Such materials may be introduced in two ways, viz.:

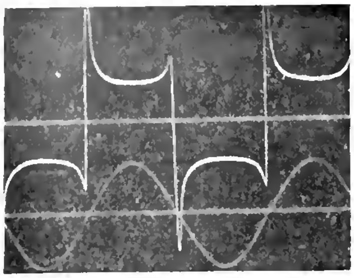


Fig. 1. 60 Cycle Arc—Titanium Electrode

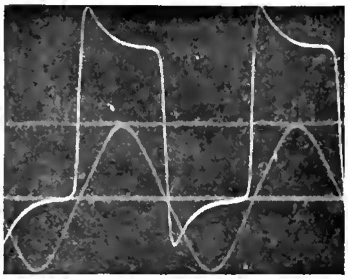


Fig. 2. 60 Cycle Arc—Hard Carbon Electrode

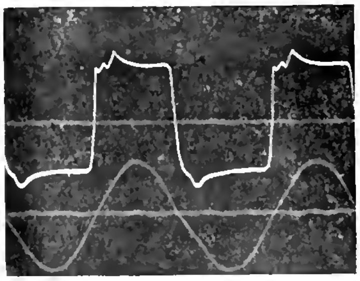


Fig. 3. 60 Cycle Arc—Cored Carbon Electrode

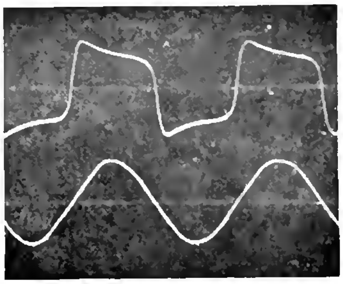


Fig. 4. 60 Cycle Arc—Flame Carbon Electrode

1. *By electro-conduction.* That is, the electric current in passing between the electrodes carries the material into the arc stream. Such arcs are called "luminous arcs." They are represented by the magnetite, the titanium, and the mercury arcs. As the negative terminal of such arcs supplies the material which carries the current in the arc stream, the light-giving material must be used as the negative terminal; and as the light-giving material is carried into the arc stream by electro-conduction from the negative terminal, and not by heat, the temperature of the terminals is of secondary importance and the terminals may be made so large as to remain at low temperature and give practically no light, as in the magnetite and mercury lamps.

2. *By heat evaporation from the terminals.* That is, the terminals are heated by the current to such a temperature that the light-giving material contained in them evaporates and thereby gets into the arc stream, coloring it and raising the efficiency. Such arcs are called "flame arcs." Their efficiency depends on the temperature of the terminals to the extent that the higher the temperature of the terminals the greater the amount of light-giving material that is evaporated from them into the arc stream. As carbon stands the highest temperature and gives the steadiest arc, it is always used in the electrodes for flame arcs. The flame arc is, therefore, a carbon arc colored by the light-giving material evaporated into the arc stream from impregnated terminals. As the positive terminal is the hotter one, the light-giving salts must be introduced into this terminal. The negative terminal may contain more or less of the light-giving material, or may be plain carbon, without affecting the efficiency of the arc to anywhere near such an extent as would similar changes in the content of the positive electrode.

The more light-giving material used in the flame arc and the quicker it is evaporated by the consumption of the carbons, the higher is the efficiency. However, since in the flame arc the arc stream must always consist partly of the light-giving material and partly of non-luminous carbon vapor, its efficiency can never be as high as if the entire arc stream consisted of the light-giving material, as in the luminous arc. Thus the luminous arc of the titanium lamp is more efficient than the titanium flame arc.

In an electric arc the current crosses the space between the electrodes through a stream of electrode vapor that issues from the negative electrode as a high velocity blast. The arc stream is conducting only in the direction of this motion, i.e., from negative to positive. Arcs are therefore unidirectional conductors. The positive terminal always has a larger crater than that of the negative and is by far the hotter. These facts therefore indicate why pure carbon arcs, both of the open and enclosed type, which depend for their efficiency upon the temperature of the arc terminals, are much more efficient on direct current than on alternating current.

With an alternating current arc the current falls to zero at the end of each half wave; the vapor stream therefore ceases, and for the next half wave a vapor stream of opposite direction is required, i.e., a spot on the other terminal raised to boiling point and sufficient material evaporated to carry the current. This requires energy, and therefore high voltage. That is, the alternating arc goes out at the end of each half wave and has to be restarted in the opposite direction by a static spark at the beginning of every half wave. The voltage required to jump such a spark depends upon the temperature, decreasing greatly at high temperatures, so that at some temperature not far below that of the carbon arc the spark voltage falls below the arc voltage; i.e., any voltage that is sufficient to maintain an arc will virtually start it at every half wave. Carbon is practically the only substance that can maintain an alternating arc at low voltage at atmospheric pressure. But even with the alternating carbon arc, especially between hard carbons which produce less vapor, this re-starting of the alternating arc at each half wave is noticeable in an oscillogram of current and voltage, being indicated by a high voltage peak at the beginning of every half wave following the period of extinction of the current. Electrically this phenomenon appears as a distortion between current and e.m.f. waves and therefore decreases the power-factor, although there is no actual phase displacement between the two waves; i.e., the two waves are apparently always zero at the same time.

In this connection it is interesting to examine the several oscillograms shown in Figs. 1 to 4 inclusive. These were taken with 60 cycle arcs operating with various materials as electrodes. The high voltage peak at the beginning of each wave is quite noticeable

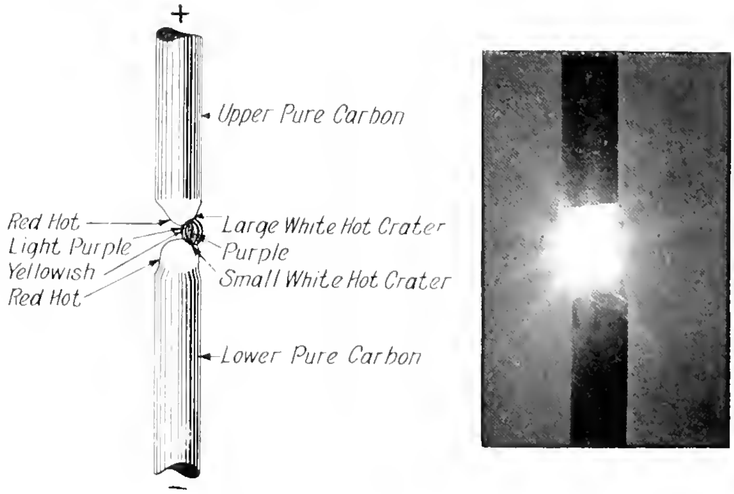


Fig. 5. Direct Current Open Arc

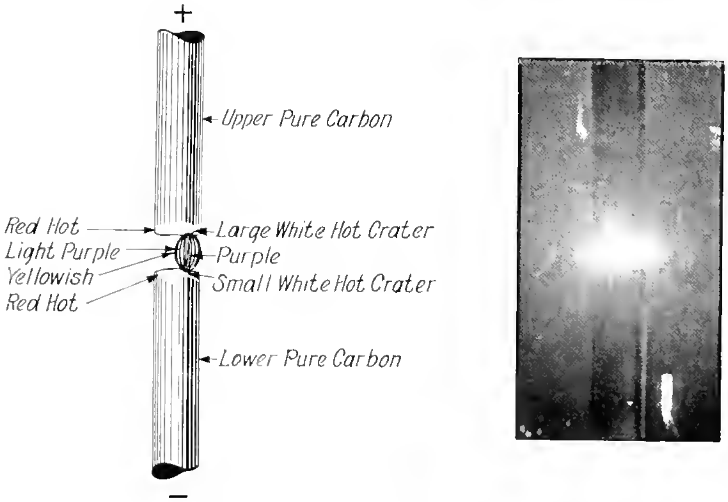


Fig. 6. Direct Current Enclosed Arc

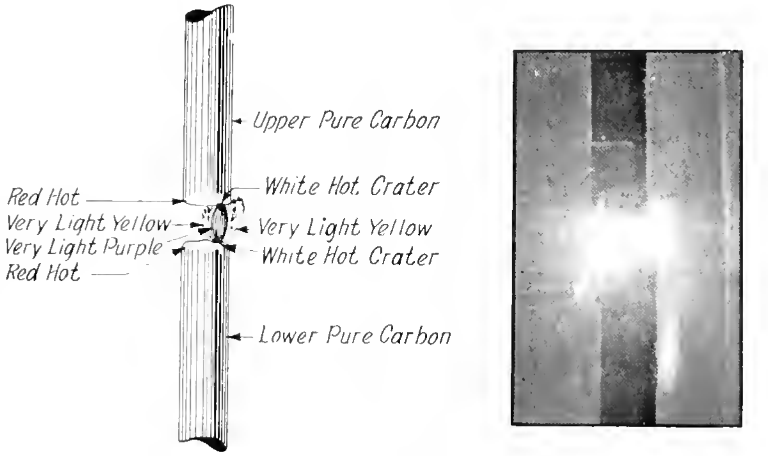


Fig. 7. Alternating Current Enclosed Arc

able in all these curves, but is particularly marked where titanium is used, due to the fact that the titanium lowers the temperature of the arc stream, thus increasing the

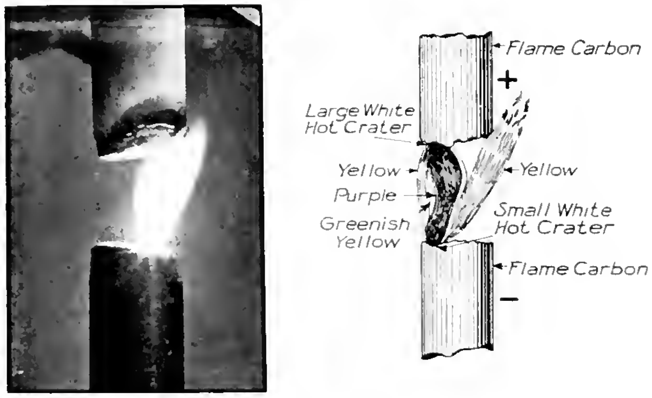


Fig. 8. Direct Current Flame Carbon Arc, Yellow Flame Carbons

sparking voltage necessary to re-start the arc. With hard carbons the front peak is also very apparent, owing to the fact that such material does not volatilize readily so as to start the vapor path. With cored carbons, soft carbons, and flame carbons there is a

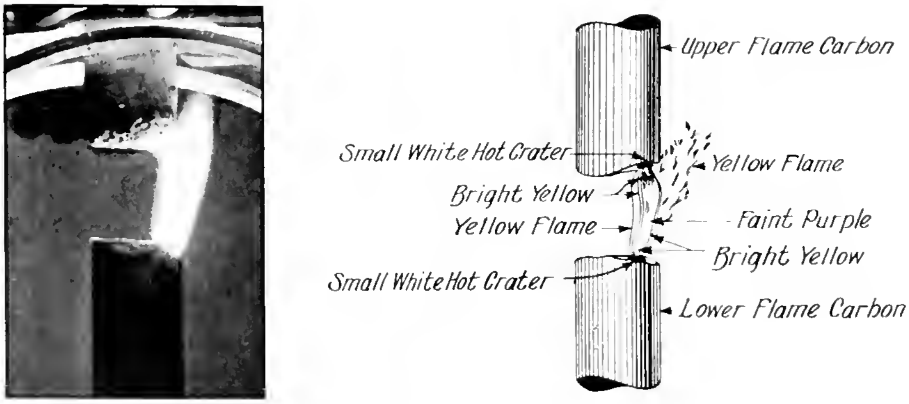


Fig. 9. Alternating Current Flame Carbon Arc, Yellow Flame Carbons

bountiful supply of soft carbon ready to volatilize quickly, and the curves of such arcs have front peaks much less pronounced. High front peaks are also naturally more marked with long arcs than with short ones, and the distortion of enclosed arc curves is greater than that of open arc curves.

If we judge the resistance of the arc from the relation of the current curve and e.m.f. curve, it seems to vary almost inversely as the current through it. Thus, with the current at a minimum, the resistance is at a maximum, and as the current rises the vapor path is increased in volume until the current is at its peak when the resistance of the arc is lowest. As the current fades away the arc stream cools and its resistance increases. This cooling, due to decrease of current, causes the characteristic small peak at the end of each half wave of the e.m.f. curve.

Figs. 5 to 12 show the various types of arcs that have been used commercially since arc lighting has been used. Beside each cut is a rough sketch indicating the color, shape and formation of the arcs, craters and carbon points. It is interesting to note that the arc streams of the flame and luminous arcs are intensely bright, while those of the pure carbon arcs are a non-luminous pale purple. The fact that the arc streams of the flame arcs have an inner core of faint purple vapor distinguishes them from the luminous arc streams, which are solid cones of intense white flame.

Electrodes

Up to about ten years ago the plain carbon arc was used exclusively for arc lighting, and even at the present time by far the greater portion of arc lighting units in commercial operation are still of that type, although they are rapidly being displaced by lamps having luminescent arcs. It would seem quite a simple matter to make pure carbon electrodes, but as a matter of fact the production of satisfactory electrodes for arc lamps has always been as much of a problem as the development and design of the arc lamp mechanisms themselves. With the original open carbon arcs the problem was to get carbon electrodes that would burn steadily, quietly, and without variation in color.

Early investigators of carbon electrode manufacture were very much handicapped by the lack of proper materials, having to use gas retort coke and wood charcoal; and the first carbons produced were hard, porous, crooked and imperfect in shape. Such carbons would often splinter and crumble when first started, owing to the explosion of gas pockets in the carbon structure; while the arc flickered, changed color, and hissed, due to the many impurities in the mixture. By using lampblack and very pure, finely pulverized coke uniformly mixed with sugar syrup or coal tar, squirted at high pressure and carefully baked at high temperature, good solid electrodes were finally produced. It was not until the cored carbon was invented, however, that really first-class operation could be secured with open arc lamps. Such carbon consists of solid carbon tubes filled with a comparatively soft carbon mixture as a core. The soft carbon cores tend to hold the arc craters in the center of the electrode tips, thus making the arc more steady and quiet.

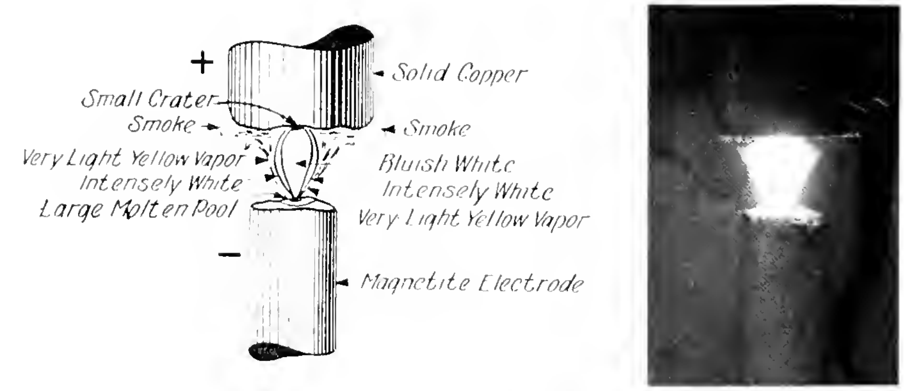


Fig. 10. Direct Current Luminous (Magnetite) Arc

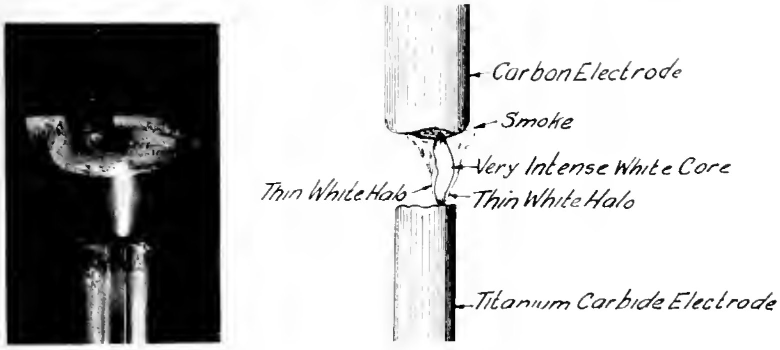


Fig. 11. Alternating Current Luminous (Titanium) Arc

The length of time of burning (so-called "life") of the electrodes has always been a most important problem, and even Davy in his first experiments with the electric arc, carried on about one hundred years ago, prolonged the life of the charcoal electrodes he used by putting them and the arc within a glass enclosure. It was early determined that with such an arc operating in the open air the upper carbon soon became pointed, owing to the great draught of air continuously wiping against its white hot tip, and that much more carbon was consumed than was really needed to properly maintain the arc. This action is termed "washing." It was discovered that if the upper carbon is electroplated with some metal such as copper, nickel or zinc, this "washing" is reduced and the life of the upper electrode appreciably lengthened.

With the arc burning in the open air, however, it was found to be quite impossible to produce a commercial arc lamp that, with one trim of carbons, would burn much longer than the length of one winter night. of every day, as with the open arc, is very pronounced. With the enclosed arc, solid carbons for both upper and lower give satisfactory operation on direct current, but with alternating current one carbon, either the upper or the lower, must be cored.

As long as the efficiency of the arc depended upon the law of temperature radiation or light from incandescence, the carbon manufacturer sought to improve his product by making it purer and more uniform. The only exception to this rule was with the material used for coring carbons, as it has been known for many years that small quantities of certain potassium and sodium salts when added to the coring material have a steadying and quieting effect. The sodium salts tend to color the arc yellow, and therefore the potassium salts, which produce whiter light, are generally preferred for the coring of pure carbon electrodes.

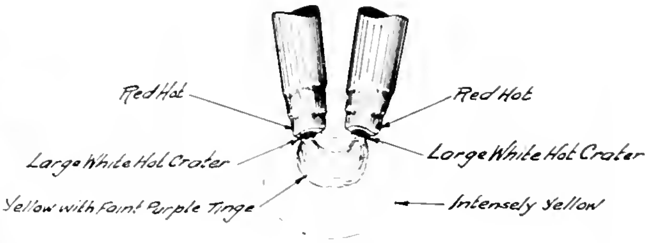
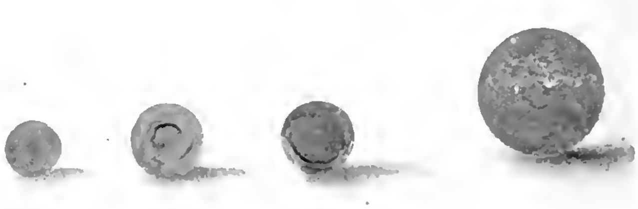


Fig. 12. Alternating Current Open Flame Arc. Converging Electrodes

By surrounding the arc and the hot tips of the electrodes by a nearly air tight glass globe or bulb the life of the electrodes is greatly increased. This increase of life with the enclosed arc is secured at the expense of efficiency; but the arc is steadier than with the open arc and a larger proportion of the total light flux is distributed near the horizontal, making it better suited for street illumination. Therefore, in order to secure longer life per trim of carbons the enclosed lamp was introduced and gained great favor in America, but not abroad.

With the advent of the enclosed arc the carbon manufacturers were faced with a new problem. Carbons that were suited for open arc service were too impure, rough and imperfect for the enclosed arc. Impurities in the carbons condense on the inner surface of the enclosing bulb, greatly obstructing the light. Imperfections in the size, surface and straightness of the electrodes tend to cause the carbons to stick in the bushings through which the carbons enter the glass bulbs. Very pure, smooth, straight carbons of uniform diameter had to be produced for enclosed arc service. Although such carbons are much more costly than the cruder carbons suitable for open arc operation, the ultimate economy resulting from the fact that the enclosed arc need only be trimmed once a week instead

For the flame or colored carbon arcs the problem is to produce carbons so made that material of very high selective emissivity, such as titanium, calcium, cerium or barium, will be uniformly fed into the pure carbon arc maintained by the carbon constituents of the electrodes. It is desirable to use as large a percentage of this light-giving material as possible, but as these salts are non-conductors



a b c d

Fig. 13. Sectional View of Electrodes Showing the Evolution of the Present Homogeneous Structure

at ordinary temperatures, only so much of the foreign material can be used as will be uniformly volatilized from the electrodes by the heat of the arc, thus keeping the tips of the electrodes clear of the non-conducting material.

Due to the difficulty of producing such electrodes from the start, the first flame arcs, which were of the open type, i.e., burning with free supply of air, were maintained between the bottom tips of long slender carbons, inclined towards each other at an angle of about 30 deg. With this arrangement any excess of impregnating material drops away from the electrodes, whereas with carbons arranged vertically one above the other, any such excess of light-giving salts is liable to lodge on the tip of the lower carbon in such a manner as to insulate the carbons from one another at starting or time of feeding, thus preventing the arc from forming. However, since flame carbons have been further improved, open flame arcs between vertical carbons are operated very satisfactorily. Because of the fact that an arc drawn between the lower points of two converging electrodes can change its length if the craters move to different points on the electrode tips, it is necessary with such an arrangement to use very slender electrodes, generally consisting of pure carbon tubes with large cores impregnated with the light-giving salts mixed with carbon and arc-steadying salts. The diameter of these electrodes is seldom greater than 10 mm. and they are used as small as 7 mm. With such small carbons the craters of the arc remain steadily fixed upon the carbon cores, and the temperature of the carbon tips is maintained so high that a large amount of light-giving material is volatilized and made luminous, thus giving very high efficiency as a light source. The carbons are so small, however, that it is necessary to make them 600 mm. long in order to get 17 hours life with one trim of carbons; while the voltage drop through these long, thin carbons is so excessive with a 10 ampere arc that it is necessary to run a metal wire (brass or lead) through a hole in the carbon in order to decrease its resistance. Such a carbon is shown in cross section in Fig. 13a. With electrodes run in the vertical position small diameter carbons are not necessary, and as such carbons cannot conveniently be longer than 300 mm., they are made 12 to 16 mm. in diameter with large cores, as shown in Fig. 13c, so as to get 17 hours' life.

Fig. 14. An Early Type of Impregnated Electrode. Star-shaped Section is Carbon, while Light-colored Material between Arms is Light-giving Material

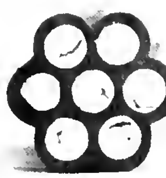


Fig. 15. Another Form of Impregnated Carbon Electrode. The Dark Section is Carbon, the Light Section Light-giving Material.

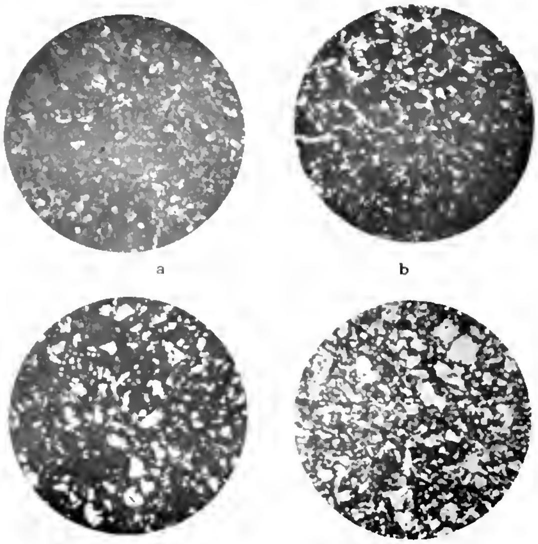
The disadvantage of the short life of the open flame arc was the direct cause of the development of the enclosed flame arc, just as the long life of the enclosed carbon arc enabled it to entirely replace the open carbon arc. In developing the enclosed flame arc lamp both the lamp designer and the carbon maker had many difficulties to solve. The former had to provide an arrangement of the arc-enclosing chamber so that the condensed fumes from the arc would not lodge on the inner surface of the enclosing glass globe, thus obstructing the light; and the latter had to produce electrodes with ingredients properly proportioned, mixed and fired, so that in the nearly inert atmosphere within the arc-enclosing chamber just the right amount of light-giving material would be uniformly fed into the enclosed carbon arc to produce maximum efficiency without danger of arc interruptions due to insulating material forming or lodging on the electrode tips. Among the many forms of electrodes that came into use, was that shown in Fig. 14. The star-shaped frame of this electrode is of pure carbon and the material pasted in between the prongs of the star is light-giving material. Another form is that shown in Fig. 15, where the salts are entirely surrounded by the carbon frame of the electrode. Many attempts were made to use a very large core in a thin carbon shell, but such carbons were not successful, owing to dropping out of the core, and to the high cost of squirting, firing and coring such large diameter thin walled shells. One particular disadvantage that applies to all three of these electrodes just mentioned is that the arc changes color and flickers due to the shifting of the craters from the pure carbon portions of the electrode, where the light would be faintly blue, to positions where the light-giving salts are strongly volatilized with resulting intensely bright illumination. The ultimate solution of this electrode problem is shown in Fig. 13d, i.e., a homogeneous mixture of all the ingredients necessary for the proper formation and maintenance of a highly efficient enclosed flame arc, constant in color, intensely brilliant and steady in operation.

Fig. 16. Homogeneous Flame Carbons at Two Different Stages of Burning

This result was not accomplished without a great deal of research work. Many thousands of carbon mixtures were produced and tested before a satisfactory commercial product was secured. Some of the homogeneous flame carbons produced gave a wonderful volume of yellow light, measuring as high as 3300 c-p. These carbons proved unreliable, however, because of the large amount of mineral matter that would boil out of them in the form of slag, which was non-conducting when cold. Many experiments were carried on, the percentages of luminous salts being gradually reduced and various mixtures of chemicals tried out in an effort to prevent slag formation. For example, the first samples had large percentages of calcium fluoride in the mixture, which, boiling out at approximately 1300 deg. C., would evaporate into the carbon stream in greater quantities than could be completely volatilized, and it was necessary to add high melting salts to the electrode to act as restrainers between the low melting salts and the boiling point of carbon. Much progress has been made in perfecting these mixtures, and today, as stated before, very satisfactory yellow light carbons are available for both a-c. and d-c. enclosed flame arcs.

It is very desirable to also produce white light carbons for these lamps, but up to the present time it has not been possible to make such carbons anywhere near as efficient as those for yellow light. Very satisfactory operating white carbons are produced for both a-c. and d-c. use, but their intensity and efficiency are lower than the yellow light carbons.

When a new trim of carbons is started in an enclosed flame lamp, the light for the first one-half hour or more is very much yellower with the yellow carbons and whiter with the white carbons than after the lamp has been burning for some time. This is due to the fact that at starting there is an excess of light-giving material at the tips of the electrodes. After the arc has been burning a short time the light-giving material is driven out of the white hot points of the carbons, leaving the ends of the electrodes in a somewhat spongy condition. After this stage has been reached the carbons will burn uniformly as to color and steadiness for the rest of the trim,



a b c d

Fig. 17a, Cross Section of Pure Carbon Electrode; b, Cross Section of Successful Homogeneous Flame Carbon; c and d, Cross Section of Coarse Texture of Unreliable Flame Carbons

as the points of the carbons always remain porous for about one-half inch from the end, where they are very hot; but beyond that point the impregnating material remains undisturbed until the heat of the arc volatilizes it and drives it out of the electrode structure, leaving the spongy carbon formation. Fig. 16 shows the same homogeneous flame carbons at two different stages of burning. The long electrode represents the condition of the tips shortly after the arc has been started. The temperature of the arc drives out the low-melting, light-giving salts in greater quantities than can get into the arc stream. These low-melting salts boil over the entire end of the carbon, until the arc has evaporated the excess vapor, when the carbons assume the porous appearance as shown by the shorter carbon.

The photomicrographs of Fig. 17 give a good illustration of flame carbon development. These photographs were obtained by polishing the entire cross section of the electrode, and the portion photographed is typical of the surface thus prepared. In this manner the evenness and fineness of the texture of the carbon is brought out. The success of an electrode depends largely upon the proper mixing of its different ingredients into a homogeneous mass of even texture. These specimens are magnified 19 diameters.

2400-VOLT RAILWAY ELECTRIFICATION

By H. M. Hobart, M. Inst. C.E.
Consulting Engineer, General Electric Company

It is gradually coming to be recognized that, even for a relatively sparse service of freight trains and express passenger trains, the economies to be effected by trunk line electrification in the direction of decreased fuel consumption, decreased repairs and maintenance, and increased annual mileage per locomotive will in many instances justify the capital outlay involved. Expanding loads, improved machinery and scientific management are responsible for a progressive decrease in the price at which the big supply companies can sell electricity at a profit; and the nature and extent of the railway load are such that a price of one cent per kilowatt-hour and less can even now be realized in many localities for this load. It is therefore becoming increasingly practicable for railways to purchase their electricity along the line of route, thereby limiting their own capital outlay to that associated with substations, feeders, contact-conductors and rolling stock. The question is purely one of economics, as distinct from engineering; and this fine paper was presented before the A.I.E.E. with the object of eliciting some fruitful discussion of the economics of railroading, and to arrive at some fairly true estimate of the present chances of electricity for trunk line operation, on the basis of superposing the railway load on the existing industrial loads and taking advantage of the resulting diversity and the present advanced state of the central station art. It is entirely regrettable that much of the time at the New York meeting was frittered away in a fruitless discussion of d-c. *versus* single-phase, to the neglect of the much broader questions at issue. The reprint of Mr. Hobart's paper will be concluded in our August issue—Editor.

The employment of electricity as the motive power for sections of railway on which a dense service is maintained has long since been demonstrated to be desirable from many standpoints. For such undertakings it is a point of relatively minor consequence whether the railway provides its own power house or purchases its electricity from independent undertakings. In the former case the capital outlay involved in carrying through the electrification is increased, but the total of the annual capital and operating costs is rarely much affected by the choice between these two plans. It requires a careful consideration of each specific case to determine which of the two policies will lead to the most economical result. The difference will usually be so slight as to involve no wide-reaching consequences.

Nevertheless, on the broad principle that specialization and concentration are usually in the interests of true economy, the general recommendation can be made that, in cases where no obvious considerable advantage accrues to the railway from owning the electricity-generating plant, and where satisfactory terms can be obtained from an independent electricity-supply company, it is on the whole desirable to purchase the electricity, leaving the railway company to concentrate the abilities of its engineers on the immediate problems of railway operation. Usually the independent electricity-supply company should be able to provide the electricity at an attractive price, for the reason that the annual consumption will usually be quite an addition to its lighting and miscellaneous power load; and for the further and important reason that the time-distribution of the railway load will usually be such as slightly to improve the total load factor at the generating station. These points have been emphasized in a paper entitled "The Relation of Central Station Generation to Railway Electrification," presented by Mr. Samuel Insull before the American Institute of Electrical Engineers on April 5, 1912.

There are, however, other classes of railway traffic where it would be a great, and often a hopeless, handicap to the project were the railway to provide its own power house for the supply of electricity. These classes of traffic are, nevertheless, of great importance. They consist in relatively sparse services of high-powered trains. When the load represented by such traffic can be supplied from the same generating stations which supply power for a dense urban and suburban service, its sparse character presents no special disadvantage. But for other sections where the traffic consists chiefly or exclusively of only a few (say eight or ten) high-powered trains passing daily in each direction, a power station, built and operated for the exclusive purposes of this sparse traffic, could only provide the required electricity at a cost very much in excess of the price at which it could be purchased from stations already supplying a large quantity of electricity for lighting and power purposes.

It is only during the last few years that the growth of the electricity generating and supply business has increased to the enormous extent to justify the statement that it already forms a fair approach to a complete network throughout most of the moderately-settled sections of this country. It has thus come about that in estimating upon the electrification of many important sections of railway where the traffic consists of relatively few high-powered trains per day, the estimates can be based upon the purchase of electricity from some large electricity-supply station, to which the additional load will be so welcome with respect to the increase which it effects in the quantity of electricity to be manufactured annually, that, notwithstanding the irregular nature of the load, the electricity can be supplied to the railway at a very moderate price. In a later section of this paper, allusion will be made to further reasons contributing to this result.

The upshot of this altered state of affairs is that propositions which, only a few years ago, must inevitably have been dismissed as not within the economic range for electrification may now be demonstrated to be highly attractive and from all standpoints commercially reasonable. By working out in this paper a few simple comparisons, attention will be drawn to the leading facts which must be taken into consideration in such estimates. No attempt will be made to work out *detailed* quantitative estimates: on the contrary, the only quantitative data put forward in the paper will be of a kind to indicate tendencies and to draw attention to the general order of magnitude of the corresponding costs for steam and electric operation. The investigation will be confined exclusively to traffic of the nature indicated, namely, high-powered freight and express-passenger trains, as it is for this class of traffic that it has until recently been considered that steam locomotive methods possess inherent characteristics of an economic nature which could not be rivalled by alternatives in which electric locomotives are employed.

Let us first consider a case where it would naturally be claimed that the steam locomotive would be most strongly entrenched, namely, an express-passenger service. It is not asserted that the results of the estimates which will be put forward are necessarily inconsistent with the above claim, but rather it is intended to point out that, even in so extreme an instance, there are attractive possibilities in the electric-locomotive alternative.

An express locomotive hauling a passenger train on any one of our Eastern railways will in actual service burn at least 3.5 pounds of good coal per indicated horse power hour. As a representative train we may take for example a Pacific-type locomotive weighing, complete, 185 tons[1] and hauling 10 modern Pullman coaches constructed of steel and weighing 75 tons each. There is thus an aggregate weight of $10\times75=750$ tons behind the locomotive. Of the total locomotive weight of 185 tons, the tender accounts for no less than 70 tons. Even of the remaining 115 tons only 85 tons is carried on the three driving axles, or 57,000 pounds per axle. On the basis of a coefficient of adhesion of 0.20, the locomotive can exert a tractive effort of

$$0.20\times85\times2000=34,000 \text{ lb.}$$

before slipping the wheels. For the usual requirements of an express-passenger service, this limit will rarely be approached. The total train weight amounts to

$$185+750=935 \text{ tons.}$$

Typical of the service of such trains is the making of non-stop runs of, say, 100 miles in two hours. This corresponds to an average speed of 50 miles per hour. In the course of this 100-mile run, *maximum* speeds of over 60 miles per hour will be attained. The average tractive effort, taking into account the variations in speed, and assuming representative track conditions as regards curves, grades, and weight and condition of rail, for

[1] The 2000-lb. ton (=0.9 metric ton) is employed throughout this paper.

a train of this composition, will be roughly 9 lb. per ton.

The total tractive resistance will be

$$9\times185+9\times750=1670^*+6750=8420 \text{ lb.}$$

On the basis of an efficiency of 85 per cent from the cylinders to the crank pins, the power required, averaged over the journey, will be

$$\frac{50\times5280\times8420}{60\times33000\times0.85}=1320 \text{ i.h.p.}$$

On the basis of an average consumption of 3.5 lb. of coal per i.h.p-hr., there will be burned during the journey

$$2\times1320\times3.5=9240 \text{ lb. of coal or } 4620 \text{ lb. per hour.}$$

This quantity is based on the use of coal of a calorific value of some 14,000 B.t.u. per pound. Since 1 h.p-hr. = 2545 B.t.u., we may express the calorific value of the coal as:

$$\frac{14{,}000}{2545}=5.50 \text{ h.p-hr. per lb.}$$

The energy in the coal burned on the journey amounts to

$$9240\times5.50=50{,}800 \text{ h.p-hr.}$$

The energy output from the cylinders is $2\times1320=2640$ i.h.p-hr.

Consequently the "journey" efficiency from the coal to the cylinders is

$$\frac{2640\times100}{50{,}8000}=5.20 \text{ per cent.}$$

It is highly improbable that this "journey" efficiency is ever exceeded in routine steam locomotive haulage.

In accordance with our assumption of 85 per cent for the efficiency from the cylinders to the crank-pins, we obtain for the "journey" efficiency, from the coal to the crank pins,

$$5.20\times0.85=4.41 \text{ per cent.}$$

But a considerable portion of the energy delivered at the crank-pins is consumed in propelling the locomotive itself. Of the total tractive effort of 8420 lb., no less than 1670 lb. is required for the locomotive, and only 6750 lb. remains available for propelling the train behind the drawbar. Consequently the "journey" efficiency from the coal to the drawbar is only

$$\frac{6750}{8420}\times4.41=3.53 \text{ per cent.}$$

It must furthermore be pointed out that coal is burned wastefully in firing up before the journey and also for a considerable time after the journey.

* Throughout this paper the accuracy is limited to three significant figures.

For the case in hand a fair value to assign to the aggregate of these two components is 3000 lb.

There must consequently be debited to the 100-mile journey a gross coal consumption of

$$9240+300=12{,}240 \text{ lb.}$$

This reduces the net efficiency from the coal to the drawbar to

$$\frac{9240}{12{,}240}\times3.53=2.65 \text{ per cent.}$$

Thus per drawbar h.p-hr. we require to burn

$$\frac{5.20}{2.65}\times3.5=6.86 \text{ lb. of coal.}$$

Now let us consider the hypothetical case of an *electric* locomotive hauling these 10 Pullman coaches over the same distance in the same time.

In order to provide equal margins as regards starting, accelerating, ascending grades, and operation at high speeds, we must, so far as relates to the provision of the same drawbar pull, arrange for the same weight on drivers per ton total weight of train. The steam locomotive had a weight of 85 tons on drivers and the complete train weighed 935 tons. If the electric locomotive were built with the entire weight on drivers, then if by W we designate its weight, and remembering that the weight of the 10 Pullman coaches is 750 tons, we should have the relation

$$W:85=(W+750):935$$

Whence $W=75$ tons.

While we thus see that a 75-ton electric locomotive provides the required capacity, it is necessary, in the interests of ensuring smooth running at high speeds, to provide guiding trucks at each end.[2]

Fifteen tons is an approximate figure for the weight of each of these guiding trucks The correct method of arriving at W, the weight of the locomotive, when, as in the present instance, the speed is such as to require two 15-ton guiding trucks, is as follows:

$$(W-30):85=(W+750):935$$

Whence $W=108$ tons.

The weight on drivers is

$$108-30=78 \text{ tons.}$$

[2] For locomotives whose *maximum* speed is less than 45 miles per hour, no wheels in addition to the drivers need be provided. The great advantage of the electric locomotive of providing double-end operation, is, for high speeds, only secured at the cost of providing *two* bogie trucks, one at each end. One of the bogie tracks places it on a par with the steam locomotive, in respect to single-end operation; the other truck endows it with the great advantage of double-end operation.

As now modified, we may take the complete weight of the electric locomotive as 108 tons, of which 78 tons is on drivers. For the electric equivalent of our typical steam train we thus have a train with a total weight of

$$108+750=858 \text{ tons,}$$

as compared with the weight of

$$185+750=935 \text{ tons}$$

for the steam train.

For the electrically propelled train the average tractive effort for the journey is

$$9\times108+9\times750=972+6750=7722 \text{ lb.}$$

The average power required at the rims of the drivers works out at

$$\frac{50\times5280\times7722}{60\times33.00}=1030 \text{ h.p.}$$

The energy expended at the rims of the drivers during the 100-mile journey is

$$2\times1030=2060 \text{ h.p-hr.}$$

It will now be shown that the overall efficiency from the coal pile in the power house, to the rims of the drivers, is, for practically any well designed and commercially sound railway scheme, purchasing its electricity from large, independent electricity-supply stations, of the order of 6.0 to 6.5 per cent.

As a representative value for the annual overall efficiency of a large modern, steam-driven electricity-supply station (i.e., the efficiency from the coal pile to the outgoing cables), we may take 11 per cent.[3]

When designed with due consideration for the economic balance between capital and operating costs, the annual overall efficiency of the transmission line will usually be of the order of 95 per cent. For a dense service, the annual overall efficiency of the substations will be at least 89 per cent, and even for a sparse service it will usually be above 78 per cent. The efficiency from the substation to the trains will be of the order of at least 93 per cent for both classes of service. The annual overall efficiency of the train equipments will be of the order of 71 per cent for a service of frequently stopping trains, and of the order of 87 per cent for a service of trains running long distances between stops. The annual overall efficiency from coal pile to driving-wheels is thus

for dense service,

$$0.11\times0.95\times0.89\times0.93\times0.71=0.061;$$

and for sparse service,

$$0.11\times0.95\times0.78\times0.93\times0.87=0.066.$$

Thus for a service of trains making long runs between stops, a value of 6.5 per cent may be considered as representative of the order of magnitude of the annual overall efficiency from the coal pile in the generating station to the rims of the driven wheels on the train.

Let us then, in the present instance, take the overall efficiency from coal pile to drivers, as 6.5 per cent. Then the quantity of coal (of a calorific value of 14,000 B.t.u. per pound, or 5.5 h.p-hr. per pound), burned at the electricity-supply station, which should be debited to the 100-mile journey of our express-passenger train, amounts to

$$\frac{2060}{5.5\times0.065}=5750 \text{ lb.}$$

This constitutes only

$$\frac{5750\times100}{12,240}=47 \text{ per cent}$$

of the amount of coal which is required in the case where the same train of 10 Pullman coaches is hauled by a steam locomotive.

The quantity of coal in the two cases may be compared as follows:

122 lb. per train-mile for steam locomotive
58 lb. per train-mile for electric locomotive.

Including the locomotives in the weights of the trains, these figures reduce to

$$\frac{122}{935}=0.130 \text{ lb. per ton-mile for the steam}$$

train and

$$\frac{58}{858}=0.068 \text{ lb. per ton-mile for the elec-}$$

tric train.

But on the basis of coal consumption per ton-mile of *useful* load (i.e., per ton-mile *behind the drawbar*) we have:

For the steam train, $\frac{122}{750}=0.163$ lb. of coal per ton mile.

For the electric train, $\frac{58}{750}=0.077$ lb. of coal per ton-mile.

[3] A few years ago 9 per cent would have been considered a high figure for the overall efficiency of large generating stations, and efficiencies of only 6 to 8 per cent were the rule. The increase over these figures constitutes in itself, considerable reason for reconsidering railway electrification limitations. One kw-hr. =3411 B.t.u. A generating station has an overall efficiency of 11 per cent, when, taken over an entire year, the B.t.u. in the coal consumed per kw-hr. of output from the station, average (3411 0.11 =) 31,000. On the basis of coal of a calorific value of 14,000 B.t.u. per pound, an overall efficiency of 11 per cent is obtained when the coal consumption for the entire year is (31,000 14,000 =) 2.21 lb. per kw-hr. of output from the power house. Overall efficiencies of from 10 to 11 per cent were obtained as early as 1905 at generating stations in Stockholm, Berlin and Vienna, (see pages 29, 34 and 47 of the author's "Heavy Electrical Engineering," Van Nostrand), and at the Interborough's 59th St. station in New York. (See page 3 of Vol. XXV, of TRANS. A I E E.) Annual overall efficiencies of 11 per cent now are obtained in the more important Edison stations. At the Interborough's 59th Station, the annual overall efficiency is now over 12 per cent.

A non-stop express run has purposely been taken in making this comparison, since it represents the case where steam locomotive methods appear to best advantage in comparison with electric locomotive methods. Had occasional stops been assumed, the comparison, so far as it relates to low fuel consumption, would have been still more favorable to the electric locomotive. There are the further considerations that, first, the cost of the coal delivered at the convenient site always with purpose selected for the generating station, is materially less than the cost of the same coal by the time it is loaded on the locomotive tenders; and second, a cheaper grade of coal can economically be employed in a generating station than on steam locomotives. Thus if the comparison were carried beyond the *quantity* of coal per train-mile and reduced to terms of the fuel *cost* per train-mile the result would, in most instances, be to increase the ratio of 1 (for the electric locomotive) to 2 (for the steam locomotive), to a ratio more of the order of 1 to 3.

Electricity will certainly be employed to a gradually increasing extent for trains of the character we have considered, over sections of line where the requirements of other classes of traffic have been such as to justify the electrification of the line. Typical are cases where the bulk of the traffic consists in a dense service of suburban passenger trains making frequent stops and nevertheless maintaining a relatively high schedule speed. In several other instances, it has been the difficulties and dangers attending the operation of steam locomotives in long tunnels, which has occasioned the electrification of the railway. The point which it is desired to emphasize is that it has, as yet, *never been* in the first instance, a *consideration of the merits of electrical as compared with steam locomotive methods for the operation of express-passenger trains*, which has led to electrification. Rather it has been in the face of a generally accepted (and heretofore entirely reasonable) opinion that, for this class of service, steam locomotive haulage is economically much the more appropriate. It is only gradually beginning to be recognized that even for a relatively sparse service of freight trains and express-passenger trains, the economies in the direction of decreased fuel consumption, decreased outlay for maintenance and repairs of locomotives, elimination of firemen on locomotives (and the substitution therefor of an assistant engineer to be available in the event of unforeseen incapacity on the part of the responsible engineer), elimination of heavy tender, and (which will ultimately be found to be of specially great importance), increased annual mileage per locomotive, will in many instances amply justify the capital outlay involved in electrification. Caution must however be used, for there are at present many cases where the traffic is so sparse, the cost of electricity so considerable, and the outlay of such magnitude (as compared to the sparse traffic), as to demonstrate steam locomotive methods to be distinctly appropriate and to constitute the economically-correct system.

However, the trend of developments is strongly in the direction of extending the legitimate field for the electrification of railways. Practically all moderately settled sections of the United States are now covered with extensive electric transmission and distribution systems of great capacity. It is becoming increasingly customary to effect interconnecting arrangements between the various systems; and it appears that there will be a rapidly increasing tendency toward providing what will, to all intents and purposes, constitute a few large networks. Steadily increasing loads and improved machinery, accompanied by scientific management, are continually leading to reductions in the prices at which electricity can be sold at a fair profit. Thus it is rapidly becoming increasingly more practicable for railways to purchase their electricity along the line of route, thereby limiting their own capital outlay to that associated with substations, feeders, contact conductors, and rolling stock. Usually the rolling stock will constitute the largest item in the capital outlay even when the service is far from dense.

Not only is there associated with the policy of purchasing the electricity the advantage of avoiding the capital outlay for electricity generating stations and for transmission lines; but there is the important consideration that the railway load is of such a character that, when superposed on the present loads supplied by the undertakings, a price per kilowatt-hour can be accepted which will be lower than the cost at which the railway could make its own electricity. The railway company will usually find that the most suitable arrangement consists in providing its own substations and purchasing from a supply undertaking the electricity in the three-phase form in which it is delivered at the substations.

To the railway the question of so designing its system as to secure the requisite conditions with a reasonable outlay for substations and for the feeders and the contact-conductor system becomes one of much importance. For a relatively sparse service, the 2400-volt system bids fair to be adopted widely. We have seen that the average power required at the drivers of an electric locomotive hauling 10 Pullman coaches at an average speed of 50 miles per hour is some 1030 h.p. At constant speed, the efficiency of the electrical equipment on the train will be of the order of 90 per cent. The average input will thus be a matter of some 1150 h.p. But during acceleration and when ascending grades, the input will rise, say, to 1600 h.p. or ($1600 \times 0.746 =$) 1200 kw. At 2400 volts this requires collecting a current of

$$\frac{1,200,000}{2400} = 500 \text{ amperes.}$$

This current can readily be collected by pantograph trolleys.[4]

Moreover, currents of much greater magnitude than this may be transmitted many miles without exceeding a reasonable pressure drop and without requiring prohibitive outlay for positive and negative feeders. The more widely apart the substations are spaced, the higher (with a sparse service) will be the load factor, and the greater will be the rated capacity of each substation (and consequently the lower will be its capital cost per kilowatt of rated capacity) and, finally, the lower will be the wages outlay associated with the operation of the substations. For 2400-volt substations, the spacing will usually be from some 30 miles apart for a relatively sparse service of high-powered trains, down to some 15 miles apart with more frequent trains. With any approach to a dense service, 1500 volts or 1200 volts would amply suffice, the substation spacing ranging from 15 miles down to some five miles. From this point downward, we come within the order of things corresponding to a very dense urban and suburban traffic. In such cases, if the area is very extensive, as at Melbourne, a 1200- or 1500-volt system may appropriately be employed, but it will be more usual and satisfactory to employ some 600 to 750 volts for the exceedingly dense traffic requirements in, through and near a great city or the metropolitan district comprising two or more adjacent cities and their suburbs. It is not only possible, but will often be eminently practical and desirable, to combine the use of 600 or 750 volts in the near neighborhood of a great city, with the use of 1200 or 1500 volts for more remote sections where the traffic is more sparse, and the same rolling stock will be operated indifferently from either pressure.

The decision between the use of a third rail or an overhead contact-conductor is not in any sense an embarrassing one, but is readily settled in accordance with the circumstances of each case. Good use will often be made on the same system of overhead contact-conductors on some sections and third rail on other sections, the rolling stock being readily equipped with contact appliances for both systems.

Returning to a consideration of the 2400-volt system, it may be said that pairs of 1200-volt motors in series will, so far as control-methods are concerned, take the place of single motors. The most usual plan will consist in driving four axles of the locomotive from the four motors. But 1200 volts is by no means the limiting pressure for the commutator of a railway motor; and it would be sound engineering to employ four 1800-volt motors connected in 3600-volt pairs on a four-axle locomotive operated from a 3600-volt contact conductor. Where the required performance of the locomotive would make it preferable to have six driven axles, the equipment could comprise six 1200-volt motors arranged in two groups, each group being made up of three motors connected in series and regarded as a single motor so far as relates to the series-parallel control features. The objections originally made that, with two motors in series driving independent axles, there would be trouble if one set of wheels slipped and occasioned most of the voltage to be concentrated on the motor coupled to these wheels, have, in practice, not been realized. In the improbable event that difficulties should arise from related reasons in future constructions, either resort could be had to employing connecting rods, or else two motors in series could drive the same axle by each having pinions engaging with the gear wheel or gear wheels on this axle. It may be as well here to point out that for the operation of trains making runs of several miles between

[4] For a given life of the contact roller, tests reveal the following relation between the speed of a pantograph trolley and the current which can be collected:

Speed in miles per hour	Current in amperes
10	1200
20	900
30	600
40	450
50	300

When estimating on two pantograph trolleys in parallel, it is well to consider their combined capacity as only 1.75 times that of a single trolley.

stops, there is less justification for series-parallel control than has been the case with the frequently starting and stopping trains for which electrical operation has heretofore been regarded as especially appropriate.

Mountain-Grade Railways

A keen interest is at present being taken in the electrification of mountain-grade divisions of main-line railways in the Western states of this country. In several concrete instances, careful estimates have demonstrated that the operating economies which can be effected by superseding with electric locomotives the steam locomotives on such railways are enormous, and are indeed, of such amounts as to defray in a very few years the initial outlays for substations, for feeders and contact-conductors, and for electric locomotives.

A chief factor contributing to this result relates to the very low cost at which the large hydro-electric supply companies in the West can profitably sell electricity for operating synchronous motors in substations. A considerable proportion of the present load of these hydro-electric undertakings consists in induction motors. The large lagging component of the current consumed by induction motors involves capital and operating costs which are very much in excess of the corresponding costs of supplying equal amounts of energy at unity power-factor. Synchronous motors may with advantage be so operated as to consume a current with a large leading component. It often pays an electricity-supply company to go to the expense of purchasing and installing large synchronous motors for the express and exclusive purpose of running them idle and with high excitation, simply to neutralize the lagging component of the current consumed by the induction motor load. If the electricity-supply companies can find customers who will take upon themselves the expense of purchasing such synchronous motors and who will so operate them from the electricity-supply companies' system as to neutralize the undesirable lagging component, then they are spared the necessity of themselves incurring this capital outlay for improving the conditions on their system. Although the electricity-supply companies may not be able to satisfy themselves that they can equitably pay the railway companies for operating synchronous motors from their systems, nevertheless it will be seen that exceptionally low prices, satisfactory to both parties to the transaction, should readily be agreed upon. The equitable price in such a case should be arrived at on the basis of debiting the railway company with the value of the energy delivered to the substations and crediting the railway company with the value to the supply company of the leading current drawn from the system by the over-excitation of the synchronous motors in the substations.

The electricity-supply companies' traditional objection to a railway load of the sparse character associated with the operation of mountain-grade divisions, has, in the past, related to its very poor load factor. But when it is understood that these Western hydro-electric companies already have enormous loads connected to their systems, it will be seen that the fluctuations of a couple of thousand kilowatts, more or less, imposed by the intermittent operation of a few freight trains, is not a factor of consequence, especially since it does not affect the leading component of the current consumed by the synchronous motors.

Engineers have in the past usually erred in their ideas regarding the order of magnitude of a railway load. The present electricity-supply companies distributed about the country could often handle the load corresponding to relatively large railway undertakings without incurring the expense of any very considerable extensions of their generating and transmitting installations.

Let us illustrate this point by the case of the Butte, Anaconda and Pacific Railway, which is electrifying 90 miles of track with the 2400-volt system. The equipment comprises 15 freight locomotives and two passenger locomotives, each of these 17 locomotives weighing 80 tons. Although the undertaking involves transporting annually five million tons of ore over a distance of some 26 miles, the quantity of electricity which will be consumed annually at the substations will only be of the order of less than 20 million kw-hr. A single 5000-kw. turbo-generator with a total weight (including steam-turbine, generator and their common base and bearings) of only some 115 tons, often turns out this quantity of electricity in the course of a year. Only two substations (26 miles apart) are required for the undertaking, and each substation contains only two motor-generator sets, each set having a *rated* capacity of 1000-kw. and an ample *overload* capacity to carry 3000 kw. for 5 minutes at intervals. The four motor-generator sets only aggregate a total weight of some ($4\times45=$) 180 tons.

The only items of large consequence involved in the electrification of this undertaking are, on the one hand, the 17 locomotives, and, on the other hand, the provision of the overhead contact line, the track bonding and the positive and negative feeders.

Trailing loads of 3400 tons[5] will be hauled by two of these 80-ton locomotives (operating as a single machine) from Butte to Anaconda over a route with a maximum grade of 0.3 per cent. For such a case we no longer have the condition which, as we have seen, so greatly affects the economy of the express-passenger proposition, namely, that the weight and friction of the locomotive constitute considerable percentages of the weight and friction of the entire train. Taking the friction of the trailing load (with reasonable allowance for curves), at 4 pounds per ton, the drawbar-pull on a 0.3 per cent grade amounts to

$$(0.3\times 20+4)\times 3400=34,000 \text{ lb.}$$

When returning empty, the trailing load of some 1000 tons must be drawn up maximum grades of one per cent. The tractive effort for the empty cars will be 8 lb. per ton and the drawbar pull will then be

$$28\times 1000=28,000 \text{ lb.}$$

Obviously, even for the heavy freight service on this mountain division, the use of two of these 80-ton locomotives will give a very wide margin of excess capacity. Each 80-ton locomotive will develop continuously a tractive effort of 25,000 lb. at 15 miles per hour. For the 160-ton combination this corresponds to a continuously sustained drawbar output of

$$\frac{15\times 5280\times 2\times 25,000}{60\times 33,000}=2000 \text{ h.p.}$$

On a level track, higher speeds will be available. At starting, the 160-ton combination will provide a tractive effort of

$$(160\times 2000\times 0.25=)\ 80,000 \text{ lb.}$$

for a 25 per cent coefficient of adhesion

$$\text{or } (160\times 2000\times 0.30=)\ 96,000 \text{ lb.}$$

for a 30 per cent coefficient of adhesion.

This tractive effort can also be provided by a Mallet locomotive with 160 tons on drivers. The engine and tender will, however, weigh some 250 tons and the weight on each of the six driven axles amounts to

$$\frac{160\times 2000}{6}=53,500 \text{ lb.}$$

as against a weight of only

$$\frac{160\times 2000}{8}=40,000 \text{ lb.}$$

on each of the eight driven axles of the electric locomotive. Obviously on the single score of the distribution of weight, the track conditions are distinctly less severe with the electrical alternative. There is also the important advantage, in the case of the electric locomotive, that the torque is uniform and in striking contrast with the pulsating torque of the steam locomotive.

But the essential contrast as regards relative capacities is brought to light when we state that the Mallet locomotive, when burning lignite of a calorific value of some 11,000 B.t.u. per pound, can, when exerting a drawbar pull of 60,000 lb., only maintain a sustained speed of some 6.5 miles per hour. Under these conditions the locomotive will be consuming about 7500 lb. of coal per hour, and will be developing

$$\frac{6.5\times 5280\times 60,000}{60\times 33,000}=140 \text{ drawbar h.p.}$$

If the 250-ton Mallet locomotive is hauling a 3400-ton train, then the indicated horse power will be about

$$\frac{3650\times 1040}{3400\times 0.75}=1500 \text{ i.p.h.}$$

The calorific value of the lignite employed as fuel may also be expressed as

$$\frac{11,000}{2545}=4.32 \text{ h.p-hr. per pound}$$

Thus the efficiency from the coal to the cylinders is

$$\frac{1500\times 100}{7500\times 4.32}=4.63 \text{ per cent.}$$

This efficiency estimate is on the basis of a fuel consumption of

$$\frac{7500}{1500}=5.00 \text{ lb. of lignite per i.h.p-hr.}$$

The efficiency from the coal to the drawbar is

$$\frac{1040}{1500}\times 4.63=3.22 \text{ per cent.}$$

The coal consumption per drawbar h.p-hr. is

$$\frac{4.63}{3.22}\times 5.00=7.20 \text{ lb. per drawbar h.p-hr.}$$

[5] Many trains will be so much lighter as to require the use of only one 80-ton locomotive. Single locomotives will also be employed in the yards and at various points of the system as switchers and pushers.

When, however, we take into account the coal wastefully burned during the large part of the time during which the steam locomotive is standing still, we arrive (for mountain-grade freight service), at figures of the order of from 10 to 12 or more pounds of lignite burned per drawbar h.p-hr. On the basis of 10 lb. per drawbar h.p-hr. the efficiency from the coal to the drawbar works out at

$$\frac{7.20}{10} \times 3.22 = 2.32 \text{ per cent.}$$

Even when, as will usually be the case in the West, the electric proposition involves obtaining energy from hydro-electric undertakings, it is nevertheless instructive to give close attention to these efficiency and coal consumption figures, and to contrast them with the results which may be obtained with the equivalent electricity generating station in which coal fuel is employed. It has already been stated that in such a case, some 6.5 per cent of the energy in the coal burned at the generating station is delivered at the rims of the drivers. We have now seen that for the freight service in question, an electric locomotive weighing 160 tons, when compared with a steam locomotive weighing with tender some 250 tons, yields at least as great a drawbar pull at starting, since with the same weight on drivers it replaces a pulsating torque with a constant torque. Furthermore it can develop this drawbar pull at 14 miles per hour as against less than half this speed for the steam locomotive.

The electric locomotive requires to be manned only by one engineer, although, as a precautionary measure, an assistant engineer accompanies him on the locomotive. But when, as in the instance we have considered, a Mallet is burning 7500 lb. of coal per hour, it is considered that it is beyond the capacity of a single fireman, and for *sustained* efforts of this amount, *two* firemen should be provided. In other words, in order to work up to a consumption of 7500 lb. of coal per hour (corresponding to a speed of 6.5 miles per hour with a drawbar pull of 60,000 lb. making 1500 i.p.h.) two firemen are necessary if these conditions of speed and drawbar pull are sustained for considerable periods. Thus a crew of three men are required on the steam locomotive when only 1500 i.h.p. are developed, while on the electric locomotive just one man is actually necessary (although two are provided for the reasons stated), even when the locomotive is developing over 2000 h.p.

Finally, as regards capital outlay and maintenance. Electric locomotives with the axles driven through gears cost a matter of some $450 per ton and the outlay for repairs and maintenance runs to some 4 cents per mile per 100 tons of weight of locomotive. The outlay for repairs and maintenance of steam locomotives is about of the order of 10 cents per mile per 100 tons of weight; and since steam locomotives are inherently incapable of the mileage per annum which can be obtained from electric locomotives, then notwithstanding that steam locomotives cost considerably less than half as much *per ton of weight*,[6] the charges per locomotive-mile for repairs and maintenance, plus interest, taxes, insurance and amortization are inherently decidedly greater for the steam locomotive than for the electric locomotive. Electric railway engineers are satisfied that these are conservative ratios. That the values which will ultimately be established will be still more favorable to the electric locomotive will only slowly be demonstrated in practice, largely for the reason that conventional methods of operating railways have been so evolved as to conform with the properties and limitations of the steam locomotive. Emancipation from these limitations will not immediately be followed by a revolution in methods of operating railways. On the contrary, the electric locomotive will for some time to come be compelled to conform to the conventions of the past. Advantage will only gradually be taken of the electric locomotive's inherently greater capacity as regards speed (in the case of freight haulage) for a given drawbar pull. It will be some considerable time before methods will so be modified that, in virtue of its greater capacity for speed in freight haulage, and in virtue of freedom from the necessity of devoting a large percentage of time to overhauling it and taking it out of service for repairs*, 50 per cent or even 100 per cent more mileage per annum will be obtained from the electric

[6] This ratio of costs is only in small part due to any *inherently* greater cost per ton in the case of electric locomotives. It is chiefly due to the fact that whereas several thousands of *steam* locomotives are built *every year*, there are not more than a matter of 1000 *electric* locomotives *in existence*, and only 100 to 200 are built annually. The number of steam locomotives in the United States, the United Kingdom, Germany and France aggregates over 100,000.

* While a comparatively short run necessitates that the steam locomotive temporarily be withdrawn from service for several hours for adjustments, cleaning and other attentions, no such limitations obtain in the case of the electric locomotive. Moreover it can be arranged that the engineer and his assistant shall relieve one another at frequent intervals, thus maintaining their strength and alertness to a degree quite impossible for the engineer and fireman constituting the crew of a steam locomotive.

locomotive than has been found expedient with its steam predecessor. Most of the present overtime expense will be eliminated with electric operation and this in itself will effect a large saving in crew expense.

The circumstances attending specific cases vary so greatly as to render it exceedingly difficult to work out quantitative comparisons. Furthermore, a reasonable consideration for commercial interests of various sorts, requires that indications of price shall be only *relatively* correct and of the right general order of magnitude. But notwithstanding the frank admission that the figures employed in the following comparison are purposely so selected that they are only quite roughly correct, and amply conservative at the present state of the art, they nevertheless, taken *relatively*, as contrasting electric with steam working, bear a very correct ratio to one another, and will be amply sufficient for the purposes of a rough comparison.

(To be Concluded in our August number)

EFFECT OF DIELECTRIC SPARK-LAG ON SPARK GAPS

By J. P. Minton

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This article presents the results of an experimental investigation of the effect of dielectric spark-lag upon both needle and sphere-gaps, which go to show that the sphere-gap is the more reliable, on account of the lesser dielectric spark-lag which it is found to possess. The correctness of this conclusion is still further confirmed by a theoretical argument based on Maxwell's theory of stresses. This type of gap should, therefore, be used wherever possible, especially for the measurement of voltages of short duration.—Editor.

The influence of the dielectric spark-lag has not, until recently, attracted the attention of the electrical engineering world. Its important connections with the protection of transmission circuits from lightning discharges and the suppression of troubles from internal surges of electrical energy have been pointed out by Prof. E. E. F. Creighton.* It seems, however, that the effect of this time-lag on voltage determinations with spark-gaps is not very generally known, and therefore a paper dealing with this subject will be interesting and instructive.

In order to illustrate the effect of the dielectric spark-lag, I have made several experiments with a static machine on sphere and needle gaps. This article will include some of the results of the tests made on a *needle gap connected in parallel with a sphere gap* (the diameter of the spheres being 3.81 cm.). After this experimental data has been presented, a discussion will be given of the results obtained, together with the conclusions derived.

Both gaps were separately calibrated with a 200,000 volt testing transformer connected to a sine wave generator. The voltage readings were taken from the calibration curves thus obtained.

* Proc. A.I.E.E., 1910, p. 1214.

Test I

The diagram of connections used in this test is given in Fig. 1, which is self-explanatory. The two gaps under comparison are G_1 and G_2. The static machine was run at a constant speed, and was used to charge the condensers C_1 and C_2. The potential at which these condensers arrived was determined by the adjustment of the various spark-gaps. The distance between the spheres of the static machine gap was made of such a value as to cause a discharge to take place across them about every second, and this adjustment remained undisturbed throughout the test.

The high resistance shown in the diagram was a U-shaped glass tube about 10 feet long and 3/4 inch in diameter, filled with tap water. The purpose of this resistance was to prevent a flow of current across the gaps, which otherwise might occur and introduce an error in the voltage readings.

The sphere-gap, G_1, was adjusted so that it discharged simultaneously with the static machine. The distance between the needle points was then decreased to a value such that the gaps G_1 and G_2 discharged alternately, i.e., a discharge took place across either the gap G_1 or G_2 when the static machine gap was broken down. The set of readings in Table I was taken in this manner.

From these readings we see that the sphere gap gives a constant percentage difference of about 48 per cent above that of the needle-gap, when compared in this way. One would not willingly admit that such a discrepancy as this could exist between the two gaps, especially when the same potential was applied to the gaps connected in parallel. I shall show later, however, that this dis-

TABLE I

Needle Gap (G_2)		Sphere Gap (G_1)		Percentage Difference
Cm.	Kv. Max.	Cm.	Kv. Max.	
1.40	17.2	0.86	28.0	+39
2.01	23.2	1.50	43.8	+47
2.92	31.4	2.34	60.3	+48
4.07	40.8	3.81	81.5	+50
4.80	46.3	4.49	89.0	+48

crepancy is due almost wholly to the dielectric spark-lag of the needle-gap, while very little of it is caused by the dielectric spark-lag of the sphere-gap.

Test II

The diagram of the connections used for this test is shown in Fig. 2. The static machine gap and the high resistance shown in Fig. 1 were taken out, and the condensers C_1 and C_2, which were connected in series with the gaps G_1 and G_2, were replaced by a single condenser connected in parallel with these

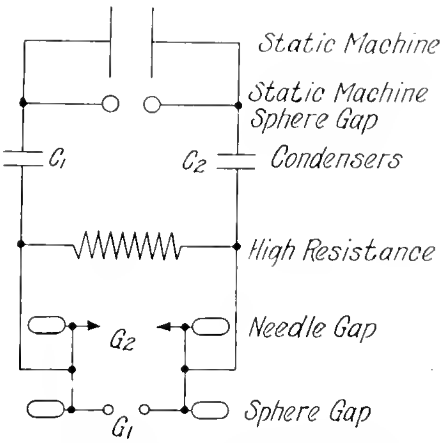

Fig. I. Diagram of Initial Connections Employed. The Values Listed in Table I Resulted from This Set-up

gaps. The machine charged this condenser, whose voltage was determined by the setting of the sphere and needle-gaps. The voltage of the condenser would rise to a certain value, when a discharge would take place across the sphere-gap, G_1. The needle-gap, G_2, which was being compared with G_1, was then adjusted so that it discharged alternately with the sphere-gap as in Test I. One set of readings obtained in this manner is given in Table II.

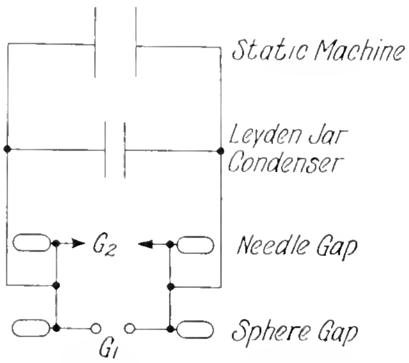

Fig. 2. Diagram of Rewired Testing Apparatus. A Sample Reading Taken with this Scheme of Connections is Given in Table II

We see that the magnitude of the percentage difference is about the same as in Test I, but that the sign has reversed. At first thought, one might say that the dielectric spark-lag of the sphere-gap is much greater than that of the needle-gap, when compared in this way. This, however, is not true, for there was a visible corona between the needle-points on account of the fact that there was no high resistance to eliminate this leakage current. This corona caused the air to break down across a much greater distance for the same potential difference, than would have been the case if the corona were absent. This effect is not present in the readings given in Table I, and so the discrepancy there noticed was due entirely to a different cause.

TABLE II

Needle Gap (G_2)		Sphere Gap (G_1)		Percentage Difference
Cm.	Kv. Max	Cm.	Kv. Max.	
3.15	37.0	0.81	26.0	−42

Test III

The diagram of the connections used in this test is shown in Fig. 3. The static machine sphere-gap, the high resistance, and the condensers C_1 and C_2 (Fig. 1) were inserted in the circuit for this test. C_1, C_2, C_3 and C_4 were Leyden jar condensers, connected in series. In order to compare the voltage readings obtained by the two gaps, G_1 and G_2, they were connected in parallel across this series of condensers, as shown in the diagram. The sphere-gap, G_1, was so adjusted that it discharged each time the static machine did, which was about sixty times a minute. The needle-gap was set so that it did not break down regularly, and the readings of Table III were taken.

TABLE III

Needle Gap (G_2)		Sphere Gap (G_1)		Percentage Difference
Cm.	Kv. Max.	Cm.	Kv. Max.	
4.24	42.2	2.01	54.3	+22.3
5.28	50.0	2.59	64.0	+21.9
7.04	60.3	3.05	71.7	+15.9
8.31	66.0	3.15	73.0	+ 9.6
7.77	64.0	3.43	75.5	+15.2
9.84	72.0	3.58	78.7	+ 8.5
10.78	76.0	3.73	80.5	+ 5.6
11.71	80.0	4.02	84.0	+ 4.8

It will be noticed that the discrepancy between the two gaps is still positive, but is not as large as that given in Test I. The percentage difference is not constant, but this is easily explained. In those readings having a percentage difference of about 22 per cent, the needle-gap was adjusted so that its frequency of discharge was about half that of the sphere-gap. Where the disagreement is about 5 per cent, the needle-gap discharged once, while the sphere-gap discharged about ten times. Where the frequency of discharge of the two gaps was the same (see Test I), the discrepancy was about 48 per cent.

From these considerations, it is clear that if the needle-gap was adjusted so that it would not discharge at all, one would expect the agreement to be within two or three per cent. Going a step farther in the argument, if both gaps were adjusted so as to be on the point of arcing over when the static machine did and yet failed to do so, we would expect the agreement to be very good. The set of readings in Table IV was taken to demonstrate that this last conclusion was true.

TABLE IV

Needle Gap (G_2)		Sphere Gap (G_1)		Percentage Difference
Cm.	Kv. Max.	Cm.	Kv. Max.	
8.66	67.5	2.67	65.8	−2.6
9.54	70.9	2.87	69.0	−2.8
11.03	76.9	3.48	77.5	+0.8
12.07	81.3	3.81	80.6	−0.9
13.42	86.9	4.39	88.0	+1.2
14.78	92.3	5.01	93.0	+0.8
16.01	97.5	5.67	98.3	+0.8

The agreement is as good as we can expect under the conditions of the test, so that the discrepancy disappears entirely when the gaps are used in this manner. We will now consider the results of these tests somewhat in detail in order to understand more clearly the cause of this disagreement.

Discussion of Results

We have seen that the two gaps, when compared in the manner described, may disagree by as much as from plus 48 per cent to minus 42 per cent. I have pointed out that this negative disagreement was due to corona between the needle points, but since corona was not present in those experiments where a positive discrepancy was observed, we must look for some other cause for its explanation.

From the results obtained, it is quite evident that this phenomenon was not due to any high frequency effect, for in that case the corona between the needle points would have caused the needle-gap to give a higher voltage reading than the sphere-gap. As a matter of fact, the distance between the electrodes of the gaps was determined by a static potential, while the high frequency oscillations started at the instant the gaps were broken down. The disagreement could not have been due to any constant error, for in that case it would not have been of so varied a nature.

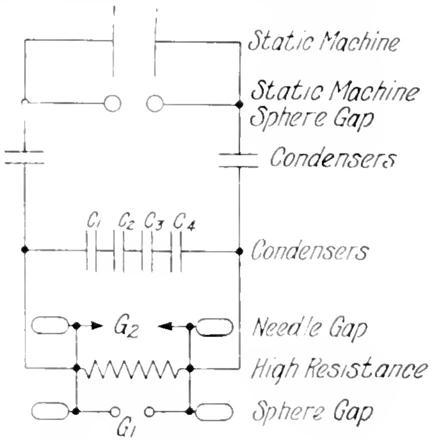

Fig. 3. Final Diagram of Connections Used. The Values Given in Tables III and IV were Obtained with this Arrangement

At first thought, one might say that the sphere-gap took its charge much more easily than the needle-gap. If this were true, the distribution of the charges between the two gaps would be such as to cause the sphere-gap to rise in potential much faster than the needle-gap. Consequently, the former would give a higher voltage reading than the latter. A certain time-interval would then be necessary for the two gaps to come to a potential equilibrium, and when this equilibrium had been established the disagreement would have disappeared. But this is not in harmony with the observed facts, because the spark occurred in the static machine gap at a constant rate, independent of the discharge or lack of discharge of the two gaps that were under comparison. If a time-interval is necessary for the establishment of the potential equilibrium, then the spark-gaps would not have checked under any condition, because the applied voltage dropped nearly to zero at each discharge of the static machine, and because there would not have been the necessary time-interval on account of the constancy of discharge of the static machine. We see, therefore, that both the gaps must rise in potential at the same rate, and therefore the discrepancy noted cannot be due to this cause.

This discrepancy could not be due to a difference in the capacity, inductance, or resistance of the two gap-circuits, for these were constant under all conditions, and any error due to them would be constant.

We have now only the dielectric itself (air) to consider, and this leads us to the cause of the behavior of the two gaps. I have pointed out that, as long as the dielectric is ruptured, the two gaps will not agree. When the potential across the gaps, however, is not great enough to cause a discharge to pass between the electrodes, the two gaps agree within the experimental error. This discrepancy, then, is due to a true dielectric spark-lag, which is that time required to ionize the air between the electrodes in order that a discharge may pass. The time required to cause this ionization is much greater for the needle-gap than for the sphere-gap, as shown by the tests given above, and for this reason the needle-gap gave much lower voltage readings than the sphere-gap. That is, the dielectric spark-lag of the latter is much less than that of the former. We see, therefore, that the sphere-gap gives more reliable results than the needle-gap, and hence the former should be used, wherever possible, in preference to the latter, especially for phenomena of short duration.

As to the nature of dielectric spark-lag very little is known, and no reason has been given why the needle-gap should have a greater dielectric spark-lag than the sphere-gap. Let us consider this last from the point of view of the "Maxwellian" theory of stress. We know that the lines of force are more nearly parallel between spheres than between needle points. We also know that there is an inward pressure (equal to the energy-density of the electric field) which tends to keep these lines parallel. * Now, the electric force (per unit charge), E, between the spheres is greater than that between the needle points, and since the energy-density at any point is $\frac{E^2}{8\pi}$, it follows that the energy-density is greater between the spheres than between the needles. Hence, there is a greater pressure tending to keep the lines of force parallel between the former than between the latter. This means that the field between the spheres is not so flexible, electrically, as that between the needle points, so that one would expect the electric stress to be relieved between the latter and not between the former. For this reason a discharge would pass more quickly between spherical electrodes than between point electrodes, the occurrence of which would account for the fact that the dielectric spark-lag of the sphere gap is much less than that of the needle-gap. This explanation may not be the correct one, and I only offer it as possible.

It must be remembered that the information given in this article is subject only to the conditions under which the tests were conducted.

* Let us consider this point somewhat in detail, in order that the exact meaning may be understood. Referring to Fig. 4, S_1 and S_2 are the two electrodes of any spark-gap. The lines of electric force are shown as dotted lines.

Suppose we consider a small cube in the neighborhood of the point P. According to the "Maxwellian" theory of stress in electric fields, the forces acting:

along the X axis are,

$$X_x = \frac{1}{8\pi}\left[E_x^2 - E_y^2 - E_z^2\right] \quad (1)$$

$$X_y = \frac{1}{4\pi}\left[E_x \; E_y\right] \quad (2)$$

$$X_z = \frac{1}{4\pi}\left[E_x \; E_z\right] \quad (3)$$

along the Y axis are,

$$Y_y = \frac{1}{8\pi}\left[E_y^2 - E_x^2 - E_z^2\right] \quad (4)$$

$$Y_x = \frac{1}{4\pi}\left[E_y \; E_x\right] \quad (5)$$

$$Y_z = \frac{1}{4\pi}\left[E_y \; E_z\right] \quad (6)$$

along the Z axis, etc.,

$$Z_z = \frac{1}{8\pi}\left[E_z^2 - E_x^2 - E_y^2\right] \quad (7)$$

$$Z_x = \frac{1}{4\pi}\left[E_z E_x\right] \quad (8)$$

$$Z_y = \frac{1}{4\pi}\left[E_z E_y\right] \quad (9)$$

The subscripts of the forces on the left-hand side of each of these equations refer to the face on which the force is exerted; thus, X_x means the x force on the x face, X_y means the x force on the y face, and X_z means the x force on the z face. The first corresponds to a direct pulse, and the other two correspond to a shearing force. Similar remarks apply to the y and z forces. E_x means the electric force per unit charge along the x axis, E_y means the electric force per unit charge along the y axis, and E_z refers to the electric force per unit charge along the z axis.

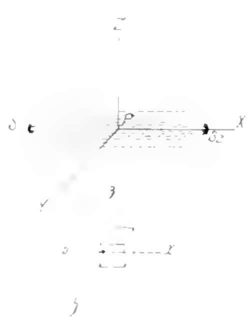

Fig. 4

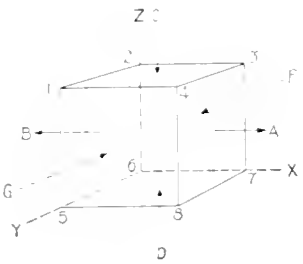

Fig. 5

Now, suppose we consider the cube sufficiently small to say that the lines of force through it are parallel. Then, $E_y = E_z = O$. Put $E_x = E$. Substituting these values, the previous equations reduce to:

$$X_x = \frac{1}{8\pi}E^2 \quad (1')$$

$$Y_y = -\frac{1}{8\pi}E^2 \quad (4')$$

$$Z_z = -\frac{1}{8\pi}E^2 \quad (7')$$

The negative sign means that the force is acting toward the interior of the cube. The conditions may be represented by Fig. 5 in which,

$A = +\frac{E^2}{8\pi}$, (Outward on surface 4-3-7-8)

$B = +\frac{E^2}{8\pi}$, (Outward on surface 1-2-6-5)

$C = -\frac{E^2}{8\pi}$, (Inward on surface 1-2-3-4)

$D = -\frac{E^2}{8\pi}$, (Inward on surface 5-6-7-8)

$F = -\frac{E^2}{8\pi}$, (Inward on surface 2-3-7-6)

$G = -\frac{E^2}{8\pi}$, (Inward on surface 1-4-8-5)

Since E was greater for a unit charge between the spheres than between the needle points, it follows that this inward pressure was greater for the former than for the latter.

THE PURCHASE OF COAL UNDER SPECIFICATION

By J. A. Capp

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The early part of this article touches on the present-day need of purchasing coal under specification, furnishes an illustrative coal analysis, discusses the various components involved, and states which of them are of sufficient importance to be included in specifications. The author then enumerates the points which in earlier specifications received consideration, resulting in a fixed analysis; and then indicates the revision made in later days, whereby a desirable degree of flexibility is obtained. A means for obtaining a truly representative sample from a bulk of coal is described, and the quantity which should be considered for unit analysis is defined. The latter part of the article presents the specifications, with quotations, employed by a large company in the purchase of its coal, to protect both itself and the seller—Editor.

It is only within very recent years that purchasers of coal have regulated the quality supplied them by the formulation of specifications and by systematic inspection testing. Buyer and seller had previously looked upon coal as a gross commodity, and it was bought and sold largely on reputation.

Trade or brand names were a valuable asset in selling; and frequently the reputation of a trade name or brand lasted long after the deposit of coal, upon which the brand had originally been established, had become exhausted, or had changed materially in character as the coal was obtained from deeper or more distant parts of the workings. The mining companies did not generally employ chemists to make regular analyses of the output of their mines; and about the only knowledge they had of the composition of the coal they were mining was of the most general sort, obtained either from the records of analyses made by the State Geological Surveys, or from occasional reports by customers. That the coal from different mines varied greatly in composition was well known, but it was recognized that the miner could do little to change his output. In fact, all he could do was to exercise care in mining, and to remove the foreign matter mined with the coal; and, by this care and preparation, keep down the ash and sulphur toward the minimum which could be expected from the output of any given mine. The buyer was welcome to all the information the seller possessed, but it was too little to enable him intelligently to make selection among the various kinds of coal offered him at a rather wide range of prices.

A typical analysis of bituminous steam coal may be quoted.

Moisture	2.05%
Volatile matter	23.62%
Fixed carbon	69.36%
Ash	7.02%
	100.00%
Sulphur	1.25%
Thermal value	14,540 B.t.u.

The moisture is more or less accidental, and may vary with so many circumstances that for most purposes it may be disregarded, being set down for information only. It is of moment only when the unit of delivery is a wagon or truck, and when the coal is weighed as it is being delivered. The proximate composition is then given on the basis of "dry coal," as representative of the coal as it really exists free from the accidental moisture. The sulphur must be separately stated, since it may be either in the volatile matter or in the ash, or more likely in both.

The volatile matter is mainly combustible, although a certain proportion is generally inert. It is of interest chiefly because of its influence on the behavior of the coal as furnace fuel. The boiler-setting and furnace are frequently such that coal high in volatile matter cannot be burned economically, especially under forced firing, and without the production of a prohibitive amount of smoke. Coal high in fixed carbon (and hence correspondingly low in volatile matter) is more easily and uniformly burned under general conditions.

Ash is inert, and may be considered a direct expense. It is paid for at the price of combustible fuel; and, when in too great proportion, it interferes with air distribution throughout the fuel bed. When, because of composition, it is of a fusible nature, it causes clinker formation, the removal of which necessitates undue prolonging of the time of opening of the furnace doors, with consequent loss of heat. Its removal and disposal is a supplementary expense.

Sulphur may exist in a free state, in which case it is relatively unobjectionable, but it is usually in combination in the ash and may increase the clinkering tendency of the coal. By proper care in preparation both the sulphur and ash can be kept down to as low a point as is possible with the coal from any individual deposit.

Considering coals of proximate composition and general character such that they may all be burned with substantially equal ease in a given furnace, their theoretical fuel efficiency will be in direct proportion to their thermal values, usually expressed in British thermal units (B.t.u.).

These data obviously make possible comparison of coals from different sources and, when supplemented by the results of practical experience in the burning of various sorts of coal in any particular installation, afford a means of estimating the relative value of coals of different character as fuel for that plant. Hence the analysis and thermal value form an excellent basis for purchasing specifications; and such specifications, having been found mutually helpful to buyer and seller for all other sorts of materials, have come into use for coal.

The specifications first prepared, and many of those in force today, fix the proximate analysis of the coal desired, and provide for payment for the coal delivered on a sliding scale above or below the base price as quality varies, and especially as the thermal value exceeds or runs under the figure fixed in the specifications as the standard. This form of specifications, however, is inflexible, and does not permit consideration of coals which might be excellent fuels, but would not meet the fixed requirements. Such coals either would be rejected for not conforming to specifications, or would be penalized prohibitively in price. Furthermore, it must be recognized that geographical location determines to a large extent the character of fuel that is available at any particular point. This follows from the fact that the distance from the coal fields and transportation facilities fix pretty closely the district from which coal for that locality must economically be drawn: if brought from other districts, the freight charges will be too high. In localities at considerable distances from the mines, the freight is from two to four times the cost of the coal f.o.b. mines. For these reasons many specifications have been so drawn that the bidder states the average ash, sulphur, B.t.u's., etc., in the coal he proposes to furnish, and this statement becomes the basis of quality.

In all of the specifications with which the author is familiar, adjustments in the price to be paid for coal delivered are made for variations in quality. In this respect, coal specifications differ from those used for the purchase of any other material, except, perhaps, pig iron. Such adjustment is necessary because it is seldom easily possible to reject coal, since in many cases the delivery has been unloaded, and may even have lost identity by the time the analysis has been made. A delivery poor in quality must usually, therefore, be accepted; and it is but just and fair that the price be lowered in some degree, commensurate with the lowering of grade below that contemplated in establishing the base price under the contract. An increase in price is equally merited if the delivery is of materially better quality than the standard.

The variations in quality to be provided for are, then, in the percentages of ash and sulphur, occasionally also of volatile matter, and in the thermal value, or B.t.u's. There are many ways of providing for adjustments in price because of fluctuations in quality. The majority of the specifications are based on the assumption that the price should rise and fall directly with the thermal value. Hence, taking the base price and the established standard of the contract, there are calculated the number of B.t.u's. for 1c. in a ton of the coal at base price. The price of deliveries is modified as the analysis shows B.t.u's. higher or lower than the standard. A further modification is made for ash, sometimes by a scheme of proportion, sometimes by fixed deductions or additions, according as the ash exceeds or is under the standard by fixed amounts or ranges. Adjustment is usually made for sulphur by fixed deductions for stated amounts or ranges by which the sulphur exceeds the standard.

Theoretically, the direct variation of price with variation in thermal value is correct. It is based, however, on the assumption that the actual fuel value varies directly with the thermal value. It is obvious, however, that it is not practically possible to realize the gain or loss in a power station from relatively small changes in B.t.u's. in the coal, because there are too many other uncontrollable variables to be taken into account. Certainly the stoker cannot take such changes into account, and its operation cannot be regulated accordingly. Furthermore, such fluctuations in thermal value as are found in shipments of carefully mined, well-prepared coal from any given mine are accidental and beyond the control of the miner. Naturally it is preferable to be able to sell one's wares at a fixed price throughout the life of a contract, and there is a certain minimum below which the sale is not profitable. The tendency, then, is for the price to be set so that any penalties which may be incurred will still leave a figure above this minimum, notwithstanding the fact that the law of averages would indicate that premiums and penalties would balance if the standard had been fairly set at the average. The same lack of fixity in price leaves the buyer uncertain as to his costs; and, whenever premiums are earned, he is left in doubt as to whether he is actually getting his money's worth. He seldom can show it by lessened coal consumption or increased steam production. This same reasoning may be applied in large degree to ash, sulphur and volatile matter.

Before discussing further the question of price adjustment under specifications, it may be well to turn attention to an equally important matter. Obviously, the successful application of any form of specifications depends wholly upon the ability to obtain samples which represent fairly the quality of the coal delivered. Much has been written upon the question of sampling coal; and the difficulty of obtaining by hand a truly representative sample of, say, a carload or barge of coal is admitted. A second sample to check the first, in case of dissatisfaction with results, is usually not possible for the same reason that coal can seldom be rejected—it has been burned, or at least has lost identity, by the time results are obtained. An automatic system by which samples are obtained from all parts of the unit of delivery, whether car or barge, and which takes out a large number of thoroughly distributed small quantities, yields about as fair and representative a sample as can be obtained.

A third point requiring consideration in preparing specifications for the purchasing of coal is the unit of analysis. In cases where the contract is filled by a few deliveries over a considerable period, the delivery itself may conveniently be the unit of analysis, and the price to be paid for each delivery may easily be determined. Similarly, if the unit of shipment is a large barge or lighter containing several hundred tons, the unit of analysis may well be the unit of shipment. But where deliveries are in carloads of approximately forty tons each, and where the normal rates vary from four to perhaps twenty cars per day, depending upon the way shipments are made and the requirements of the buyer, it is seen that some scheme must be worked out to take care of wide fluctuations in receipts. The matter may be complicated by shipments coming in from two or three or more contractors at the same time. In such a case, which is by no means rare with industrial establishments, the laboratory cannot possibly be flexible enough in equipment with men and apparatus to handle analyses upon samples from each car as a unit, and provision must be made for sampling and analyzing at such intervals that the work may be carried out under commercial conditions.

The industrial establishment with which the writer is connected has studied the problem of coal specifications for several years, two or three different types of specifications being tried out in the course of evolution. In the specifications last adopted are embodied several schemes which are novel, and which have solved the difficulties discussed in a manner which has worked out very satisfactorily.

First, with respect to the standard, the contractor states the average composition and heat value of the coal to be delivered; and agrees "that this average composition and heat value shall be the standard basis of quality of the coal delivered." No restrictions upon either chemistry or thermal value are imposed in the tenders, but bids upon any coal offered are considered. Acceptance or rejection of bids is based upon the quality guaranteed and the price quoted.

Second, sampling and analysis. Samples are obtained automatically from the cars as they are unloaded at the power stations. The coal drops from the car into hoppers, discharging through rolls by which the coal is crushed before being conveyed to bins feeding the stokers. In one station the sample is obtained by the opening of a small trap-door in an incline down which the crushed coal slides to the conveyor. In the other station, where the crushing rolls discharge directly onto the conveyer, the sample is taken by a small one-bucket conveyor, or "thief," which dips a small amount of coal from a conveyor bucket at regular intervals. In either case the sample is dropped to a receptacle which holds the entire 180, more or less, little portions that are taken from all parts of a car. This sample is then passed through a grinder by which it is reduced to about 16 mesh and finer, and then put through a mixing machine. Any reasonable portion of this 40-lb. sample is then as thoroughly representative of the car as it is possible for any sample to be. A 2-oz. sample is taken from this car sample to represent the car in the final analysis. The 2-oz. samples from all of the cars sampled during any calendar month, and representing the delivery by any one contractor, are then thoroughly mixed and quartered in the customary manner until a final average sample of about one pound remains. "This final average sample shall constitute the sample upon a portion of which analysis shall be made to determine the average character of the coal received during the month, and upon which settlement shall be based." In this way the utmost flexibility is provided for handling the greatest variations in the number of cars delivered.

Third, basis of settlement. No clearer idea may be given of the provisions in the specifications for adjustment of price for variations in quality, than by direct quotation:

"Settlement for coal received during any calendar month shall be made after the completion of analysis of the average sample representing coal received during said month, and not later than the fifteenth day of the next month. The price per ton to be paid by the purchaser shall be the base price quoted by the contractor, with deductions and additions for variations in quality, and for failure to deliver in drop-bottom cars, as hereinafter provided."

"When the analysis upon the average sample for any calendar month shows that the percentage of ash is not more than one higher or lower than the standard average percentage, and that the percentage of sulphur is not more than 0.25 higher than the standard average percentage, and that the thermal value is not more than 150 B.t.u. higher or lower than the standard average B.t.u., then settlement for the coal received by the purchaser during said calendar month shall be made at the base price, without additions or deductions for quality. When the analysis shows that the percentage of ash is more than one lower than the standard average percentage, then an addition of 2c. to the base price per ton will be made for each 0.50 or fraction thereof, that the percentage of ash is more than one lower than the standard average percentage; and when the analysis shows that the percentage of ash is more than one higher than the standard average percentage, then a deduction of 2c. from the base price per ton will be made for each 0.50, or fraction thereof, that the percentage of ash is more than one higher than the standard average percentage. When the analysis shows that the percentage of sulphur is more than 0.25 higher than the standard average percentage, then a deduction of 2c. from the base price per ton will be made for each 0.25 or fraction thereof, that the percentage of sulphur is more than 0.25 higher than the standard average percentage. When the analysis shows that the thermal value is more than 150 B.t.u. higher than the standard average B.t.u., then an addition of 1c. to the base price per ton will be made for each 50 B.t.u. or fraction thereof that the thermal value is more than 150 B.t.u. higher than the standard average B.t.u. When the analysis shows that the thermal value is more than 150 B.t.u. lower than the standard average B.t.u., then a deduction of 1c. from the base price per ton will be made for each 50 B.t.u. or fraction thereof that the thermal value is more than 150 B.t.u. lower than the standard average B.t.u."

It is seen that the specifications are founded upon averages, and the idea of averages includes a certain expected variation. The record of a large number of analyses made over a period of several years has shown that the limits set in the specification, within which there are neither additions to or deductions from the base price, are sufficiently wide to cover the variations that should reasonably be expected from carefully mined and prepared coal, at least from the district from which coal is customarily shipped to Schenectady. At the same time, experience has shown that acceptable coal which falls within the limits of the "base zone" of the specifications is good commercially acceptable fuel, and that there is no warrant for any change in price of coal which does not vary more than the limits to the "base zone." Coal which does vary more than these limits is either of distinctly better quality and should earn a better price, or of markedly poorer quality meriting a reduced price.

The object of purchasing specifications is two-fold: first, protection against unscrupulous or ignorant competition, by insuring a common basis for all bidders; and, second, the provision of standards by which deliveries may be evaluated, thereby insuring the acceptance of good material and making provision for the rejection or other disposition of that which is below the standard established. The standard established, then, should be such that, while it is high enough to insure safe and satisfactory service in the use for which the material is intended, it may be reached by recognized commercial methods of making and marketing. The specifications should provide a continuous supply of satisfactory commercial material at the lowest price at which such material can be furnished; and, during the term of the contract, there should be as little disturbance as possible either in quality or price. The specifications quoted were drafted to meet these conditions; they call for good commercial coal for which a fair price is to be paid, and make provision for an adjustment in the price only under what may reasonably be called extraordinary conditions. Purchases made over a period of over three years under specifications embodying the principle of the "base-zone" have shown their fairness by the fact that settlements have been made at base price in the greatest number of instances. Obviously, the bidder must state his "standard average" fairly and correctly. If the quality is set too low in the hope of getting additions in settlement, the price will be too high to be consonant with the quality offered. If the bidder sets his quality too high, so as to make an attractive looking bid, he is automatically paid a proper price when his delivery is poor. Furthermore, provision is made for cancellation if a contractor continuously furnishes coal warranting deductions of 4c. or more per ton. When the standard average is properly stated, both buyer and seller may count upon the delivery of good coal at a fixed price.

TRANSFORMER CAPACITY AND CONNECTIONS FOR INDUCTION MOTOR FEEDER CIRCUITS

By J. L. Moon

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This article gives rules and tabulated data for determining approximately the size of transformer which must be supplied for taking care of an induction motor load of given voltage and horse power. The latter section specifies and illustrates the wiring connections of transformers and motors, which are followed in cases likely to be met with in practice, for wiring induction motors into two-phase and three-phase systems.—Editor.

The question as to the nature of the load—inductive or non-inductive, which is to be placed on the various feeders of a supply system determines to a large extent the regulating capabilities which must be provided in the design of the generator and switchboard equipment. The same matter also comes up in selecting the sub-station equipment, and affects the transformer capacity and connections. Thus, while with a non-inductive load, such as incandescent lamps, the regulation of transformers may be within 3 per cent, with an inductive load the drop in potential between no load and full load may increase to about 5 per cent. If the motor load is large and fluctuating and close regulation is important, it is desirable to use separate transformers for the motors.

This article will, in a most elementary fashion, consider some of the chief factors which determine such questions as the capacity of transformer, which must be selected to take care of a given induction motor load, and some of the wiring connections commonly adopted. The proper voltage rating of transformers for three-phase and two-phase induction motors on various circuits is given in Table I.

TABLE I

Delivered Voltage of Circuit	Single-Phase Transformer Voltages: 110 Volt Motor, Primary	110 Volt Motor, Secondary	220 Volt Motor, Primary	220 Volt Motor, Secondary
1100	1100	122	1100	244
2200	2200	122	2200	244

For the operation of induction motors from three-phase systems, three single-phase units or one three-phase are recommended, although if desired two single-phase transformers may be used. The use of the three-phase transformers greatly reduces the space required and makes the wiring very simple; while the only advantage gained in using three single-phase transformers rather than a three-phase transformer is that in the case of one transformer burning out, the other two may be used to operate the motor at reduced load.

As an approximate rule it may be said that for the larger motors the capacity of the transformers in kilowatts should equal the output of the motor in horse power. Thus a 50 h.p. motor requires 50 kw. in trans-

TABLE II—CAPACITIES OF TRANSFORMERS FOR INDUCTION MOTORS

Size of Motor Horse Power	Kilowatts per Transformer: Two Single-Phase Transformers	Three Single-Phase Transformers	One Three-Phase Transformer
1	0.6	0.6	
2	1.5	1.0	2.0
3	2.0	1.5	3.0
5	3.0	2.0	5.0
7½	4.0	3.0	7.5
10	5.0	4.0	10.0
15	7.5	5.0	15.0
20	10.0	7.5	20.0
30	15.0	10.0	30.0
50	25.0	15.0	50.0
75	40.0	25.0	75.0
100	50.0	30.0	100.0

TABLE III—CURRENT TAKEN BY THREE-PHASE INDUCTION MOTORS AT 220 VOLTS

H.P. of Motor	Approx. Full Load Current	H.P. of Motor	Approx. Full Load Current
1	3.2	20	50
2	6.0	30	75
3	9.0	50	125
5	14.0	75	185
10	27.0	100	250
15	40.0	150	370

formers. Small motors should be supplied with a somewhat larger transformer capacity, especially if (as is desirable) they are expected to run most of the time near full load, or even at slight overload. Transformers of less capacity than those given in Table II should not be used even when a motor is to be run at only partial load. The current taken by motors of higher voltage will be proportionally less than that given in Table III. The table gives average current values which may vary slightly from the actual values in particular cases.

Up to and including 5 h.p., squirrel cage motors are started by simply closing the switch without any starting device. At starting, these motors require from four to five times full load current and give about $1\frac{1}{4}$ times full load torque. Motors with self-contained rotor resistance (built in sizes of 10 h.p. and over) require at starting about the same current for a given torque that would be required when running. As the resistance is cut out, the torque and the current will increase practically in the same proportion until a maximum of about two or three times full load torque is reached.

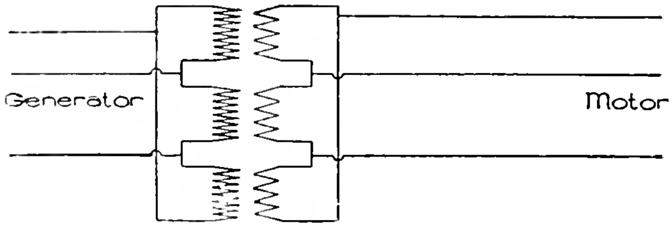


Fig. 1 Three Transformers for Three-Phase Transformation

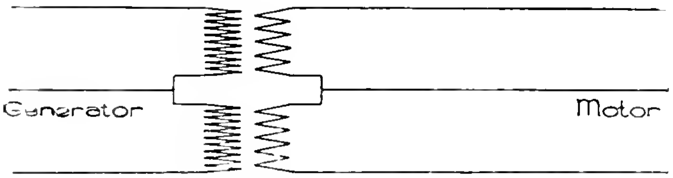


Fig. 2. Two Transformers for Three-Phase Transformation

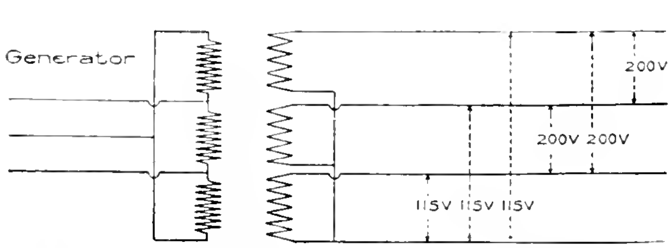


Fig. 3 Three Transformers for Four Wire Three-Phase Distribution

Connections

The three transformers, with their primaries connected to the generator and their secondaries to the induction motor, in a three-phase system, are shown in Fig. 1. The three primaries are connected between the three lines leading from the generator, and the three secondaries are connected to the three lines leading to the motor, in a delta connection. The connection of two transformers for an induction motor on a three-phase circuit is shown in Fig. 2. It is identical with the arrangement in Fig. 1 except that one of the transformers is left out and the other two transformers are made correspondingly larger. The copper required in any three-wire three-phase circuit for a given power and loss is 75 per cent of that necessary with the two-wire single-phase or four-wire two-phase system having the same voltage between lines.

The connections of three transformers for a low tension distribution by the four-wire three-phase system are shown in Fig. 3. The three transformers have their primaries joined in delta connection, and their secondaries in Y. The three upper lines are the three main three-phase lines, and the lowest line is the common neutral. The difference of potential between the main conductors is 200 volts, while that between either of them and the neutral is 115 volts; 200 volt motors are joined to the mains, while 115 volt lamps are connected between the mains and the neutral. The neutral is similar to the neutral wire in the Edison three-wire system, and carries current only when the lamp load is unbalanced.

The potential between the main conductors should be used in calculating, and the section of the neutral wire should be made in the proportion to each of the main conductors that the lighting load is to the total load. When lights only are used, the neutral should be of the same size as the main conductors. The copper then required in a four-wire three-phase system of secondary distribution to transmit a given power at a given loss is about 33.3 per cent, as compared with the two-wire single-phase system or a four-wire two-phase system having the same voltage across lamps.

The connections of two transformers for supplying motors on the four-wire two-phase system are shown in Fig. 4. This system consists practically of two separate single-phase circuits, half the power being transmitted over each circuit when the load is balanced.

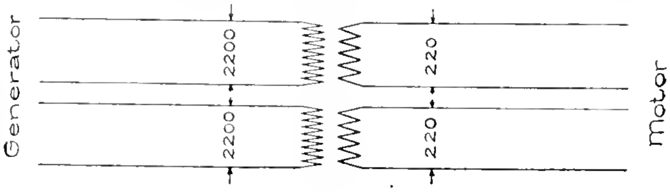


Fig. 4. Two Transformers for Two-Phase Four-Wire Transformation

Standard three-phase motors may be operated from a two-phase circuit by connecting a 9:1 transformer and a 10:1 transformer as shown in Fig. 5. While this does not give a true balanced three-phase secondary it is within 5 per cent, and sufficiently close for motor work. With a teaser voltage of 199 instead of 208 the circuit would be balanced.

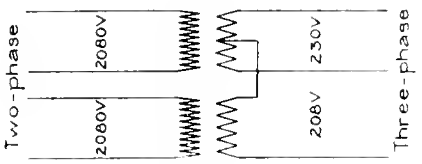


Fig. 5. Two-Phase to Three-Phase Transformation

Each lead for a three-phase motor should be 58 per cent of the cross section of each wire of the single-phase system, based on the same apparent kilowatt capacity and voltage. Before starting a motor, the secondary voltages should be tested by means of a voltmeter or one or several incandescent lamps in series, to ascertain whether the connections have been properly made, since with wrong connections excessive currents will flow and burn out the transformers, and possibly even the motor.

TYPES OF DISCONNECTING SWITCHES AND THEIR APPLICATION

By H. G. French

Switchboard Engineering Department, General Electric Company

Disconnecting switches for low voltages are simple devices, consisting of lever switch parts mounted on suitable insulators and arranged for connection at either front or back. As the voltage for which such switches are to be used increases, however, the matter of insulation becomes more and more of a problem, and at very high voltages corona formation has to be combated. A switch for such service, to be satisfactory, simple, and as inexpensive as possible, involves careful consideration of every factor in its design, and much experimenting to perfect it. Descriptions of disconnecting switches suitable for use on circuits up to 150,000 volts are given in this article.—Editor.

In the layout of circuits in generating and substations the use of switches of some kind is necessary for disconnecting the outgoing or incoming lines from the oil switches, transformers or other apparatus to which they lead. Such switches are necessarily made as simple as possible in order that the apparatus in series with them may be quickly isolated.

Probably the earliest type of disconnecting switch is that consisting of lever switch parts, the blade being a plain bar with an eye in the end, mounted on insulator caps clamped on line insulators of the well known petticoat type. These insulators are mounted in turn on suitable pins which are arranged for mounting on a base, flat surface or pipe framework. (Fig. 1.)

This type of switch was followed by one in which an insulator of the bushing style is used, thus permitting the construction of switches with back connections, or front connections if desired. When front-connected, clip blocks are secured to the insulators by corrugated pins extending from the clip blocks down into the interior of the porcelains and held by cement. The back-connected clip blocks do not, of course, require cementing, but are held on the insulators by clamping up the first nut on the back end of the stud against a washer on the end of the insulator. These insulators are secured to marble or slate bases by cementing into suitable holes and are corrugated in order to provide the requisite creepage surface. (Fig. 2.)

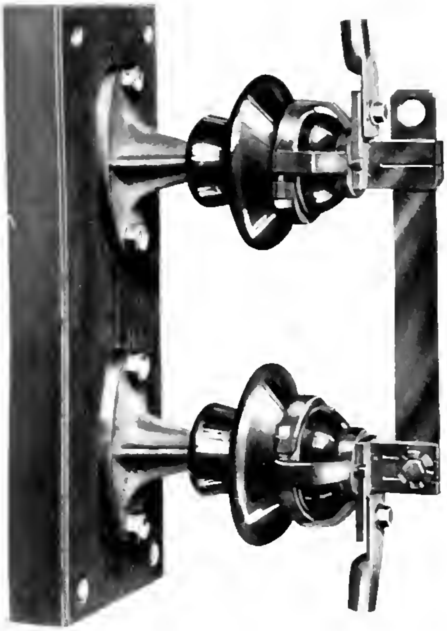


Fig. 1. Early Type of Disconnecting Switch Made up of Lever Switch Parts, Line Pins and Petticoat Insulators

These switches are suitable for moderately high voltages, but with the introduction of the voltages now commonly used it became desirable to develop a type of switch for which insulators of greater size and weight could be conveniently made and installed. The characteristic feature of this line of switches is the use of insulators built into the switch and attached to bases or other supports without the use of cement. This is a very marked advantage in the installation of such switches, and also makes it easy to change or replace insulators. These switches are intended for indoor installation and have insulators of the corrugated post type, manufactured of especially prepared porcelain carefully glazed to prevent the absorption of moisture. They are secured to bases and supports by means of suitable clamps, the switch parts in turn being clamped on the insulators. Switches for 2500 volts or less, alternating current, are mounted on marble bases without insulators, as the marble is a sufficient insulation itself. The post insulators used for the higher voltages are superior to the line insulators of the earliest switches, because they can be mounted in any position without becoming clogged with dust, a con-

Fig. 2. Later Design of Disconnecting Switch. The Bushings, which are Cemented Into the Baseboard, Permit of Back or Front Connections

dition which would greatly decrease the insulating qualities.

The back-connected switch is as readily constructed as the front connected, and switches of as high as 35,000 volts have been made with no special difficulty, although the

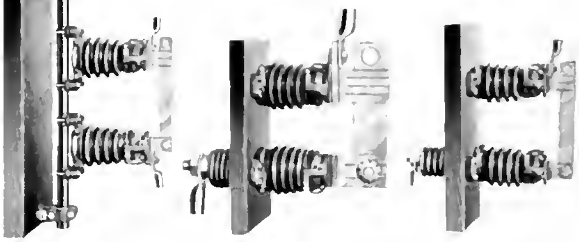


Fig. 3. A Line of 15,000-Volt Disconnecting Switches Whose Insulator Bushings are Clamped to the Base, Permitting of Easy Replacement

15,000 volt back-connected switch is the highest voltage standard switch so made. (Fig. 3.)

Front-connected disconnecting switches have been built for as high as 150,000 volts, the necessary height of insulators being obtained by the use of several porcelain posts, of such dimensions as are practicable in porcelain manufacture. For such high voltages as this it becomes necessary to make the switch parts of a special form to avoid the corona loss which occurs with switch clips and blades having square corners and sharp edges. The blade is made of tubing and the switch clips are protected by a metallic extension having edges and corners terminating in heavily rounded sections, while the insulator caps are covered by a sheet metal hood having a rolled edge. This switch, Fig. 5, shows no corona at less than 275,000 volts, and the arc-over voltage of the compound post insulators is not less than 500,000 volts.

Disconnecting switches are usually operated by means of an insulating rod or switch hook which is made of selected material especially treated for the purpose and capable of standing a test of 100,000 volts per running foot. The necessity of operating disconnecting switches in this manner leads to one of the later developments in this line of apparatus. It has been found that disconnecting switches are liable to be thrown open at times of short circuit by the heavy rush of current, when the circuit of which the switch is a part is so disposed that the blade forms one side of a loop, the magnetic force suddenly exerted tending to expand the looped conductor. The opening of a disconnecting switch under such circumstances produces an arc that may disable the switch, and such an occurrence usually results in much inconvenience if not considerable delay in resuming the service. This contingency is provided against by the use of a safety catch or locking device which retains the blade in the contacts except when it is desired to release it by means of the switch hook.

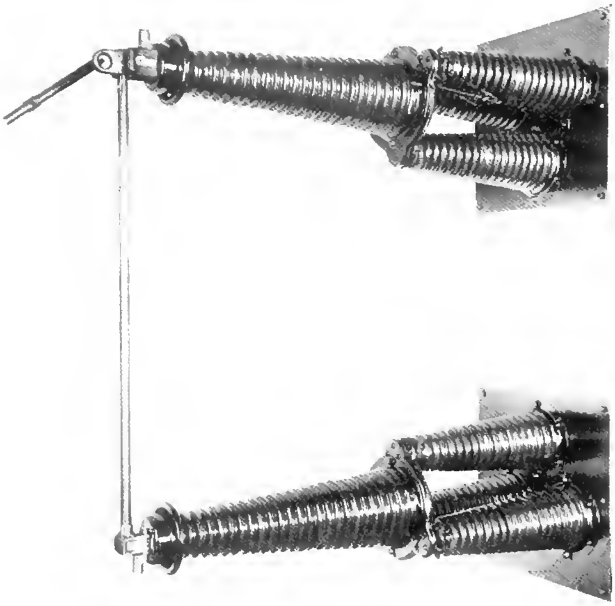


Fig. 5. Built-up Disconnecting Switch for Very High Voltages. All Corners of Current-Carrying Parts Rounded to Prevent Corona. Arc-over Voltage is 500,000 Volts

This locking device has been developed primarily for use with the type of switches shown in Fig. 3 and is so made that it can be attached to any of these switches that are mounted on post insulators, without any modification of the switch itself. The catch is very strong and well constructed, although it is small and necessarily compact. It consists of two identical members which lock around the blade close to the contact clips and are held in the closed position by strong springs. These parts are so disposed that when the switch blade is thrown into the contacts it is automatically locked and cannot be withdrawn until the catches are thrown open by a slight blow with the end

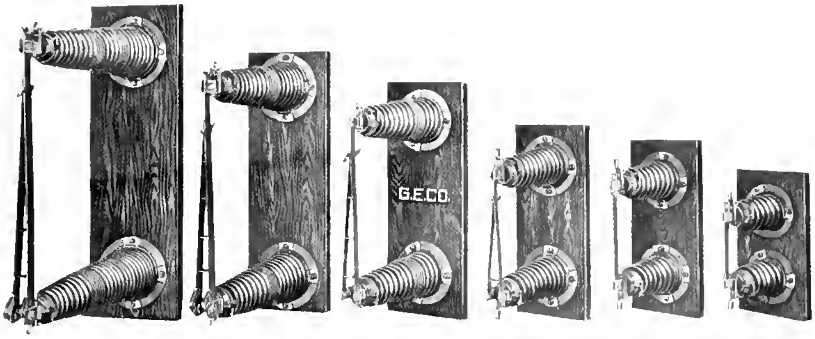


Fig. 4. A Line of Front-Connected Disconnecting Switches, of Voltage Ratings 110,000, 90,000, 70,000, 45,000, 35,000, 22,000 Respectively

of the switch hook. A simple device which is included in the lock causes these members to remain in the open position until the blade has been withdrawn from the contacts.

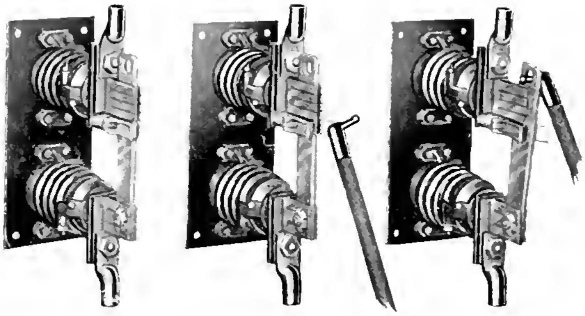


Fig. 6. Steps Taken in Opening a Disconnecting Switch which is Equipped with a Locking Device

whereupon they resume their closed position as before. Fig. 6 illustrates the method of releasing the switch blade and indicates quite clearly the construction of the lock.

Disconnecting switches for the higher voltages are frequently located high up in the station, to comply with the circuit arrangements of which they are a part. This necessarily renders them somewhat inaccessible, and for such cases a line of disconnecting switches has been designed in which the switch blade is operated by compressed air, and controlled from a convenient location by means of a motorman's control valve. (Figs. 7 and 8.) The connection for carrying the air to the switch is made by two pieces of rubber hose which form an insulating section in the piping between the control valve and switch. The control valve may be hand-operated or arranged for operation from a remote point by means of a control switch. These switches may be arranged to operate as single-pole units, or two or more connected to the same control valve to form double or triple-pole units. They are designed to operate at 40 to 50 pounds air pressure, and, if the supply pressure is higher, a suitable reducing valve and storage tank should be installed to take care of the necessary reduction in pressure.

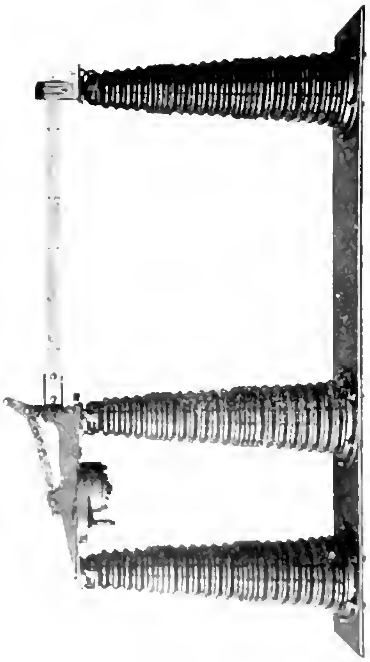


Fig. 7. Pneumatically Operated High Voltage Disconnecting Switch for Remote Control

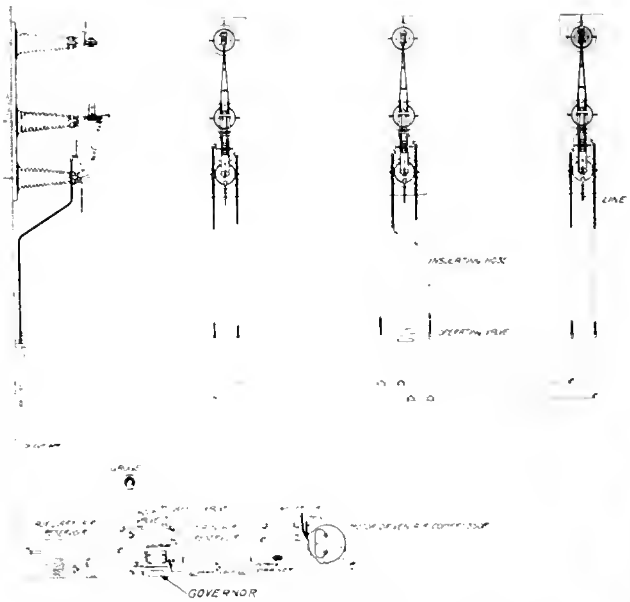


Fig. 8. Layout of Compressor, Piping, Control and Switches of a Pneumatically Operated System

HYDRAULIC MINING OF PHOSPHATE ROCK

By C. B. Pentecost

Nashville, Tenn., Office, General Electric Company

Apart from the applications of electricity in the manufacture of commercial fertilizers, the electric drive is playing an increasingly important part in the hydraulic mining of the phosphate rock which constitutes the raw material at the phosphate fertilizer factory. Most of this rock comes from Florida: and in this article Mr. Pentecost presents the result of a careful tour of inspection of the phosphate properties in that state. His story conveys a clear idea of the various processes involved in quarrying the rock, removing the overburden, conveying the material from the field of operations, and the washing and drying of the rock preparatory to its shipment to the fertilizer factory; and indicates the advantages of the electric drive in these services, and the factors governing the nature of the electrical equipment to be recommended.—Editor.

One of the most gratifying results of our scientific researches in agriculture is the practical application of the knowledge gained to the conservation of the land. Productive soils in all parts of the world have been worn out by "over cultivation," cultivation, as one geologist aptly expresses it, that too frequently has been on the order of the "wolf cultivating the lamb," until, when the cultivating process had finished, there was nothing left. Crops are taken year after year without returning to the soil any of the chemical constituents necessary for efficient cultivation. It is one of the principles of modern science that besides an intelligent rotation of crops the soil must be supplied with the necessary lime, phosphate or other fertilizer to replace those elements which have been exhausted. Farmers both in this country and in the old world have taken up the use of manufactured fertilizers to such an extent that the output of the United States has more than doubled during the past five years.

In this country the production of phosphate rock, which is extensively used as a base for acid phosphate fertilizer, was more than 3,050,000 tons for 1911. Workable deposits have been mined in South Carolina since 1867, and in Florida and Tennessee for several years. In 1906 new fields were discovered in Wyoming, Idaho and Utah. During the year 1911 the State of Florida produced nearly 80 per cent of all the rock mined in the United States, and more than one-third of the world's production. These deposits occur in two forms called hard rock and pebble rock; but, in order to be worked at a profit, they must contain a high percentage of tricalcium phosphate. The hard rock consists of boulders of all sizes deposited in a soft matrix of phosphatic sand, clay and other foreign matter. Immediately surrounding the large rocks the sand contains many particles of fine phosphate resulting from the disintegration of the large boulders.

Land pebble occurs in all sizes up to the size of a walnut, and is embedded in sand. The proportion of phosphate to other rock contained in the matrix varies from 1 to 10, to 1 to 4. High-grade land pebble contains 68 to 75 per cent of tricalcium phosphate. The nature of the deposits now being mined in Florida is such that it is easily broken up by powerful streams of water and washed into "sump-holes."

Briefly, the mining of phosphate rock by hydraulic process in the Florida pebble districts includes the following steps: removing the overburden (the top layer of dirt or sand); washing down the phosphate-bearing deposits; lifting the mineral by dredging pump to the washers; washing and cleaning, and drying the rock.

After the ground has been prospected and the amount of overburden and phosphate deposits determined, the mining operations are begun. The overburden is first removed either by steam shovels or by hydraulic methods. The steam shovel is not especially adapted to this kind of work, and is only used where it is not possible to obtain sufficient electric or other cheap power to operate the hydraulic pumps.

The high-pressure water for the hydraulic process is usually supplied by reciprocating pumps, and directed into the soil to be removed at from 100 to 150 pounds pressure by nozzles called guns. A good idea of the hydraulic method can be obtained from the frontispiece on page 470 and Fig. 1. The nozzles are from 1 inch to $1\frac{3}{4}$ inches in diameter and are ordinarily used in pairs. A ditch hose with a $\frac{3}{4}$-inch nozzle is also used to wash the material along to the sump when the ditch shows any tendency to clog up. The character of the overburden is quite favorable to hydraulic working, being a clean fine sand with some small pebbles. A majority of the foreign substance is sod, stumps and roots, but in some operations grades off into a soft but tough sandstone which must be blasted before handling. The overburden, after being washed into the sump-hole, Fig. 2, is dredged out by centrifugal motor-driven pumps and deposited in large dumps either in an abandoned mine or other unused ground.

The methods outlined for removing the overburden do not differ materially from the process of mining the phosphate itself. The rock strata are broken up by playing one or more streams from the "hydraulic giants" against the full face of the rock matrix, causing it to crumble and wash down a ditch cut into the under-lying marl. At some place near the center of the field is located the sump-hole about 8 ft. square, around which the guns work, washing the material to the bottom of the pit. From this hole the mined rock is dredged out by an 8-in. or 10-in. centrifugal pump (Fig. 3).

These pumps are of the type ordinarily used for handling sand, either 10-inch with 28 to 32-inch runners, or 8-inch with 24 to 28-inch runners. They are usually induction motor-driven, the larger pump requiring from 100 to 150 h.p. and the smaller from 60 to 100 h.p., the general tendency being to standardize the 10-inch pump. The amount of material handled by the dredge pump varies greatly owing to the variation in the number of guns in service; and variable speed pumps are therefore necessary. When the power supply is alternating current, the wound rotor type of motor is used with slip rings, controller and suitable external resistance. In the Florida "pebble district" the engineers in charge have used motors for the dredge pumps operating at both 514 and 600 r.p.m. with external resistance for 50 per cent speed reduction. This equipment for handling rock has been most thoroughly tested and has given entire satisfaction. One of these pumps is capable of handling material through about 1500 feet of pipe or an equivalent static head. When the distance from the sump-hole to the washers is greater than this a booster or relay pump must be used. This pump is also a motor-driven unit placed either directly in the pipe line to boost the material along, or installed over a second sump from which the material is again dredged out. This last method is the most satisfactory from an operating standpoint since it precludes danger to other machinery in case one of the pumps should stop for any reason, which would allow the water to flow back into the pump behind it and thus raise the pressure beyond a safe limit. Such an accident may cause a pump to burst, with attendant loss and delay.

Fig. 1 Removing the Overburden. Placed under a pressure of 100 to 150 lbs. by reciprocating pumps, a stream of water is directed at the face of the quarry by nozzles or guns. These nozzles are from 1 to 1¾ inches in diameter

Where several relay pumps are used the speed of each of the motor-driven pumps is regulated by an attendant, according to the material being delivered by the pump at the first sump. To obtain the proper speed regulation, where the pumps are used as "boosters" (placed directly in the pipe line), the control panel is provided with two ammeters, one connected in the pump motor circuit and the other in the circuit of the motor which drives the pump in the pipe line. Each attendant is thus able to adjust the speed of his pump to handle the material being delivered by the preceding pump. Where the height of the washer is very great an auxiliary known as a lift pump is placed in the pipe line for throwing the material into the washers.

Two methods are used for supplying the high-pressure water. When the mining operations are well grouped together, a centralized pumping station is used from which water is piped to the various pits for the hydraulic guns.

Fig. 2. At some place near the center of the field is located the sump-hole, about 8 feet square, around which the guns work, washing the material to the bottom of the pit

This method is desirable on account of the fact that high duty pumps can be installed and satisfactorily operated in the power station. In many cases, however, the pits are so widely separated that this method is impractical; in which case several smaller stations are used each one being a complete steam station in itself.

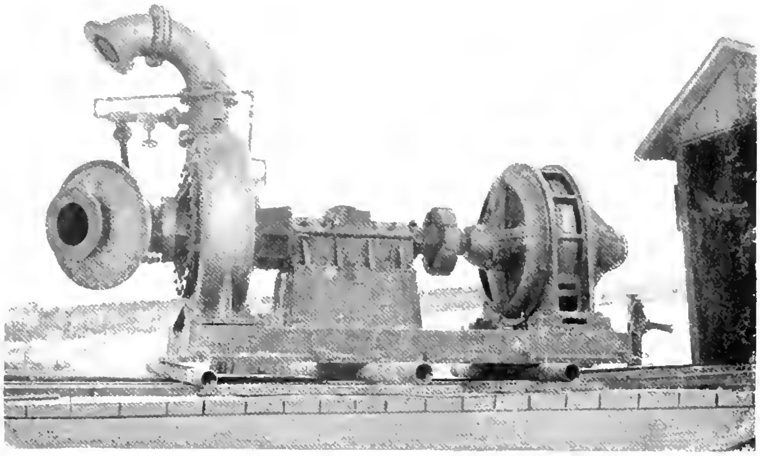


Fig. 3. The Portable Centrifugal Pumping Unit used for dredging the mined rock from the sump-hole and pumping it to the washers. One of these pumps is capable of handling material through about 1500 feet of pipe or equivalent static head

High pressure centrifugal pumps have been used for this work, and, according to the Florida operators, have given excellent results in the way of service and cost of up-keep. The rough usage, however, has the effect of impairing the efficiency more rapidly than is the case with the reciprocating type. In the opinion of the writer this is a field for investigation, as recently improved designs of centrifugal pumps operate at much higher efficiency than the old types. These pumps can be so constructed that they will not be materially affected by the gritty water; and when operated by direct connected motors show a higher overall efficiency than is obtainable with the present scheme of piping long distances from a central pumping plant or constructing separate steam pumping stations. For electrically driven units, a duplex or triplex pump geared to the motor is very satisfactory for this kind of work. At the plant of the Blue Grass Phosphate Company, at North Pleasant, Tennessee, a motor-driven duplex pump has been used to supply water for the hydraulic guns, and it has been entirely satisfactory. From 125 to 135 h.p. is required for each gun.

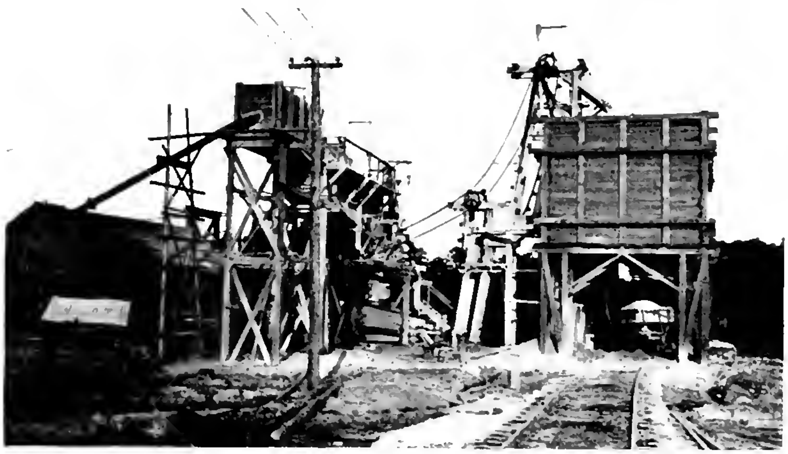


Fig. 4 Washing equipment at the quarries of the Prairie Pebble Phosphate Company, Mulberry, Fla., containing double log washers driven by 50 h.p. induction motors

The dredging pump with its direct-connected motor is usually mounted on skids and covered with a light frame house. This permits the outfit to be moved along to a new sump as the mining operations progress. An attendant looks after the motor and controlling mechanism, regulating the motor speed to the amount of material to be lifted. It frequently happens that motors direct connected to dredging pumps in the pit are flooded by the breaking of valves or pipes. Before these motors can be placed in service again on the 2300-volt circuits, they must be carefully dried out. At the Florida Mining Company this drying is done by connecting up to the motor a 20-kw. transformer with 2300 volts primary, 110 volts secondary. This transformer will give about normal current through the stator of the motor with the rotor stationary.

A comparison of the cost of "stripping" or removing the overburden by steam shovels and by hydraulic methods shows that, while shovel work is done at a contract price of about 20c. per yard, the material can be removed by hydraulic process at from 5c. to 8c. per yard. When the character of the soil is favorable, therefore, the hydraulic method is used.

Washing Equipment

A different arrangement is used for the washing process in nearly every plant in the Florida district. The washers are usually of home-made construction, and every company's engineer has a different idea as to the best method of obtaining the desired results. The general principle, however, is the same, with perhaps some modifications to adapt the machinery to the particular deposit.

The mixture of rock and foreign material in the water as it comes from the dredge pumps is thrown into cylindrical revolving screens of a coarse mesh. Here the largest pieces of rock and other foreign material are removed. The mixture is then passed over very fine flat screens, and at the same time sprayed with water at a high pressure. This stage removes the sand and other fine foreign matter and delivers the material to the "log rolls." This arrangement consists of a long rectangular bin in which one or more shafts revolve at a very low speed. To these shafts are fastened blades, or paddles, which are given a slight pitch, similar to the blades of a propeller. The revolving shafts are set on an incline so that the "paddles" push the solid material upward, and discharge it from the bin above the surface of the water. The object of this process is to break up any large pieces of clay which might have passed the screens, and carry it away in the water at the lower end of the bin.

These processes are repeated as often as necessary, and with variations conforming to the ideas of each engineer as to the best method of washing. The washing arrangement outlined above is particularly suited to the rock found in the pebble districts of Florida, inasmuch as nearly all the phosphate rock comes out in small pieces and not in the form of sand or large rock such as are found in the hard rock districts. It is obvious that in any case each particular deposit is a problem in itself and requires its own individual process for the maximum amount of material saved in washing.

The application of motor drive to these washers has been found somewhat difficult owing to the very severe starting duty. The great number of revolving parts makes the inertia load very high. Furthermore, when the washer is shut down, the clay and other material left in the log rolls settles down around the paddles; and, after standing awhile the water drains off and leaves the material cemented together in a hard mass around the paddles. It is usually necessary to remove this rock by hand from around the blades before starting up the washer.

The Prairie Pebble Company, of Mulberry, Fla., is now using a 30 h.p. 900 r.p.m. back-

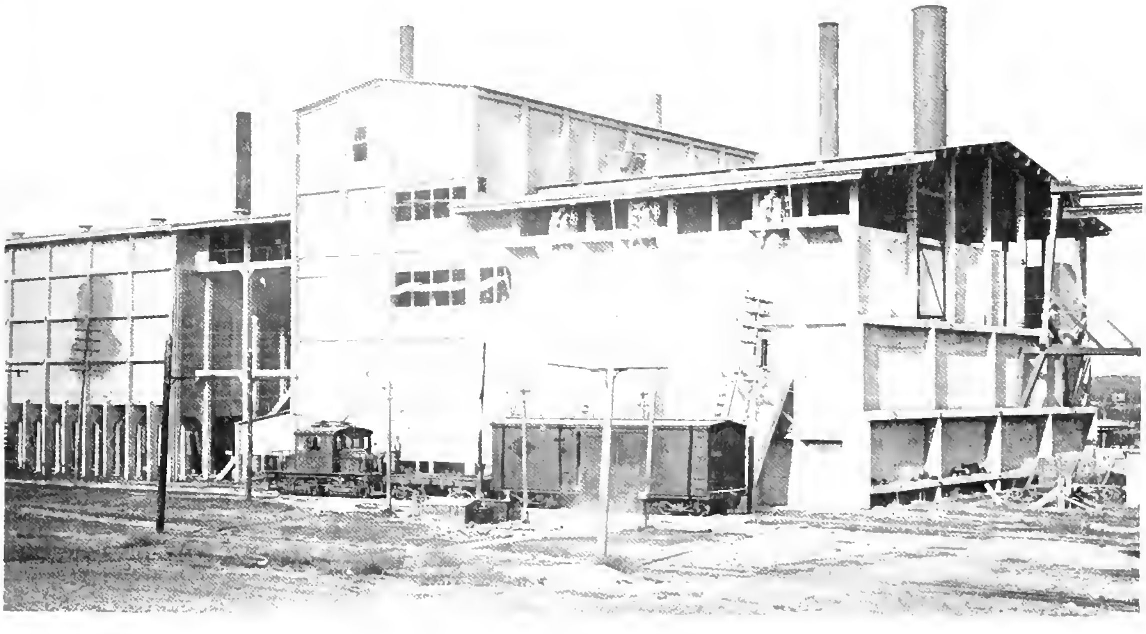


Fig. 5. Drying equipment at the quarry of the Prairie Pebble Phosphate Company. One drying plant will usually take care of all the material from several different washers, and both electric and steam locomotives are used for transporting the rock

geared squirrel-cage type induction motor driving the washer through a chain and sprocket. However, this type of motor is not entirely satisfactory, owing to the excessively heavy starting duty. The operating engineers of the company, therefore, have decided to use on their next washer a 50 h.p. wound-rotor induction motor with external resistance and controller designed for two-minute starting duty. This motor will also be more satisfactory on account of the severe cycle of duty required of motors connected to this type of machine. The actual power demanded by one of these washers varies with the design from 20 to 50 h.p. Under favorable conditions washers of this type will handle 1200 tons of rock in twenty-four hours.

Dryers

The cleaned rock is carried from the washer to the drying plant, Fig. 5, which is usually located at the central point, and the rock carried to it from the different washers. One drying plant will usually take care of all the material from the several different washers. Both electric and steam locomotives are used for transporting the rock. In the hard rock fields where the phosphate is found in large pieces the rock is kiln-dried, i.e., mixed with some combustible material and fired, although in several cases cylinder dryers, as described below, have been used in the hard rock fields with varied success. The method most commonly used in the Florida fields is known as the cylindrical dryer. Steel cylinders are employed about 36 inches in diameter, varying in length from 20 to 40 feet, and revolving at about 10 revolutions per minute. The wet rock is fed in from the cold end and discharged at the opposite end just outside the furnace. On the inside of the cylinders are fastened baffle-plates which serve to stir up the rock so that the heated air may reach every part. The cylinders are set at a slight incline, so that, by the time the rock has worked its way through, it is completely dry and ready for the dry storage bin, where it is stored away to await shipment. The Prairie Pebble Phosphate Company employs a slip ring induction motor of 175 h.p. running at 514 r.p.m. to operate their dryer. This motor is also required to operate three elevators for carrying the wet rock to the wet storage bins, as well as elevators to remove the dry rock after it has passed through the cylinders, and to carry the fine dry rock to the dry storage bins.

Pumping Plants

In some few phosphate mines now in operation it has been found possible to make use of a centralized pumping station from which all of the water is pumped to the various pits where it is used by the hydraulic guns for mining the rock. Whether or not centralized stations can be used depends entirely on local conditions. In the Florida district it has sometimes been found necessary to install several small stations, owing to the widely separated location of the phosphate deposits. Due to the fact that oil is very cheap in Florida, and that it can be transferred more easily than coal, it has been found an easy matter to operate small isolated steam plants near the location of each new deposit.

With the introduction of electric power, however, it has proven more economical to install a central generating station with either steam boilers, using fuel oil, in conjunction with steam engines or turbines; or with gas or oil engines, the prime mover in either case being connected to electric generators. From these central stations it is possible to transmit electric power to any distance, where it is utilized by motor-driven pumps both for supplying high-pressure water and for pumping out the phosphate rock. In the Florida field it is an almost universal practice to use a three-phase, 60 cycle, 2300 volt supply for all power purposes. Where the transmission lines extend over a radius of more than 2 or 3 miles the current is usually stepped up to higher voltages for transmission. Practically all of the motors operate at 2300 volts.

Industrial railways operated by electric power are used by many phosphate mining companies. The direct current at 500 volts used on the trolley is supplied either by rotary converters or synchronous motor-generator sets operating from the three-phase transmission system. The Prairie Pebble Phosphate Company has three synchronous motor-generator sets for supplying direct current to the trolley system. The advantage of these units over the rotary converter is that the synchronous motor field can be over-excited to improve the power-factor on the line. For satisfactory regulation, however, this should be accomplished automatically to obviate the effect of line surges, and changes of load and voltage.

The above discussion of methods of hydraulic mining is based on the standard practice in the pebble districts of Florida. Owing to the nature of the deposits, hydraulic methods are much more adaptable to the mining of pebble rock than hard rock. However, on account of the low cost and other advantages, as compared with other methods of mining, several companies operating in the hard rock fields have used the hydraulic method, with a degree of success depending upon the nature of the deposits. One of the first operators in the hard rock district to attempt this method was the Central Phosphate Company, of Dutton, Florida, and the results obtained in this instance have been extremely satisfactory.

As previously mentioned, the hard rock which is found in boulders of all sizes is deposited in a soft matrix which is composed largely of particles of fine calcium phosphate, resulting from disintegration of the large boulders. In the earlier days of the industry, when the deposits seemed almost inexhaustible and the demands for the product were comparatively small, workings of this character were mined very inefficiently. Large pieces of phosphate rock were taken out with forks or by other hand methods, and no attempt was made to save the finer particles. The washing process was also inefficient, and the tailings from the washers contained a large percentage of high grade phosphate sand which was thrown out into the "sand-ponds" as waste.

More recently, on account of the increasing popularity of commercial fertilizer and a consequent increase in the demand for phosphate rock, several of these old mines are being re-worked with improved forms of sand washers and all of this phosphate sand is thus being recovered from the old workings and from the "sand-ponds." Obviously, this character of deposit can be worked much better and cheaper by the hydraulic method than by any of the other methods now in use; and several operators in the Tennessee fields are contemplating the installation of equipments suitable for this kind of work.

IN MEMORIAM

GEORGE D. ROSENTHAL

George D. Rosenthal, Manager of the St. Louis district of the General Electric Company, died at 3 o'clock on Monday morning, May 19th, in the German Hospital, New York City, as the result of a major surgical operation performed one week earlier. The operation was pronounced successful by the attending physicians, of whom one, Dr. Max R. Rosenthal, was his brother. The news of his death following the first favorable reports from his bed side came as a severe shock to his friends.

George D. Rosenthal was born in the south of Russia in 1869. In 1882 he came to this country with the other members of his family and for a number of years was employed on his father's farm in Dawson County, South Dakota. In 1886 he went to New York City, where he secured employment, and two years later accepted a position in the newly organized statistical bureau of the Edison Electrical Manufacturing Company, with headquarters at Harrison, N. J. After a time he set himself the task of learning the electrical business, and with the determination to be thorough, started in the lamp manufacturing department. His quick perception, aggressiveness, and pronounced executive ability promptly manifested themselves, and following a number of promotions from department to department he was sent to Chicago in 1890 to take charge of the supply department at the warehouse of the General Electric Company. He remained in Chicago until the fall of 1892, when he was transferred to the St. Louis sub-office and placed in charge of supply sales for that territory. Three years later, in 1895, he was appointed local manager of the St. Louis office, which was a part of the Chicago territory. In April of the present year the St. Louis district was created, with Mr. Rosenthal as manager. At the time of his death he was just perfecting his organization and was anticipating many years of usefulness in his new position.

His natural aptitude for business, his foresight and perseverance, and his marked faculty for presenting the telling points of an argument, convincingly and without offense—qualifications all shaped and molded by long association with the electrical business—eminently fitted Mr. Rosenthal for the duties of such an important office. The greater share of the immense business enjoyed by the Company in the St. Louis territory is a splendid tribute to the zeal, perspicacity, and excellent judgment of George D. Rosenthal.

Mr. Rosenthal was one of the most popular men in the organization, and was held in the highest esteem by all of his business associates. By nature genial, whole-hearted, unaffected, he leaves a host of friends, numbered among whom are some of the most prominent men, socially and politically, in the Middle West.

He took an active interest in matters of public welfare, and his advice and counsel were frequently sought by those in charge of public affairs, always to excellent advantage.

Some seventeen years ago Mr. Rosenthal was married to Miss Josephine Murphy, daughter of P. C. Murphy, of St. Louis. He is survived by his wife and six children, one son and five daughters.

Interment was made in Calvary cemetery, St. Louis, on Friday, May 24th.

FROM THE CONSULTING ENGINEERING DEPARTMENT OF THE GENERAL ELECTRIC COMPANY

ENERGY DENSITY

BY DR. CHARLES P. STEINMETZ
CHIEF CONSULTING ENGINEER

While electric energy is the most convenient form to transmit and distribute, there exists no economical method of storing electric energy: the electric storage battery does not store electric energy, but stores chemical energy, by double conversion from electrical to chemical, during charge, and from chemical to electrical, during discharge. It is thereby limited in economical usefulness. As the result, electrical energy essentially plays the part of the connecting-link joining the source of energy—nature's fuel supply or water power—with the energy consumer.

As energy storage is essential throughout all modern industrial life, the maximum weight and space efficiency which may be reached with the different methods of energy storage are of interest.

Chemical Energy

1 kg. of hydrogen contains 33 kw-hr. stored chemical energy, which is set free as heat in combustion.

1 kg. of gasolene contains about 13 kw-hr. and 1 liter of gasolene about 10 kw-hours of stored chemical energy.

1 kg. of the lightest storage battery contains less than 120 watt-hours of stored energy.

Mechanical Energy

The highest mechanical energy density obviously is found in the rifle bullet or cannon ball; and, at the highest bullet velocities of about 1000 meter-seconds, represents 0.14 kw-hr. per kg. Thus a tungsten bullet (sp. g. 20) carries nearly 3 kw-hr. per cubic decimeter (liter) of volume, that is, approaches the energy density of chemical storage. Thus the impact of a tungsten bullet approaches the destructiveness of the detonation of the same volume of high explosive. This explains the interest taken in the introduction of tungsten as bullet material.

The highest velocities in rotating machinery are reached in the revolving rim of the steam turbine disk, approaching 200 meter-seconds, and representing a stored energy of 5.6 watt-hours per kg. of rim weight.

Hydraulic Energy

At the highest heads of water powers, of about 1000 meters, the energy density would be only 2.8 watt hours per kg. or liter of water, and thus would be less than a thousandth of the energy density of chemical storage. However, the ease and simplicity of storing large quantities of water in reservoirs make hydraulic storage of economical importance.

Electrical Energy

Dielectric: At the limits of disruptive strength of the best insulating material, mica, of one million volts per centimeter, the energy stored in the electrostatic field is only 0.05 watt-hours per cubic decimeter or liter, and thus is insignificant compared even with mechanical storage.

Magnetic: At the highest magnetic densities ever reached in iron, of $B = 60,000$ lines of magnetic force per cm², at $H = 40,000$, the energy density is 28 watt-hours per cubic decimeter or liter—of about the same magnitude as in the average storage battery.

In power limiting reactances, under short-circuit conditions, in the air field inside the reactance, energy densities as high as 2 watt-hours per liter are reached.

EASTERN NEW YORK SECTION OF N.E.L.A.

A meeting of the Eastern New York Section of the National Electric Light Association was held in the Y. M. C. A. Building at Poughkeepsie, on Wednesday, May 28th. The subject of the meeting was "Rural Installations, Switching and Protection." Mr. E. B. Merriam was the first speaker, and spoke particularly on getting current to rural installations, such as farming and dredging equipments, harvesting machines, etc. He showed a number of lantern slides of power substations of large and small capacity, high-tension lines, together with the arrangement for mounting the transformers and lightning arresters. Mr. E. E. F. Creighton spoke on the subject of "Protection," showing by means of lantern slides the various types of lightning arresters, arcing ground suppressors, and other devices particularly suitable for power substations for rural distribution. Both papers were discussed by Mr. A. T. Throop of the Utica Gas & Electric Co., Mr. Leon Scherck of the Central Hudson Gas & Electric Co., Mr. H. W. Peck of the Schenectady Illuminating Co., and others. Mr. H. M. Buegler, Chairman of the Entertainment Committee for the Poughkeepsie meeting, was unable to be present on account of illness. About 75 members of the Section were present.

At a meeting of the Executive Committee preceding the meeting of the Section, plans for a midsummer annual meeting were discussed, and arrangements will probably be made for a meeting the latter part of July or some time in August. The annual meeting last year was held at Trenton Falls, and was one of the most successful in the history of the section.

DYNAMO LABORATORY OUTLINES

By John Fay Wilson, B.S., E.E.

129 Pages McGraw-Hill Book Co. $1.00 net

These outlines have been prepared from an analysis of the laboratory work of a large number of American universities and technical schools. It was found impracticable to include every experiment listed by these schools, but the substance of every experiment having general engineering interest has been incorporated. The laboratory student may be led, by means of a proper outline, to certain experimental facts which he should connect with the theory as developed in the class-room or by outside reading.

These outlines consist of short but explicit instructions regarding the performance of the experiment, and conclude with a list of questions covering both the theory and the practical operation of the apparatus studied. It is not intended that the order in which experiments are arranged should indicate the order in which they should be performed. Neither is it expected that the subject-matter under one heading should, necessarily, be covered in one laboratory period. The subdivisions of the subject make it possible to omit parts of any subject where, for lack of time or any other reason, it may be deemed advisable.

QUESTION AND ANSWER SECTION

The Q. and A. Section has been started with the sole object of increasing the practical usefulness of the REVIEW; and in order that it may be made of real value, we invite correspondence from any of our readers who are looking for information on any technical matter in the field covered by this magazine, and which they think we can furnish.

Where possible the answers to such inquiries will be the work of this office; where desirable we shall obtain our authority from that engineering or commercial party in the General Electric Company's organization best fitted for handling the particular subject. We hope our readers will not hesitate to avail themselves of the expert engineering opinion which should be made available through this section of the REVIEW. Information on matters of general importance and interest will be published here; questions of interest solely to the querist will be handled by mail.

Sketches should accompany questions in all cases where this is necessary to give us complete and accurate information on the point at issue. Scale drafts will be made up here from correspondent's rough pencil sketches. Questions must be accompanied with the name and address of the sender, although these will not necessarily be for publication, and should be addressed to the Editor, Q. and A. Section, GENERAL ELECTRIC REVIEW, Schenectady, N. Y.

TRANSFORMER BREAKDOWN ON A GROUNDED NEUTRAL CIRCUIT

(40) Please furnish information as to the cause of the continued transformer burn-outs, which occur in a transmission system operating under the following conditions: The transmission line voltage of 44,000 is reduced to 11,000 for local distribution by $\triangle - Y$-connected transformers. The middle point of the Y-connection is thoroughly grounded. A further reduction to service voltages is obtained by additional transformers, whose high-tension sides are wound for 6600 volts, and connected in Y. These latter are the ones which suffer from burnouts.

The transformers are operating under a greater electrostatic stress than that for which they were designed. A 6600-volt transformer is tested for one minute at $2 \times 6600 = 13{,}200$ volts across single insulation, and is intended for operation on a 6600-volt system, where normally 6600 volts comes across two insulations, namely, from conductor to ground and back again to conductor. A safety factor of 4 is thereby realized. Grounding the neutral does not relieve insulation strain, and if such a 6600-volt transformer is operated on an 11,000-volt system, with one transformer terminal grounded, 6600 volts comes across a single insulation. The safety factor is, therefore, cut down to 2, and it is well known and generally recognized that a safety factor of 2 is insufficient for electrical insulation. Hence, the transformers break down and will continue to do so, until proper ones are used. The A.I.E.E. specifications require a one-minute high potential test at twice the *line* voltage, i.e., $2 \times 11{,}000 = 22{,}000$ volts in this case.

C.P.S.

BRASS *vs.* FIBER WEDGES

(41) The present fiber or horn wedges used for holding the coils in the slots of a 50 h.p. 440-volt induction motor, which is operating in a very damp place, cause considerable trouble by swelling. Would it be feasible to replace these wedges with others made of thin brass?

The re-equipping of the above motor with thin brass wedges may be done only under certain limited conditions. The wedges would have to be thoroughly insulated, where driven in the grooves of the slots; otherwise, excessive heating would result, owing to the local currents around the teeth, which would pass through the circuits formed by the tooth laminations and the brass wedges. Even with the wedges insulated there would be a certain amount of loss, owing to the tooth stray flux passing through the brass wedges and setting up eddies. It is doubtful, however, if this latter loss, and its resulting heating, would be serious.

A plan, which avoids all of these disadvantages relating to brass wedges, would be to use moisture-proof fiber wedges. These latter are rendered impervious to moisture by an impregnation of paraffin, boiled oil, or some kind of varnish. In case the motor is likely to become very damp indeed, it would probably be better to use those wedges which are prepared with boiled oil or varnish.

A.E.A.

TESTING POLARITY OF A FIELD COIL

(42) A six-pole d-c. motor, which has always given satisfactory service, recently burned out one of its field coils by reason of its having become grounded. The damaged coil has been replaced, but since that time serious sparking takes place under the brushes of two adjacent studs. Is this due to the new coil having been wound in the wrong direction? If one does not possess a compass, is there some other simple test which can be applied to determine the existing conditions?

The reason for the poor commutation, as presupposed in the question, is probably not the cause of the trouble, although its effect would have been the same. Field coils are usually wound in a standard direction, so that this one has doubtless been placed upon its field core end for end. This view is strengthened by the fact that many field coils have externally such a symmetrical appearance, that it is impossible to determine, without a knowledge of the code markings or a test, which is the armature end. In the absence of a compass, however, the desired information may be easily obtained in the following manner. Slip a sheet of paper between the commutator and all the brushes, which will electrically disconnect the armature. Then excite the fields in the usual manner. With an iron bolt or a short iron bar of any kind successively span the gap between each field pole and the next. Note the effort required to pull the bar away from each gap. Those gaps which demand the greater pull indicate that the poles adjacent to them are of unlike polarity, as should be the case; but those which need but a small pull show that the adjacent poles are of like magnetism. If this latter condition exists relative to the two gaps adjacent to the new field coil, then the coil should be removed and reversed.

E.C.S.

ELECTRICAL CONTACT

(43) In making an electrical contact, which is the more important factor, area or pressure?

For minute currents and often also for currents as much as 20 amperes or more, pressure is usually of more importance than area. The reason is that the conditions present for the transference of heat from the immediate neighborhood of the point of contact are generally ample for maintaining low temperature, even though the current density be high. Moreover, in such cases, the resistance of the contact usually can be readily made entirely negligible by the application of sufficient pressure. Consider, however, the other extreme. With currents of from one to ten thousand amperes, no amount of pressure would suffice to permit of maintaining low temperature at a contact of small area. It is necessary, in dealing with such heavy currents, to employ such large areas of contact as to reduce the *current density* to very low values. For intermediate values of current, viz., for currents lying between the range of tens of amperes and a thousand amperes, it is necessary that the circumstances attending each particular case be known, in order to discuss the matter.

In reflecting upon a question of this sort special instances naturally occur as of interest. Thus, when dealing with the contact between a brush and a high speed commutator, there are many complicated considerations. It is impracticable to resort to any considerable pressure as this is not compatible with good commutating results. If the only consideration were to reduce the resistance at the contacts, large areas associated with very considerable pressure per square centimeter could be employed, but this would result in a prohibitive friction loss and its resulting prohibitive heating. For railway motors the pressure on the brushes must be heavier than for stationary motors, since otherwise the vibration arising from the motions of the car would occasion poor contact. Confining attention to stationary generators or motors, it may be said that the narrower the brush, the greater may be the current density and the lower the pressure per square centimeter. The appropriate pressure also varies with the "rake" given to the brush and also, in general, with the type of brush-holder. Considerably higher current densities can be employed when a given current is transmitted by, say, a dozen small brushes, than when it is transmitted by three or four large brushes; and in the former case a lower brush pressure per square centimeter will, in general, be sufficient. H.M.H.

ALUMINUM LIGHTNING ARRESTER OIL

(44) A quantity of oil, which is intended to be used in the assembling of some aluminum lightning arresters, has absorbed a small amount of water. Will it be necessary to dry out the oil before using?

If the amount of moisture present is slight no harm will be done by using it; for, when it is placed in the arrester itself, it is in contact with the electrolyte, which is a moist solution. The oil will, therefore, at this time absorb moisture, even if it has none when initially installed. Liberal dimensions in the design of the arresters permit this to occur without the likelihood of a breakdown.

V.E.G.

HEATING OF PARALLELED TRANSFORMERS

(45) Two transformers have been satisfactorily used in parallel for a number of years in the lighting of a certain church. During the past four months, however, one of them has burned out twice, being replaced temporarily during the repair period by one of the same voltage but greater capacity. Can you explain what is wrong with this transformer, i.e., why it is that one of two duplicates should burn out twice, and still run hot at the present time, while the other causes no trouble at all?

You will doubtless find that in this case the trouble is where you least expected it. The "good" transformer may have only behaved so well because it was idle, making the other unit carry double load as a result of the parallel connection. A break or an open circuit in the primary or secondary of the former would give this condition. The fact that the temporary transformer supplied did not burn out was probably due to its larger carrying capacity. E.C.S.

LEADING OR LAGGING CURRENT IN SYNCHRONOUS MOTOR

(46) Please give a feasible explanation, or one which by analogy may be easily understood, of the well-known fact that an over-excited synchronous motor draws a leading current.

A leading current flowing into the stator windings of a synchronous motor causes a magnetomotive force (m.m.f.) which opposes the m.m.f. set up by the field excitation on the rotor. Consequently, when a synchronous motor is over-excited to a given amount, the current flowing into the motor must lead. It will do this to just such an extent as will occasion a sufficient opposing m.m.f., that the resultant of the rotor and stator m.m.f.'s shall be sufficient to occasion a flux M in the magnetic circuit. This flux will be of an amount corresponding to the voltage V, the turns T, and the cycles $\sim$ in the formula

$$V = K\ T\ \sim\ M$$

where K is a constant. Were it not for the presence of the opposing m.m.f. thus occasioned, the counter electromotive force of an over-excited synchronous motor would exceed the impressed electromotive force, which is manifestly an impossibility. By similar reasoning, it is readily seen that the current absorbed by an under-excited synchronous motor must lag, in order to establish equilibrium between the impressed and counter e.m.f.'s.

H.M.H.

PARALLELED DIRECT-CURRENT GENERATORS

(47) Two 110-volt compound-wound generators, which are connected in series to deliver 220 volts, fail to maintain this voltage when placed under load. With an increase in line current the generated voltage falls off. Several unsuccessful attempts have been made to hold voltage with load, by changing the shunt adjustment of the series field. What is the remedy?

The description of the action seems to indicate that the current flow is reversed in one or both of the series fields. A conclusive test, as to when this condition is present, consists of taking readings of the armature volts no-load and volts full-load of each machine. If the difference of potential increases in changing from no-load to full-load, the series field is connected correctly and is boosting; but if it decreases, the series field is bucking the shunt field and its terminals should be reversed. After having connected the series field in the right direction, the degree of compounding may be varied by changing the adjustment of the shunt across the field. E.C.S.

METERING THREE-PHASE POWER

(48) In metering a three-phase Y-connected circuit, assuming 100 per cent power-factor and balanced load, with two meter potential taps to third wire, the readings will be the same, which is equivalent to multiplying the reading of one meter by 2. In metering the same circuit, assuming 100 per cent power-factor and balanced load as before, with three meters and potential taken to neutral, the readings will all be the same, which is equivalent to multiplying one reading by three. In the first case the three-phase power is E.I. · 1.73 × 2 or 3.46 E.I. In the second case the three-phase power is 3 E.I. The multipliers are as 2 to 3 and the voltages as 58 to 100. Which method is correct?

Both the methods described for making wattmeter connections in measuring three-phase power are correct and no discrepancy exists provided the readings are combined in a mathematically correct manner. The inaccuracy in the question lies in the formulæ for total three-phase power as measured by the first method, viz., it should be E.I. × 1.73 and not E.I. × 1.73 × 2.

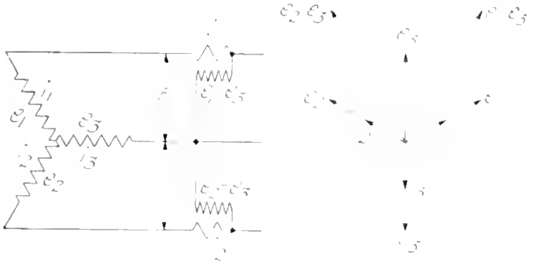


Fig. 1

Figs. 1 and 2 give diagrams of connections and vector relations for the first and second methods respectively. From these it will be seen that the currents in all the lines are equal, but that the voltages applied to the potential coil of the wattmeters in the two methods differ from each other by a factor of $\sqrt{3}$. This is due to the fact that in the first

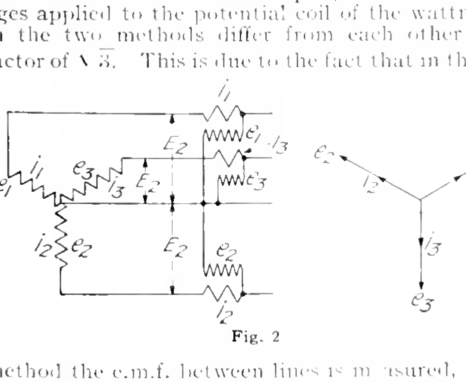


Fig. 2

method the e.m.f. between lines is measured, which is the vector sum of the potential of the two lines above neutral and is $\sqrt{3}$ times greater than either of them; while in the second method the potential coil of the wattmeter has impressed upon it only the voltage from line to neutral. A further difference in the two methods exists and it was the neglecting of this which caused the apparent discrepancy mentioned in the question. In the latter method what may be called the local power-factor within the instrument is 100 per cent, while in the former, owing to the combination of voltages, it is not 100 per cent but 86.6 per cent. Therefore in the first case each wattmeter measures not E_1I, but $E_1I \times \cos. 30 \text{ deg.} = \frac{\sqrt{3}}{2} \times E_1I$. The total power then, as measured by each method, is first, $\sqrt{3} \times E_1I$, second, $3 \times E_2I$. The two wattmeter voltages of the system, as stated in the question, are as 58 to 100 or $E_1 = \sqrt{3} \times E_2$, which relation substituted in either formula, for total power gives the other.

E.C.S.

REDUCTION OF POLARIZATION

(49) Since zinc amalgam is an alloy, not a compound of zinc and mercury, why does not the amalgamation of the zinc plates of primary batteries increase rather than eliminate polarization, owing to action between the zinc and mercury?

The amalgamation of the zinc plates of primary batteries decreases the rate of consumption of the zinc plate, by preventing that local electrolytic action due to impurities in the zinc. In the unamalgamated plate these impurities form miniature couples with the zinc and cause localized corrosion or solution of the zinc accompanied by the evolution of hydrogen, which coats the impurity and adjacent zinc.

The effect of amalgamation is to cover the zinc with a continuous coating of mercury, preventing the local action by presenting a homogeneous surface to the solution. Mercury is insoluble in dilute sulphuric acid. The zinc diffuses through to the surface of the mercury and dissolves in the acid, but hydrogen is not liberated upon the latter, on account of its high over-voltage. According to Ahrens, it would be necessary, in order that hydrogen may separate upon mercury, that this latter be at a potential of 0.080 volts higher than the zinc. It requires a higher voltage to separate hydrogen upon a mercury cathode than upon any other metal, consequently polarization of the amalgam surface does not occur. H.R.H.

INDUCTION MOTOR CHARACTERISTICS

(50) What would be the effect on an induction motor of a supply voltage lower than normal?

The starting torque and maximum torque would decrease as the square of the voltage.

The efficiency after the first small decrease in voltage would be lowered a small amount, falling off rapidly, however, after a further decrease of impressed voltage.

The power-factor would rise at first by a few per cent but would then fall off rapidly with a further lessening of terminal voltage.

The current taken from the line would increase approximately by an amount inversely proportional to the decrease of voltage.

The heating would increase as the square of the current.

The speed would decrease only slightly at first; but at about two-thirds voltage, depending upon the load, it would break down. H.M.

General Electric Review

Published Monthly by the
GENERAL ELECTRIC COMPANY'S PUBLICATION BUREAU

Manager, M. P. RICE   Editor, D. S. MARTIN   Associate Editor, B. M. EOFF   Assistant Editor, E. C. SANDERS

Subscription Rates: United States and Mexico, $2.00 per year; Canada, $2.25 per year; Foreign, $2.50 a year, payable in advance. Remit by post-office or express money orders, bank checks or drafts, made payable to the *General Electric Review*, Schenectady, N. Y.

Entered as second-class matter, March 26, 1912, at the post office at Schenectady, N. Y., under the Act of March 3, 1879.

VOL. XVI., No. 8

August, 1913

CONTENTS

HANDLING THE CANE ON A CUBAN SUGAR PLANTATION

After being carried by the ox-carts to the railroad siding, the cane is transported thence to the sugar "central"—the name given to the headquarters plant where the refining operations are performed. The operation of the central on a sound economic basis provides a promising field for the application of the electric drive; and the many outstanding advantages of the electric method are well brought out in an article by Mr. P. S. Smith on page 571 of this issue. The difference between selling price and production cost is a very narrow one. Fuel is the all-important item; and the strongest argument of the advocates of the electric method is that, with waste eliminated through the utilization of modern electric apparatus operated efficiently in a modern power station, all the necessary steam can be raised from combustion of the waste cane—the "bagasse," and the cost of production be thus materially reduced.

GENERAL ELECTRIC REVIEW

THE CENTRAL STATION AND THE ISOLATED CONSUMER

Signs were not wanting, at the recent Chicago convention of the N.E.L.A., of the very great interest which is now being taken by the electricity supply companies in the question of reaching out to the isolated consumer and connecting up his possible load to the main system. The urban territory of course is not yet anywhere near the saturation point, and new-business campaigns in the cities must still be a feature of the work of the commercial engineer; but the high diversity and excellent load factor which can be provided by many of the rural installations have of late become more clearly recognized, and it is certain that in the future more attention is going to be given to the matter of securing the advantages of some of this business than has been devoted to it in the past.

In the printed transactions of the Convention, reference to these matters is made in several different papers and reports, in the technical, general and commercial sections; and a growing appreciation is evidenced of the fact that, in determining the economic feasibility of opening up the rural business, the prime factor is the cost of providing the service. The suitability of electricity to agricultural uses has been proved time and again; but it is now also obvious that the average monthly bill which will be rendered to the average farmer is going to be something distinctly meagre, and that the farming load is not going to prove a gold-mine. The Committee for the Central States on Electricity in Rural Districts formulated the opinion that the farming business by itself holds out no prospect of making an adequate return on the investment; and suggests that the only way to handle the farming load is to boost electricity very hard for every possible kind of rural application, and to pick up the agricultural business as a side-line or a by-product. In other words, if we have a 33,000-volt transmission line across the state, it can never, in many cases, be possible to run distributing feeders from the line to any of the farms within a few miles distance of the line unless there are some other "scattered" loads, such as coal mines, drainage works, gravel pits, ice harvesting plants, country clubs, or what not, which can be tied in with the same feeder and be made to carry some portion of the line and substation expense.

Thus *cost of rendering the service* is now very rightly taken as the basis for making calculations as to rural possibilities. As to the cost of the distributing line, and who will stand the expense of erecting and maintaining the feeder, the supply companies will decide for themselves. As to the minimum of substation equipment for taking given blocks of power from the main line and transforming from the fixed primary voltage to the desired secondary with a sufficiency of flexibility and protection, the manufacturer must be held largely responsible. Mr. E. B. Merriam presented a paper at Chicago on this subject; and we are publishing on page 549 a further article from him along the same line. Briefly, this deals with the engineering end of the question, and does not touch money matters; but as the recommendations as to the apparatus required for given services are quite explicit, the article should prove of very distinct use to central station men. In the same class may be placed a paper by Mr. F. C. Green on "The Operation of Large Transformers Out-of-doors," which will appear in the September number of the REVIEW. The transformer is about the most vital, and possibly also the most vulnerable, part of the whole substation equipment; and the development of an efficient line of this class of apparatus, suited to withstand the worst conditions of outdoor service, has been the first engineering requirement of the case. Mr. C. J. Rohrer is now preparing a paper for the October number, in which he will discuss methods of metering and charging, and the probable revenue return from typical isolated loads. People who are interested in these matters are invited to communicate with the editorial office here, and to give us some pointers in regard to other phases of the rural business which we might arrange to take care of.

PRESIDENT COFFIN LAYS DOWN THE REINS OF OFFICE

[illegible] board of directors of the General Electric Company held on June 13, Mr. C. A. Coffin, [illegible] company since its organization, resigned and was thereupon elected chairman of the board of [illegible] Mr. E. W. Rice, Jr., vice-president of the company, was chosen as the successor to Mr. Coffin. We [illegible] a few extracts from notices which have appeared in the electrical weeklies regarding the event.
—EDITOR.

FROM AN EDITORIAL IN THE "ELECTRICAL WORLD" FOR JUNE 21, 1913

The present commanding position of the General Electric Company must be attributed to the leadership of retiring-president Charles A. Coffin, of whom it may be truly said that the electrical industry has in every way been the beneficiary of his marvelous constructive ability, his skill as an organizer, his economic efficiency as a manufacturer, his diplomacy as an administrator, his judgment of men, his appreciation of genius, his innate courtesy and adroit suavity in manipulating delicate situations, his untiring capacity for work, and, above all, his adamant resolve to reach any goal that seemed worth while.

With a keen divination of possibilities that has never left him, during those pioneer days in the early 'eighties when nerve and courage were required to make such a decision, Mr. Coffin, then a young New England shoe manufacturer, determined to throw in his lot with electrical development. He can have no reason now for regretting his decision. We shall not attempt here to sum up the notable lifework of Mr. Coffin: its significance cannot be disposed of in a few lines. Struggling desperately for supremacy in a field of unparalleled invention and expansion, enlisting and creating wealth that runs into the billions of dollars, Mr. Coffin has been a brilliant and successful exemplar of the old *régime*, one of its leading exponents.

Let it be acknowledged as one more tribute to an exceptional man that, from a long period of terrific conflict and upbuilding, he emerges well-nigh scatheless as to any personal animosities against him, and with the loyal affection and esteem of thousands to whom his energy and genius have given opportunity and prosperity.

FROM AN EDITORIAL IN THE "ELECTRIC RAILWAY JOURNAL" FOR JUNE 21, 1913

An event of this kind, besides bringing a realization of the shortness of the period of electrical development, also emphasizes the indebtedness of those engaged in electrical work to the efforts of individuals, especially in the pioneer days. We are usually too prone to accept conditions, especially when they mark rapid progress, as inevitable, and to assume that things would have occurred as they did without the services of this or that individual. But this is not true. The human element is as inseparably linked with the history of a business organization or of an industry as with that of a nation; and the stories of nations have shown that they have risen or fallen because a strong or a weak man has directed their affairs. The present status of the electrical industry in this country is certainly due very largely to the fortunate combination of circumstances which, early in the art, brought to the front the individuals who have left their permanent mark upon it; and to look back occasionally at the work of such men as Mr. Coffin, and to remember the obstacles which they overcame, should be an incentive and encouragement to those who have entered later into the field.

PROFESSOR ELIHU THOMSON IN THE "ELECTRICAL WORLD" FOR JUNE 21, 1913

Thirty years ago Mr. Coffin became interested in the electrical industry then just opening up. His sagacity, business ability and splendid courage in the face of great difficulties, his fine personality, his faith in the future of electricity, his ever-ready help and encouragement—so inspiring to those who were endeavoring to solve the new problems—gave to the Thomson-Houston Electric Company its position as a leading organization in the electric field. When the Thomson-Houston Electric Company and the Edison General Electric Company combined to form the General Electric Company, Mr. Coffin became its president for the simple reason that no other man existed who was so fully equipped and so competent for the position. How well he has met the arduous tasks and duties of his position during the past twenty years is evidenced by the growth of the organization itself.

E. W. RICE, JR. ASSUMES THE OFFICE OF PRESIDENT

Mr. Coffin's resignation has left a big gap in the organization, and there was inevitably only one man capable of filling it. Mr. Rice's qualifications as an engineer and an executive have been well proven by the vicissitudes of the last thirty years; but he comes into the presidency with finer credentials than these—the warm loyalty of his many thousands of employees, and the fullest esteem and confidence of the outside interests with whom, as chief executive of the company, he will have to deal—the public utility operators, the bankers, and the consulting engineers.

When, in 1880, Edwin Wilbur Rice, Jr. graduated from the Central High School of Philadelphia, he had already been in close association with Prof. Elihu Thomson in experimental work on telegraph and telephone instruments, induction coils and dynamos; and in the summer of that year, with a coolness of judgment which has continued to be one of his distinguishing characteristics, he turned his eyes resolutely away from the attractions which a college course presented, in order to become Prof. Thomson's assistant and confidant in the American Electric Company at New Britain, Conn.

The two years that followed were fruitful in technical development; and Mr. Rice, while acting practically as foreman of the electrical works, found time to wind armatures and otherwise to acquaint himself most thoroughly with manufacturing details. In the fall of 1882 Messers. H. A. Pevear, C. A. Coffin and Silas A. Barton came from Lynn to purchase a lighting plant, and ended by buying a majority interest in the American Electric Company, which they transferred to Lynn and renamed the Thomson-Houston Electric Company. By 1885 the activities of the company had become so great and so diversified that an urgent need was experienced for a superintendent of the works with an adequate technical knowledge of electricity; and Mr. Rice, although considerably under 30 years of age, accepted the position. In 1892 the Thomson-Houston organization was consolidated with the Edison General Electric Company of Schenectady to form the General Electric Company, with Mr. Coffin as President, and Mr. Rice as technical director; and to follow the career of the latter from that point would be to write a history of the engineering expansion of the General Electric Company in the last two decades. In 1896 Mr. Rice was elected to the office of third vice-president of the company, in charge of all its manufacturing and technical departments, eventually becoming senior vice-president, and on the retirement of Mr. Coffin the unanimous choice of the directors as president.

It is worth while to look back upon the large experience which Mr. Rice has had during the past 28 years, during which he has been engaged in positions where his word counted with that of only nine or ten other men in the world in picking out the path of least resistance for the advance of electricity in the arts. He has seen the flexibility of the arc lamp developed to meet almost every condition of the electrical circuit. The responsibility for making the crucial experiment of the West End Street Railway of Boston an electrical and mechanical success fell upon his shoulders. He has furthered the growth of long-distance electrical transmission of energy with its many difficult problems, and has followed closely the electrical and mechanical development of the polyphase motor. He has attacked successfully the weak point in distributing polyphase currents at high voltage, by the invention of an oil-switch and the cellular system for separating busses and circuits, which have now become so widely used and resulted in a switching system at once safe and simple. To him is also due the present system of alternating-current distribution, and its subsequent conversion into direct current through rotary converters. He has been instrumental in the development of steam turbines, and has witnessed the final overthrow of the reciprocating engine by the steam turbine in large central-station systems, and their erection in sizes as large as 30,000 kw. Owing to his faith in the tungsten lamp and its final triumph, he caused investigations to be pursued which finally resulted in the present metallic-filament tungsten lamp, which has been such a boon to the electric-lighting industry and a conspicuous milestone in the development of the art.

Mr. Rice's genius for engineering has ranged, indeed, broadly through the whole field of activity covered by the great production organization which he has directed with such wonderful skill. From the smallest beginnings he has influenced its growth until its output per annum may be expressed to-day in millions of lamps, in thousands of motors, and in miles of switchboards. No other man can ever have accomplished more in a purely pioneering field of industry.

THE ELEMENTS OF THE LAW RELATING TO CONTRACTS

By R. Moot

Legal Department, General Electric Company

Engineers engaged in active business frequently come in contact with legal questions involving buyer and seller, and should possess some knowledge of the fundamental principles of equity as applicable to contracts, guarantees, etc. The fact, so well brought out in the present article, that there is a basis of common-sense justice underlying these principles, should help materially to a more ready understanding of the subject, without incurring the necessity of memorizing a large number of burdensome details.—Editor.

A contract is the basis of every purchase, sale or lease and in fact of almost every business transaction, and some knowledge of the law relating to contracts is therefore necessary to every business man. This branch of the law is the result of the application of the principles of equity and fair dealing to the transactions of merchants extending over many centuries. It is the accumulation of experience with the customs of the business world. Space does not permit of discussion of the reasons for various rules of law governing contracts. Many are obvious; and, while the law in a given case may not appear to be common-sense, it is safe to assume that, if a rule of law or a decision of the court has withstood the attacks of a generation of lawyers, it must have some common-sense back of it. It is the purpose of this article to state briefly some of the elementary principles of law relating to contracts.

At law the theory of a contract is that the minds of two or more parties have met upon an agreed proposition; and a contract which has an essentially different meaning to the different parties is not generally enforceable. For this reason it is essential that every contract, whether oral or written, should be as clear and concise as it can be made. For this reason, also, if changes are made in a typewritten or printed contract, they should be made in ink and initialed by the parties to the contract; or, better still, the contract should be rewritten so that there may be no possible dispute concerning the matters on which the minds of the parties met at the time of making the contract.

In business practice contracts usually take the form of a proposal and acceptance. One party offers to do a certain thing, at a certain time, for a certain consideration. An unqualified acceptance by the other party makes a valid contract. If the party to whom the proposal is made wishes to change the terms of payment or any other condition of the proposal he may make a counter proposal; but the final proposal, by whomsoever made, must have unconditional acceptance of the other party before a contract is consummated. This rests on the same principle we have already referred to, viz.: that there must be an unqualified agreement between the parties in order to make the contract binding.

Every contract must rest upon a valid consideration. Some benefit or consideration must pass, either between the parties or to a third party; and the consideration must not be a past consideration. For example, if *A* and *B* make a contract, *A* to deliver the goods and *B* to pay a definite price, *A* and *B* may agree to deliver the goods and the purchase price to each other or to a third or fourth party. If, however, *B* made a gift of $500 to *A* before the contract was made, the agreement by *A* subsequently to perform work or deliver goods in consideration of that $500 would not be a valid contract; and *A* could not be compelled to render the services or deliver the goods, *B* not having agreed to do anything, or part with anything, as a consideration for *A* performing his part of the agreement. A contract without a consideration is unenforceable. The contract must cover something which both of the parties can legally do, and which it is physically possible for both to do. A court will not enforce impossible contracts, nor contracts clearly beyond the power of the parties. An agreement made by a City Official on behalf of a City, which is not authorized by the provisions of its charter or of the statutes, is unenforceable for this reason.

Memory of man is faulty, and there is also a temptation to misrepresent or forget terms of a contract which has turned out to be unprofitable. The statute of frauds was enacted to avoid disputes between parties as to what was agreed upon, and to make contracts more easily enforceable. Briefly, the statute of frauds provides that an agreement which by its terms is not to be performed within a year, or a guarantee of the debt of another person, or a contract for the sale of goods for $50 or more unless some part of the goods is delivered or some part of the purchase price is paid is void unless there is an agreement in writing, or a memorandum in writing signed by the party to be charged. It is advisable either to make an agreement in writing or to confirm the agreement by letter, this being a memorandum in writing signed by the party to be charged within the statute. Telephone orders should always be confirmed by letters of both parties for this reason.

Most contracts are made in writing; and it is desirable to bear in mind certain essentials which enter into practically every written contract. The essentials of a written contract are:

1. Date of the contract. This date is frequently the basis on which time for delivery of merchandise or payment is figured; and sometimes is important also in determining whether recovery is barred under the statute of limitations. A note is a contract to pay a certain sum at a given date. A demand note is payable any time after its date. The statute of limitations in most states is six years on contracts not under seal, including notes, so that a recovery on a demand note would be barred by the statute of limitations six years from its date. While oral evidence is admissible to show that the contract was in fact executed or delivered on a date other than that stated in the contract, the date written in a contract raises a legal presumption that it was made and delivered on that date.

2. *Consideration.* A good consideration is essential to every enforceable contract; and it is always desirable to state a consideration, as this raises the legal presumption that the contract rests upon a good consideration. In deeds and many other forms of written contracts it is customary to show consideration by a formal recital "in consideration of one dollar and other good and valuable consideration, receipt of which is hereby acknowledged." This is done when it is not desired to disclose what the actual consideration was, in a contract to be filed or which may otherwise have publicity. Proof is admissible if necessary, to show what the consideration really was.

3. *A definite description* of the apparatus to be shipped, work to be performed or services rendered under the contract.

4. *Date when shipment is to be made* or services rendered, place of delivery of goods, and a definite time for the completion of the contract.

5. *All terms and conditions of payment* and the date and place where payment is to be made. Oral evidence is not admissible to vary the provisions of the contract on these last three points, the only evidence that can be introduced being to explain the meaning of a provision which is not clear.

6. *Execution of the contract by all parties* or by someone having authority to bind each party. Contract with an individual should be signed by the individual or by an attorney in fact, power of attorney being given to show authority to execute. An agreement signed by a partnership should be signed with the partnership name by one of the partners. When a partnership becomes insolvent the assets of the partnership must first be exhausted, and then the assets of the partners can be reached by creditors. If the act is not within the apparent scope of the partnership business, the signature of the partnership name by all the partners should be obtained in order to bind the partnership. This applies most frequently to the making and endorsing of notes. Execution by an association should be by its Trustees or someone authorized to contract for them. Execution by a corporation should be by its duly authorized officers.

Execution may also be by an authorized agent. One who contracts with a purchasing agent or sales agent of a corporation, partnership or association may assume that the agent has authority to bind his principal, if he is acting within the apparent scope of his authority. This is within the well known principle of the law of agency that the principal is bound by the acts of one whom he holds out to the world as his agent, when such agent is acting within the apparent scope of his authority and the principal is disclosed. Execution by a municipality should be by a duly authorized officer of the municipality, care being taken to ascertain that the contract is duly authorized according to the laws in each particular case by the municipality itself; for the statutes generally provide that a municipality is not liable under a contract made by any officer or agent, when such contract is not duly authorized, although the officer or agent is acting within the apparent scope of his authority.

The law does not recognize the right of a party to a contract to exact a penalty for its breach or for failure of the other party to comply with its terms. The law, however, recognizes the right of either party to recover damages suffered by reason of breach of contract or delay or failure in the performance of its provisions. It is sometimes difficult to ascertain the exact amount of the damages suffered and accordingly when it is known at the time of making the contract that either party will suffer damages by reason of delay or other failure a provision is inserted in the contract to the effect that whereas damages will be suffered if delay occurs it is agreed that a fixed amount per day or week shall be recovered as liquidated damages for delay. The courts look to the substance rather than the form of such a provision and if the amount stated as liquidated damages is in fact simply a penalty where no damage is suffered the courts are inclined to construe even such a clause as a penalty clause and unenforceable.

A contract of conditional sale is a contract containing a provision that title to the apparatus sold shall remain in the vendor until the full purchase price has been paid. Such contracts make it possible for a vendor to sell more apparatus or goods to a purchaser whose credit is limited than would otherwise be possible with safety, the vendor in all cases having the right to retake the property sold if payments are not made as agreed. In states where there are no statutes concerning contracts of conditional sale such contracts are good against the purchaser and subsequent purchasers for value. In states where statutes have been passed requiring the filing of contracts of conditional sale in a designated place, as the County Clerk's office, or office of the Secretary of State, such filing is under the statute a notice to everyone that the holder of the apparatus is not the owner and that the purchase price has not been paid and if a contract of conditional sale is filed as required by law in such state any one purchasing from the vendee does so at his peril. If, on the other hand, in such a state the contract is not filed it is possible for a purchaser under a contract of conditional sale to resell what he has bought under the contract, although he has not paid the full purchase price, and the purchaser from him, if a bona fide purchaser for value without notice of the contract, acquires good title. The original vendor's only remedy in such a case would be an action against the original purchaser for the balance of the contract price. Each state has different requirements with regard to the acknowledging, witnessing, etc., of contracts of conditional sale and also with regard to the place and time of filing or re-filing. In such case the law of the state in which the apparatus is to be located governs and to secure adequate protection on such contracts the law must be carefully complied with.

Mohawk Valley at Schenectady, N. Y.

SUPPLYING THE ISOLATED CONSUMER FROM THE TRANSMISSION LINE OF MODERATE VOLTAGE

By E. B. Merriam

Switchboard Engineering Dept., General Electric Company

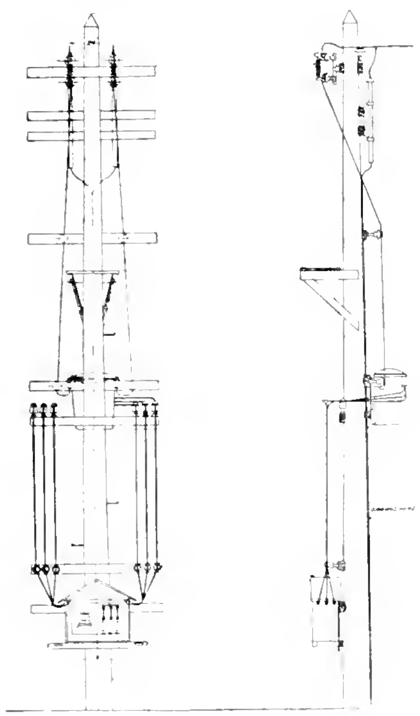
This article deals first with the reasons underlying the present-day demand for cheap and reliable substation apparatus for connecting up the isolated consumer with the central station system. Then, with seven outline drawings, the author presents a specification of the pole or tower structures for distributing various quantities of power at given voltages from the main line to the consumer, and afterwards deals with the different parts of the equipment making up these outfits. The latter part of the article describes and illustrates a number of installations of this character in successful operation. Much new ground is being broken every month in opening up this field, and we shall certainly have more to say on the matter in early issues of the Review.
—Editor.

The question of supplying electrical service to the isolated consumer holds a very prominent place in the mind of the new-business staff of the central stations throughout the country. There has never been any question as to the unique possibilities for a multitude of electrical applications in rural communities; and it is now very many years since the first trial installations were made to prove the ability of electrical service to meet the requirements of the various power applications about the farm. In nearly every case these functions were found to be discharged in a very satisfactory manner—in many cases notably so; and since those days the electrical business has made enormous strides in the towns. The dweller in the rural territory is nevertheless debarred from enjoying the fruits of these achievements; and the instances of any considerable distribution of electrical energy, from the city station to the country residents and farmers, are relatively very few, when we consider the enormous amount of new connections which are yet unmade, and even beyond the present range of contemplation.

Many very interesting isolated plants have gone into operation meanwhile; but, while these represent of course good engineering, they have been of little moment to the central station man, beyond possibly furnishing him with data as to the requirements of the scattered loads, whether dairying, harvesting or irrigating. The assimilation of some of these isolated loads into the central station system is highly desirable to the latter, as they provide a high degree of diversity and certainly tend toward a raising of the load factor of the system. Under this class of load may be placed the small town where a substation of the usual design would be uneconomical; while there are many others, such as power supply for farms, mills, mines, and other similar service along the right-of way of the transmission line. Irrigation systems and other forms of pumping are a further application.

The factor which has hindered the extension of electrical service to the isolated consumer has been the fact that the revenue which may be expected from the load must be at least great enough to justify the expense of carrying the lines to his property and making the connection. In the past the cost of the equipment required, or thought to be required, for this, has in most cases put the matter beyond the range of economic possibility, although physically it may have been in all respects a feasible proposition. Much enterprise has recently been shown by the supply companies in examining thoroughly the possibilities of line extensions, and even in making experimental excursions into the sparsely settled territory, with a view to securing the load first, and of making money or losing money afterwards; while many instances may be recalled in which the farmers themselves have shown a wonderful belief in the possibilities of electrical help on their land, and where they have made themselves responsible for the construction of the connecting lines—sometimes as many as 15 and 20 miles of moderate-voltage construction. The line, however, is but one item in the cost; and of greater importance is the question of the minimum of apparatus which is required for stepping down the supply voltage to a value suitable for use at the point where it is wanted. It is proposed in this article to deal briefly with some of this apparatus, and to give the details of the switching equipments which have been designed to provide a safe, economical and efficient means for obtaining small blocks of power from transmission lines of moderate voltage.

It will be understood that the prime factor which has had to be observed in the development of this apparatus is that first cost must imperatively be brought to a minimum, since it is for use in installations where, under the most favorable conditions, the revenue can never be high. It might be imagined that the endeavor to reduce the cost of the substation equipment had resulted to some extent in the weakening of the transmission line; but actually this is not the case, as much care has been given to the matter of protection, and the new designs are calculated to afford a maximum degree of protection and continuity of supply of the main line. Physically the apparatus must be entirely suitable for the worst conditions of outdoor service, designed for erection actually on the right-of-way of the transmission line itself. Skilled attention is not required, and the equipment may be efficiently tended by almost any labor which happens to be available at the site of the installation. We will first discuss and illustrate the complete equipment required for tapping lines of various voltage, from 16,500 upwards, and for the supply of various amounts of power from 5 kv-a. upwards. We will then consider the individual parts of the electrical apparatus in greater detail, concluding with some notes on actual installations of this character which have been made and which are now in successful operation.



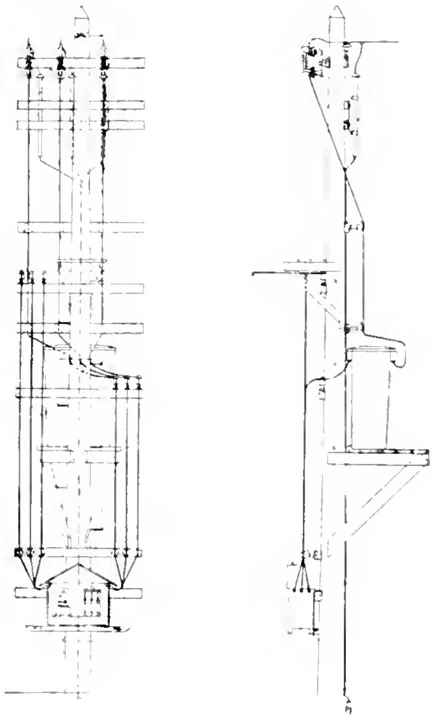


Fig. 2

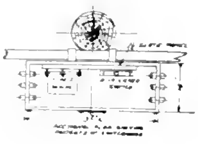


Fig. 1

Fig. 1. Wooden Pole Construction. Arrangement of switching and transforming apparatus on pole for distributing 5 kv-a. at 110 to 220 volts from single-phase 16,500-volt transmission line

Fig. 2. Wooden Pole Construction. Arrangement of switching and transforming apparatus on pole for distributing 50 kv-a. at 110 or 220 volts from three-phase 16,500-volt transmission line, using one three-phase transformer

In tapping a transmission line for the supply of an isolated load or a few consumers bunched into a territory remote from the principal distributing centers, the chief factor governing the design of the step-down and controlling apparatus is, of course, the voltage of the line. Fig. 1 shows the arrangement of switching and transforming apparatus for supplying a load of 5 kv-a. at 110 220 volts from a single-phase 16,500-volt transmission

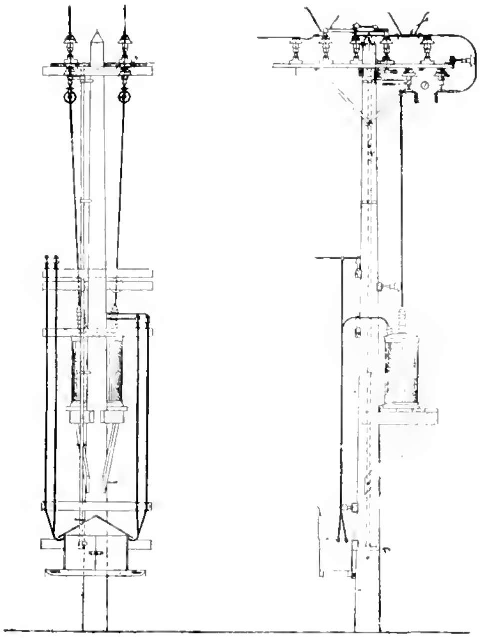


Fig. 3. Wooden Tower Construction. Arrangement of switching and transforming apparatus for distributing 25 kv-a. at 2200 volts single-phase from 33,000-volt transmission line

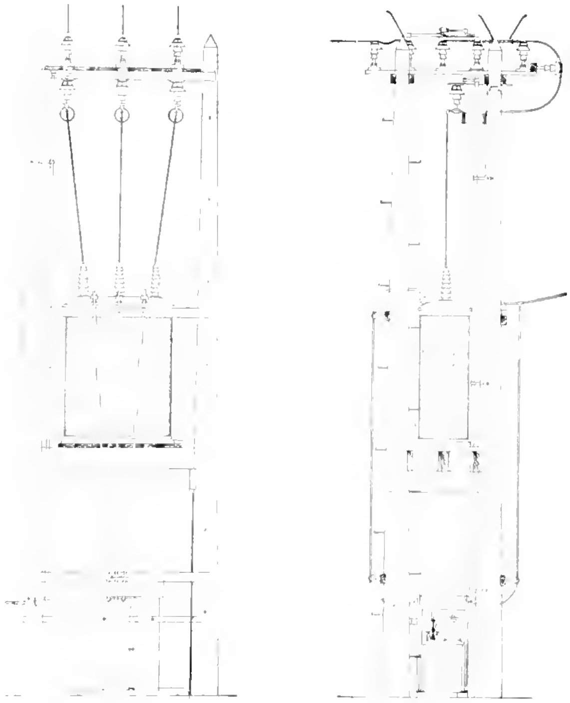


Fig 4. Wooden Tower Construction. Arrangement of switching and transforming apparatus for distributing 200 kv-a. at 2200 volts three-phase from 33,000-volt transmission line, using one three-phase transformer

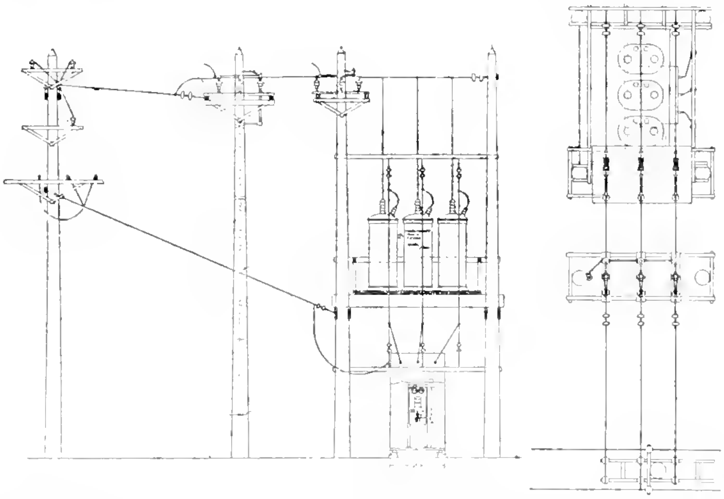


Fig. 5. Wooden Tower Construction. Arrangement of switching and transforming apparatus for distributing 225 kv-a. at 2200 volts three-phase from 33,000-volt transmission line, using three single-phase transformers. It should be noted that the outline drawings in Figs. 1 to 7 inclusive are intended merely to indicate the physical layout of the distribution equipment and the relative location of its component parts. The cuts have not been made to a common scale, and the sizes are therefore not to be regarded as comparable

line. It will be seen that the incoming line connects direct on to a combination expulsion fuse and disconnection switch located at the top of the supporting pole. The switch house at the base of the pole contains a watthour meter and a triple-pole double-throw knife-switch. The height of the switch house roof is 6 ft. 4 in. from the ground. Above this, midway up the pole is the step-down transformer, surmounted again by a platform at such a height as to bring the lineman, when standing upon it, within reach of the top of the pole. The incoming line is shunted to ground through a compression chamber lightning arrester, the ground wire being carried direct down the pole and secured thereto at intervals. For such voltages as this the entire equipment for any load up to 50 kv-a. is erected upon a single pole. Fig. 2 shows the arrangement for a 50 kv-a. equipment, few differences being noted between this and the 5 kv-a. layout. In this figure the transformation is assumed to be from a three-phase 16,500 line. A three-phase transformer is employed, and the mechanical details are, of course, stiffened up to care for the increased weight of apparatus.

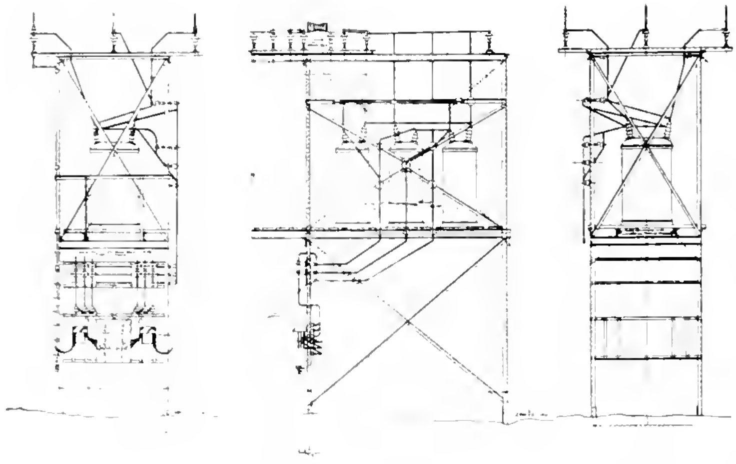


Fig. 6. Steel Tower Construction. Arrangement of switching and transforming apparatus for distributing 180 kv-a., at 2200 volts three-phase from 22,000-volt transmission line, using three single-phase transformers

The equipments for 33,000 volts differ from those used on 16,500 in several respects. In order to carry the greater weight of apparatus, the pole construction is abandoned in favor of a tower design. The low-tension switching equipment is enclosed in a portable switch house; while included in the high tension switching apparatus are separate switches and fuses, and a choke coil. Figs. 3, 4 and 5 show three types of wooden tower construction; while the steel design is illustrated in Figs. 6 and 7. Fig. 3 shows a wooden tower arrangement of switching and transforming apparatus for distributing a load of 25 kv-a. at 2200 volt single-phase, from a 33,000 volt transmission line; and Fig. 4 illustrates the layout for a load of 200 kv-a. at 2200 volt, three-phase, taken from a three-phase line at 33,000 volts, and using a single three-phase transformer. A somewhat different design is adopted in the equipment shown in Fig. 5, in which a 33,000-volt three-phase line is tapped to supply 180 kv-a. at 2300 volts by means of three single-phase transformers.

Fig. 6 illustrates a steel construction, which supports an equipment for taking off 180 kv-a. of power at 2200 volts three-phase from a 22,000-volt transmission line. In the design shown in Fig. 7 one three-phase transformer is used for supplying 500 kv-a. three-phase at 2300 volts from a transmission line operating at 70,000 volts. The steel tower is again employed here. In nearly all cases the steel construction is to be preferred to wood, owing, of course, to the lack of durability, and the high first cost of the latter, to say nothing of the fire hazard involved in its use. The use of three single-phase transformers, in place of one three-phase results in a minimum of expense for repairs in case of a breakdown in the transformer, and also admits of carrying the load even though one unit be completely disabled. It also permits the standardization of any one size of transformer by any one operating company and allows the company to utilize this plan of three-phase as they see fit, thus minimizing

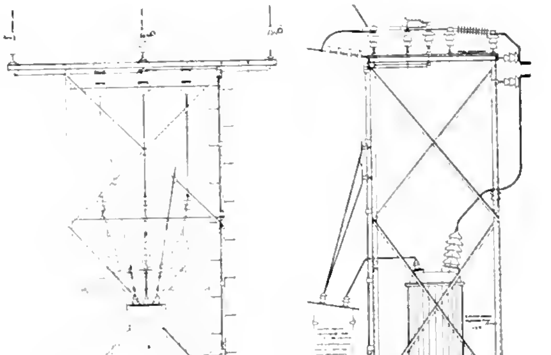


Fig. 7. Steel Tower Construction. Arrangement of switching and distributing apparatus for distributing 500 kv-a. at 2300 volts three-phase from a 70,000-volt transmission line, using one three-phase transformer

the stock of transformers which they must carry. The weight per unit is reduced so that erection is also a simpler matter.

DETAILS OF INDIVIDUAL PARTS OF EQUIPMENT

Fuses and Disconnecting Switches

Fig. 8 shows a single-pole primary cut-out of 10 amperes capacity, for lines of 10,500 volts. This fuse is used primarily as a protection for the transformer against short-circuits; but it is sometimes also made to serve as a disconnecting switch. A modification of this design, indeed, is to employ the same construction and to build the fuse in the form of a disconnecting switch. This fuse is a particularly effective piece of apparatus on circuits carrying a moderate amount of power where the voltage does not exceed 16,500 volts. A fuse for higher voltages is shown in Fig. 9, which illustrates a triple-pole 50-ampere combined expulsion fuse and disconnecting switch for outdoor service on 35,000-volt lines. This combination provides an automatic disconnecting device which is highly economical as well as thoroughly protective, and is designed for outdoor

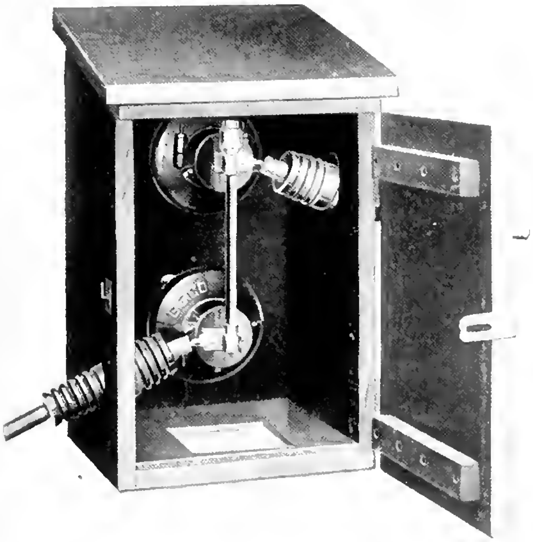


Fig. 8. Single-Pole Primary Cutout for Rural Installations

mounting in either a horizontal or vertical position. As the tubes are weatherproof, no additional housing for the switch is required. Fig. 10 illustrates a 20-ampere 35,000-volt outdoor high-tension fuse for horizontal mounting; while Fig. 11 shows a single-pole single-throw 300-ampere disconnecting switch for outdoor service on lines of 70,000 volts.

A triple-pole fuse of the goat-horn type, is shown on the cover of this issue. The horns are 10 inches apart, and in this picture the

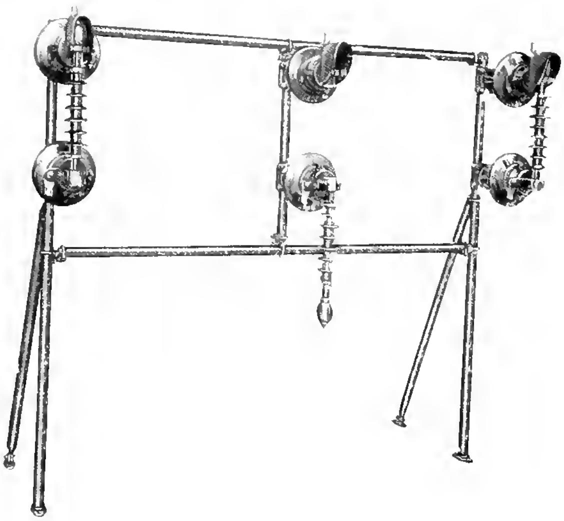


Fig. 9. Triple-Pole Combined Expulsion Fuse and Disconnecting Switch, 50 Amperes Capacity, for Outdoor Service on 35,000 Volts

device is shown clearing a three-phase short-circuit on a 29,100-volt bus. Fuses operating on this principle possess several objectionable

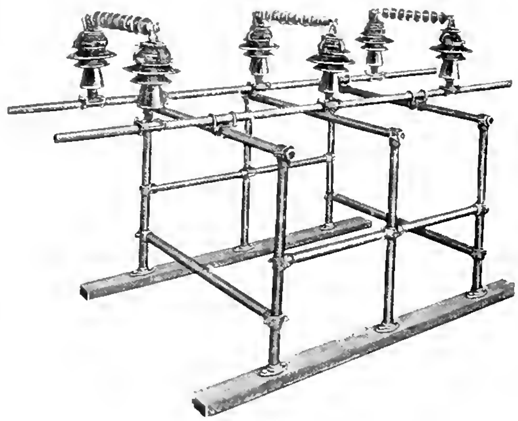


Fig. 10. High-Tension Fuse for Horizontal Mounting, 20 Amperes Capacity, for Outdoor Service on 35,000 Volts

features. The arcs often rise over the horns to considerable length and of large volume; and, as they are readily disturbed by air-currents, they are quite likely to blow across and short-circuit the line unless the phases are spaced sufficiently far apart. Some of these fuses have been used with more or less success on transmission lines of moderate

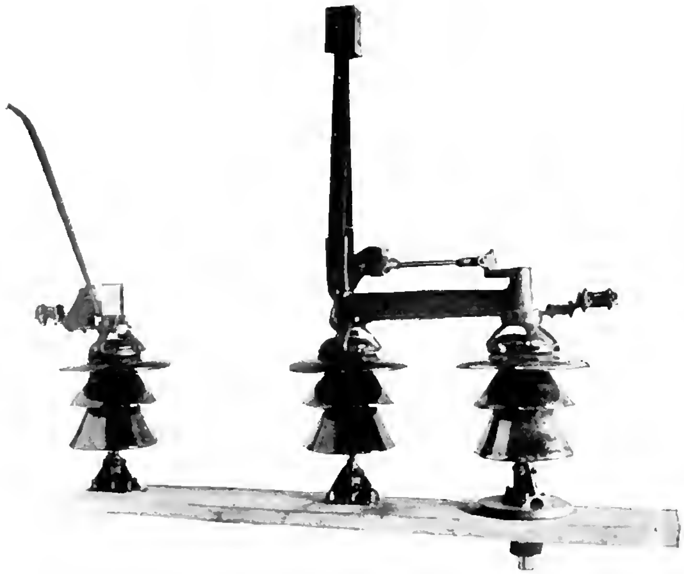


Fig. 11. Single-Pole Single-Throw Disconnecting Switch, 300 Amperes Capacity, for Outdoor Service on 70,000 Volts

capacity for a considerable time; but it has been found by test that they may introduce high-frequency surges and oscillations into the transmission line, and are therefore a source of danger to transforming apparatus located nearby, unless the transformers are adequately protected from high-frequency surges by increased insulation, or unless other means are taken for dissipating the energy. These fuses have, however, been very successfully used at junction points in systems where the transformers have been located several miles away—an arrangement, of course, which has allowed the intervening line to dissipate the energy of the high-frequency surges.

Oil-Switches

The progress which has been made in the development of oil-switches has recently been treated in the Review.* The switch for outdoor service is, of course, substantially the same as the indoor variety, except that everything exterior to the cover is enclosed and protected from the weather. For voltages up to 70,000 the bushings consist of a one-piece porcelain with petticoat-shaped projections outside the tank. The external operating and tripping mechanisms are enclosed in a weatherproof case, and may be either hand or solenoid-operated. Although it has been produced primarily as a part of a complete substation equipment, it is eminently suitable for the small rural installation in cases where the extent and nature of the load will justify the expense of the switch. That the outdoor installation is capable of providing service for electrical apparatus of a kind which is certainly not encountered in indoor practice is indicated in an interesting manner in Fig. 12 which is produced from a photograph of a 110,000-volt single-pole outdoor oil-switch taken just after a sleet storm.

Transformers, Choke Coils and Feeder Regulators

The transformers represent another special part of the rural substation equipment. They receive the line pressure and transform it to a voltage suitable for distribution either direct to the consumer, or to intermediary

Fig. 12. Single-Pole Oil-Switch on 110,000-Volt Circuit After a Sleet Storm

* "Recent developments in high voltage oil-break switch design," by E. H. Jacobs, General Electric Review, June, 1913.

feeders from which the consumer may obtain his supply by the employment of a subsidiary transformer. For the rural service the transformers are specially designed for outdoor service under the worst climatic conditions; and in addition to the mechanical features of design which this condition entails, they are provided with special insulation in order to meet any demands which may be placed upon them. The subject of the operation of large transformers in outdoor service will be taken up in greater detail in an article by Mr. F. C. Green in our September number.

For protecting the transformers and other parts of the equipment from line disturbances, resort is frequently made in rural and other installations to the use of choke-coils. Fig. 13 illustrates this apparatus and shows a 300-ampere coil for a 45,000-volt circuit.

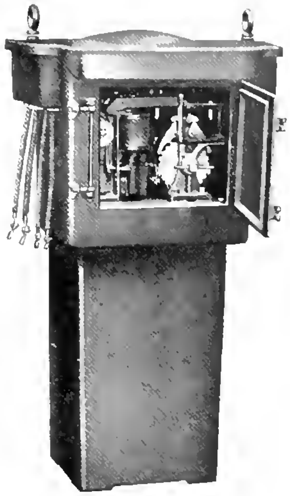


Fig. 14. Small Automatic Feeder Voltage Regulator

In opening up this isolated load business, the supply companies have found many cases in which it has been necessary to furnish small blocks of power from transmission lines to consumers who require principally a lighting service, in which constancy of the distributed potential is a prime consideration. For meeting the requirements of such cases there has been developed line of self-contained outdoor-type feeder voltage regulators. A small automatic regulator representative of this class of apparatus, is

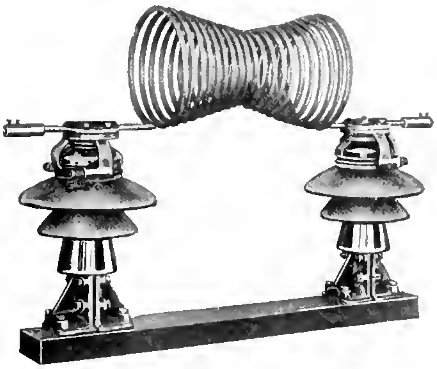


Fig. 13 200-Ampere Choke Coil, 45,000-Volt Circuit

illustrated in Fig. 14, which, in conjunction with one or other of the switching units already described, provides an effective and cheap means of meeting the wants of the rural distribution demand. Fig. 15 shows the regulator installed on a pole.

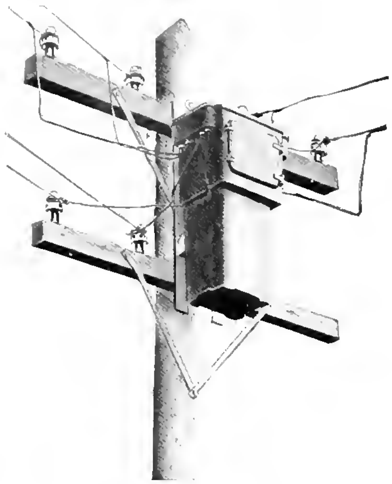


Fig. 15. Automatic Feeder Voltage Regulator on Pole

Switchboard Panels and Switch Houses

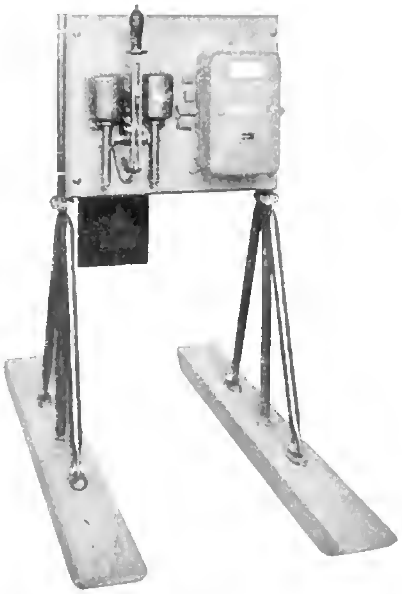
In the first few pictures illustrating this article, the switch house could be seen located at the foot of the pole or tower which supports the step-down and control equipment. These houses contain the switch-panels which control the supply received from the secondary of the transformers and distribute it to the feeders which are run to the individual consumers fed from the pole or tower in question. In designing this apparatus, it has been necessary to bear in mind the requirements of three classes of loads:

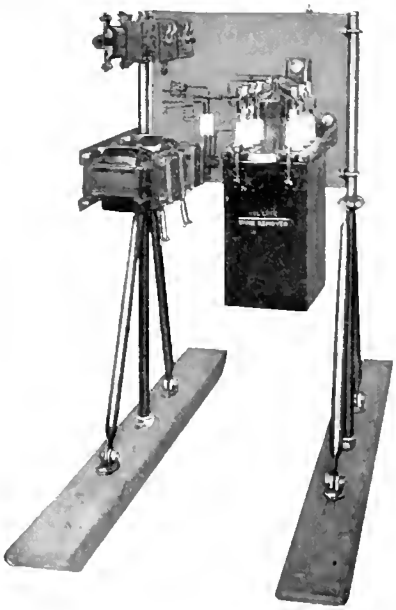
(1) Small consumers handling a mixed load.

(2) Localities requiring a mixed load of (a) commercial lighting; (b) street lighting; and (c) power.

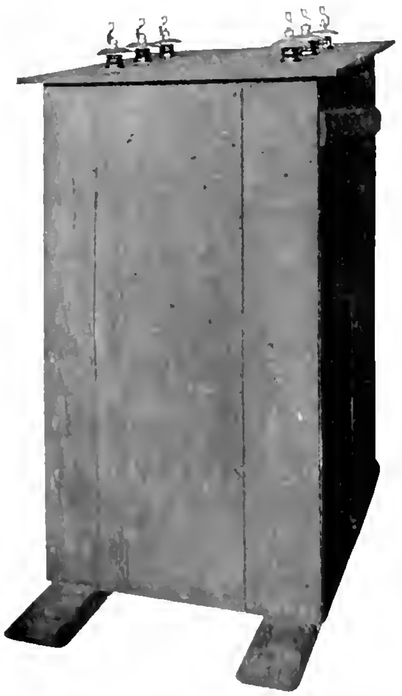
(3) Consumers requiring large blocks for purely power purposes.

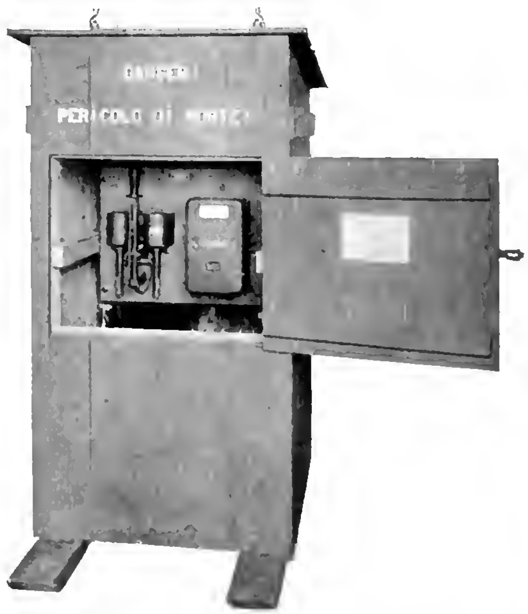
The switch houses shown are made of wood or steel as desired, although the latter of course is always to be recommended, for reasons which have already been noted. The houses are self-contained and portable. As far as placing in service is concerned, all that is required is to attach the incoming and outgoing leads to the terminals located at the top of the switch-house, and to fill the





Figs. 16 and 17. Front and Rear Views of Switchboard Cabinet Panel for 2300-Volt Distribution to Rural Consumers. The panel is provided with oil-switch and watthour meter for controlling and metering the distribution of 25 kv-a. of three-phase load. These panels are installed in a housing of wood or steel, as desired, and are then mounted on pole or tower as indicated in outline sketches shown in the early part of article





Figs 18 and 19. Two Views of Switching House for Distributing 25 Kv-a. at 2300 Volts Three-Phase to Rural Consumers from High-Voltage Transmission Lines. The houses contain the switch panels which control the supply received from the secondary of the transformers and distribute it to the feeders, which are run to the individual consumers, fed from the pole or tower in question. The house shown here is of wood, although the steel construction is to be preferred. The houses are self-contained and portable; and, so far as placing in service is concerned, all that is required is to attach the incoming and outgoing leads to the terminals located at the top of the switch house and to fill the tank of the switch with oil tank of the switch with oil. Figs. 16 and 17 show front and rear views of a switchboard panel for 2300-volt distribution to rural consumers. Figs. 18 and 19 give two views of a switch-house containing the equipments for controlling and metering the distribution of 25 kv-a. of three-phase load at 2300 volts.

INSTALLATIONS

Much experience has of course already been gathered from installations which have already been made in various parts of this country and abroad, in which transmission lines of moderately high voltage have been tapped for the supply of isolated consumers.

Fig. 20 represents a 44,000-volt switching tower at Mooresville, N. C. A feeder is tapped off from the main 44,000-volt line through oil-switches, and the energy distributed to the town nearby at the same pressure. Fig. 21 shows the outdoor switching equipment at Lake Crystal, Minn. This is a substation of the Consumers Power Company of Minnesota for distributing energy from its high-voltage transmission lines to

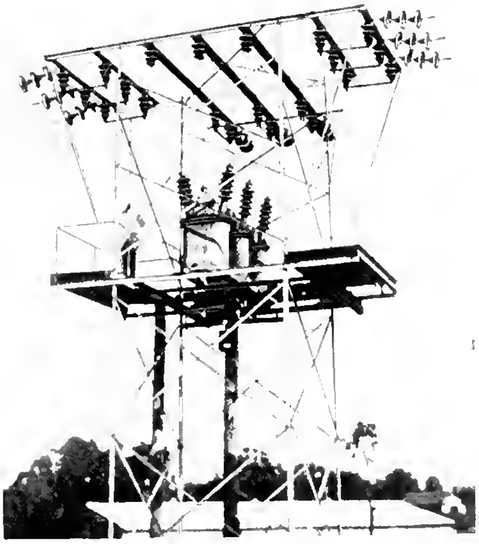


Fig 20. 44,000-Volt Switching Tower at Mooresville, N. C.

one of the towns near its right-of-way. The transformers, fuses and lightning arresters will be placed out-of-doors, and the low-tension switching equipment and meters located in the house built around the base of the tower. This switching equipment supplies power for all the classes of service to be found in these localities; and, with a minimum first cost and low maintenance charges, may be said to offer all the advan-

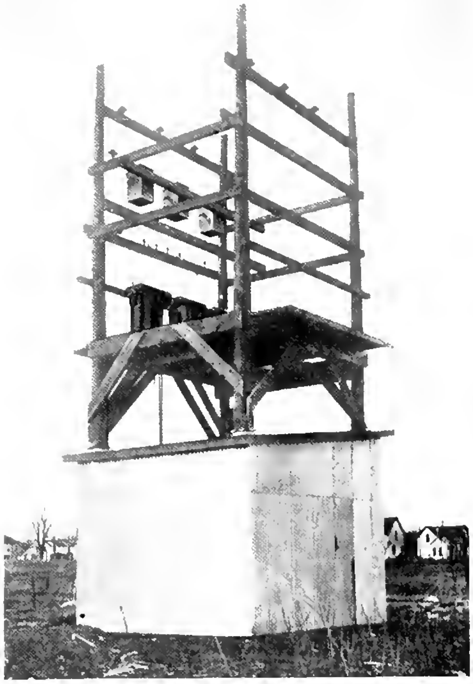


Fig. 21. Lake Crystal, Minnesota, Substation of Consumers Power Company. Note that this photograph was taken before lightning arresters and other apparatus had been erected

tages of electrical service which are realized by the urban dweller.

In developing the rural, or, broadly, the isolated loads, it will be found that mining and irrigation represent two of the most promising fields for new business, from the standpoint of the central station. Fig. 22 illustrates an outdoor switching and transformer equipment for supplying large blocks of power to mines, and shows the Cascade substation of the Great Falls Power and Townsite Company which receives its primary voltage at a pressure of 110,000. Fig. 23 illustrates a switching and transforming equipment which has been installed for an isolated irrigation service. The apparatus includes three 20 kv-a. outdoor transformers. The equipment is mounted on a drag, and can thus be readily transported from place to place along the transmission line supplying low voltage for irrigation pumping service. The transmission pressure is 33,000 volts, while voltages of 2200 and 440 are used on the secondary side.

Contracting for various engineering enterprises provides another fruitful field for this class of apparatus. The application of outdoor switching and transforming apparatus for supplying power in connection with the building of the Los Angeles aqueduct is well illustrated in Fig. 24. Here all the substation equipment is installed on a float. Three 20-kv-a. transformers are used in stepping down the transmission voltage from 33,000 to 440 low-tension, available for dredging service on the aqueduct at whatever point desired.

There are many miscellaneous applications of this general character, the requirements of which can be efficiently met by some such equipment as those which have been described above; and the next few years will undoubtedly witness an accretion to the central stations of many of these highly desirable loads. Harvesting machinery, for instance, can be cared for by the installation of such an equipment as that shown in Fig. 25, which is an illustration of what the supply companies are doing abroad; while in Fig. 26 can be seen the complete transforming and switching equipment for this service being drawn by a team of farm horses. Possibly the future will see a similar equipment under the traction of an electric farm runabout. Fig. 27 shows a pole line disconnecting switch and the connections for carrying the supply from the transmission line to the transformers and switches for this class of agricultural duty.

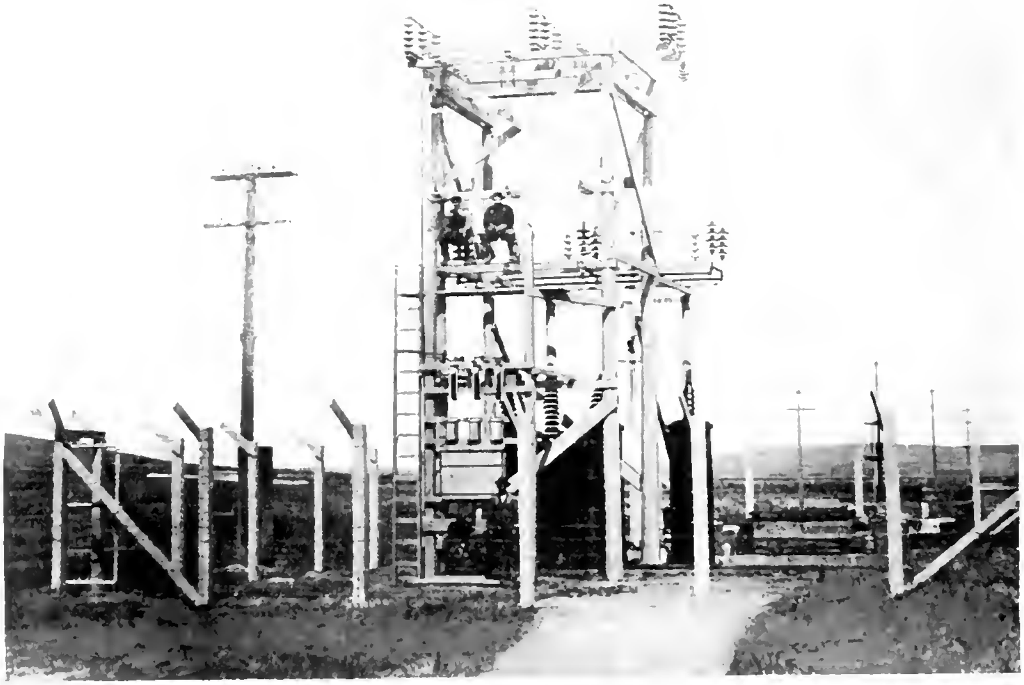


Fig. 22. General View of Cascade Substation on Lines of the Great Falls Power and Townsite Co., Butte, Montana

Although these distribution developments have been made in the behalf of the central stations, and with a view to tying-up the

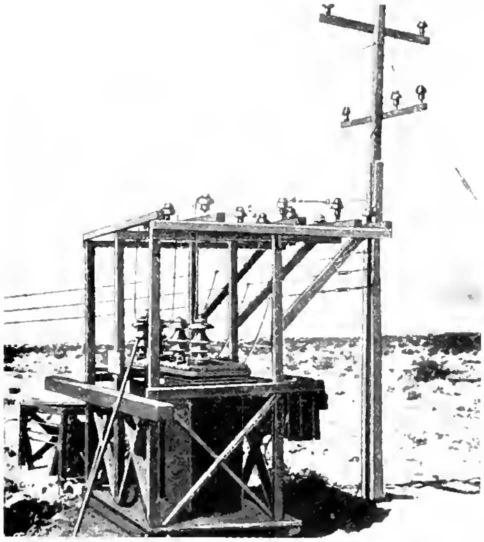


Fig. 23. Three 20 Kv-a. Outdoor Transformers in Irrigation Service

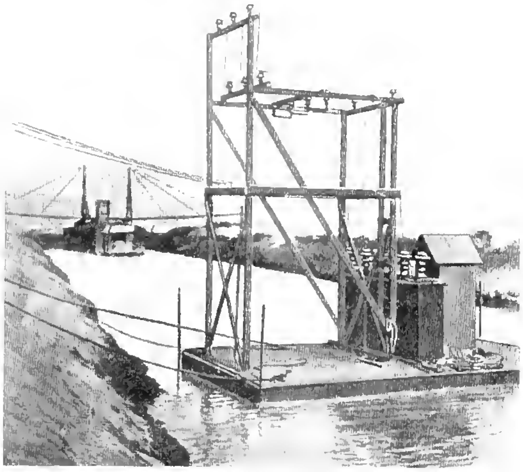


Fig. 24. Three 20 Kv-a. Outdoor Transformers Installed on a Float Reducing from High-Tension Transmission Line of 33,000 Volts to 440 Volts for Dredging Operations of Los Angeles Aqueduct

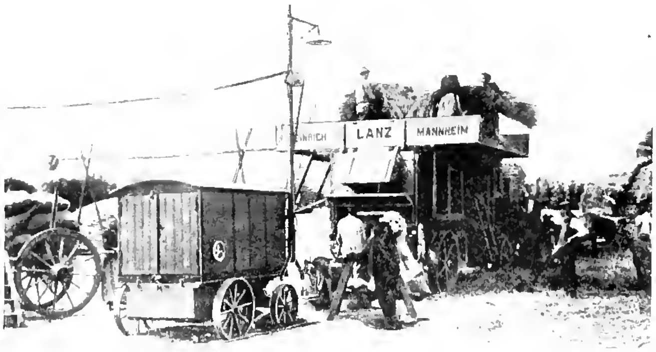


Fig. 25. This Cut Illustrates Foreign Practice, and Shows Harvesting Machinery Driven by Electric Motor Mounted on Horse Drawn Wagon

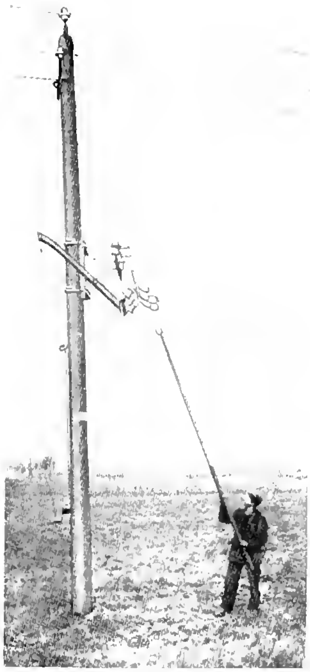


Fig. 27. Pole Line Disconnecting Switc.. and Temporary Connections for Supplying Power to Transmission Wagon Shown in Fig. 26 for Power Supply on Farm

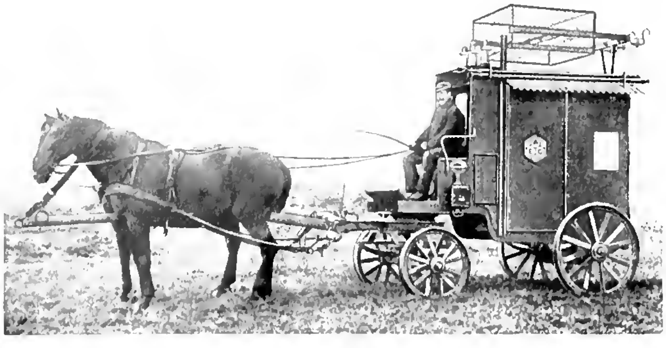
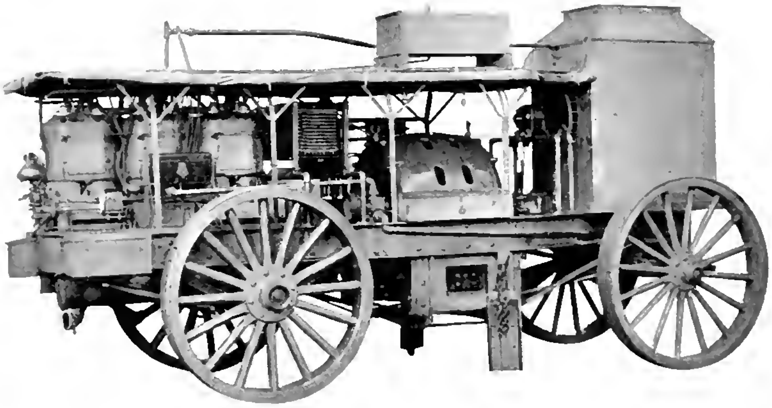
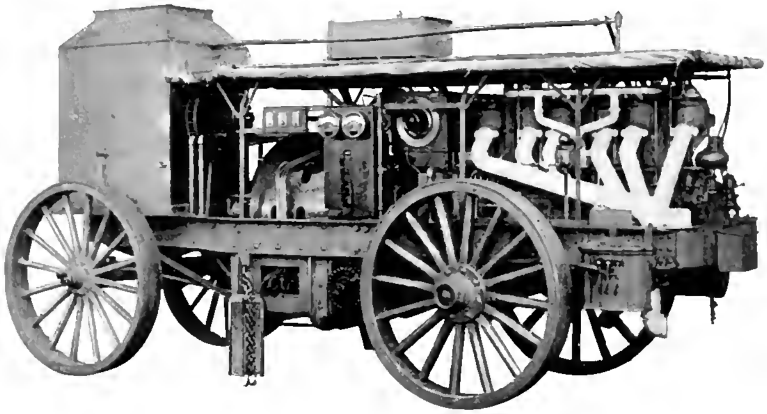


Fig. 26. Transformer and Switching Wagon Mounted on Horse Drawn Vehicle

isolated consumer with the central station system, there are still many uses which may be found for the isolated generating equipment in supplementing and helping out the supply from the company's mains. Figs. 28 and 29 show two views of a portable generating equipment developed to take care of such duties as breakdown auxiliary service, temporary peak loads, construction work, operations during the rehabilitation of an old station, and in assisting in new-business soliciting. Such equipments should form an efficient and useful auxiliary to all transmission line operators.





Figs. 28 and 29. Two views of Portable Generating Equipment for Use on Central Station Distribution Systems for Such Purposes as Breakdown Auxiliary Service, Temporary Peak Loads, Construction Work, New-Business Soliciting, Testing, Etc.

2400-VOLT RAILWAY ELECTRIFICATION

PART II

By H. M. Hobart, M. Inst. C. E.

Consulting Engineer, General Electric Company

Proceeding from a discussion in the first installment of the economic advantages to be derived from present day operation of high speed passenger trains by electric locomotives, and a preliminary digest of the requirements as regards horse power and electrical energy consumption or coal consumption for steam and electric locomotives in heavy freight service over mountain divisions, the author selects as a basis for comparing operating costs, first, a hypothetical example of such service employing ten electric locomotives, or, alternatively, fifteen steam locomotives of the heaviest type; and second, a specific case of main line electrification, having in mind a 96-mile single track mountain grade division now operated by steam locomotives. The soundness of the whole proposition, commercially, hinges on the cost of coal and the price at which electricity can be obtained, a small difference in either commodity in either direction from the figures used resulting in a pronounced change in the operating expenses and consequently in the savings effected by one system over the other.—Editor.

Hypothetical Example

Let us contrast the case of employing 10 electric locomotives weighing 160 tons each, with the entire weight on drivers, with the alternative of employing 15 steam locomotives of the Mallet type, weighing, with tenders, 250 tons each, of which 160 tons is on drivers. Let the work to be performed consist in hauling freight. Let the conditions governing the capacity per steam locomotive consist in the requirement of hauling 1400-ton trains up long 1.5 per cent grades at 6.5 miles per hour, and starting 1400-ton trains on 1.5 per cent grades; and let it be proposed that the electric locomotives shall start and haul trains of the same weight over the same grades at speeds 50 per cent greater. Let the total length of single track including terminals and sidings be a matter of 50 miles.

Let each electric locomotive traverse 24,000 traffic miles per annum as against 16,000 traffic miles per annum for each of the steam locomotives.[7]. In both cases the total traffic amounts to 240,000 locomotive miles per annum.

When hauling a 1400-ton train up a 1.5-per cent grade at 6.5 miles per hour, the output at the drawbar is

$$\frac{6.5\times 5280\times 38\times 1400}{60\times 33{,}000}=923 \text{ h.p.}$$

The corresponding output from the cylinders of the 250-ton steam locomotive is

$$\frac{1670\times 923}{1400\times 0.75}=1450 \text{ i.h.p.}$$

On the basis of employing as fuel Western lignite of a calorific value of 11,000 B.t.u. per pound (4.32 h.p-hr. per pound), the coal consumption may be taken at 5 lb. per i.h.p-hr. while the locomotive is hauling its train under these conditions of maximum load. Thus we have a coal consumption of

$$\frac{1450\times 5}{6.5}=1120 \text{ lb. per train-mile.}$$

Let it be premised that the average load for the entire 16,000 traffic miles traversed by the locomotive in a year is only one-third of this maximum load. The average coal consumption with which the locomotive must be debited per train-mile will not, however, fall to 1120/3=373 lb. per train-mile, for we must make allowance for the large amount of coal burned in the course of the many hours during which the locomotive is standing still, but with fires up.[8] We shall be decidedly

[7] Experience has demonstrated that an electric locomotive will be available for service every day for eleven out of the twelve months of the year, the remaining month affording a liberal margin for general repairs. During the 11/12×365 =) 334 days of service, even a low-speed electric locomotive hauling freight over a mountain division will readily yield 100 miles per day. This works out at an annual mileage of 33,400. It is exceedingly conservative to cut this down to 24,000 miles, or an average of (24,000/334 =) 72 miles per hay, averaged over 334 days, or (24,000/365 =) 66 miles per day, averaged over 365 days.

On the other hand, to credit each steam locomotive with (16,000/365 =) 44 miles per day, when averaged over the 365 days in the year, is to take an exceedingly high figure which is seldom if ever reached by Mallets when dealing with the class of service on which the example is based.

[8] At page 53 of Ripley's "Railroad Rates and Regulations" (Longmans, Green & Co., 1912), the author, in discussing the cost of fuel for motive power, writes: "This item, amounting in 1905 to no less than $156,000,000 for the railroads of the United States, was the largest in the budget, constituting 11 per cent of all operating expenses. Yet brief consideration shows that even here much of this expense is constant and invariable. A locomotive will burn fully one-third as much coal merely to move its own weight as to haul a loaded train. Five to ten per cent of its total daily consumption is required merely for firing up to the steaming point. Twenty-five to 50 pounds of coal per hour go to waste in holding steam pressure while a freight train is waiting on a siding. Every stop of a train going thirty miles per hour dissipates energy enough to have carried it two miles along a level road. In brief, expert evidence shows that of this important expenditure for coal 30 to 50 per cent is entirely independent of the number of cars or the amount of freight hauled."

favoring the steam locomotive in this comparison if we debit it with an average coal consumption of 560 lb. per locomotive-mile for the 16,000 miles which it travels annually. On the basis of $2.50 per ton, the fuel cost amounts to

$$\frac{560}{2000}\times 2.50 = \$0.685 \text{ per train-mile.}$$

In the case of the electric locomotive we shall supply the drawbar pull at a 50 per cent higher speed. Consequently on the 1.5-per cent grades, the power at the drawbar will be

$$923\times 1.5 = 1390 \text{ h.p.}$$

The output at the drivers of the electric locomotive will be

$$\frac{1560}{1400}\times 1390 = 1550 \text{ h.p.}$$

The input to the locomotive will be

$$\frac{1550\times 0.746}{0.87} = 1330 \text{ kw.}$$

The input to the substations per train-mile will be

$$\frac{1330}{0.93\times 0.78\times 6.5\times 1.5} = 188 \text{ kw-hr.}$$

But this input corresponds to the load on the ruling grade. We have already premised an average load equal to one-third of the maximum load. Consequently we have

$$\text{Average input to substations} = \frac{188}{3} = 63 \text{ kw-hr. per locomotive-mile.}$$

On the basis of a price of one cent per kw-hr. delivered to the substations, the average cost of the electricity per locomotive-mile comes to

$$63\times 0.01 = \$0.63.$$

This is in comparison with the average cost of $0.685 for fuel per locomotive-mile corresponding to a price of $2.50 per ton for lignite.

The item of wages for the locomotive crew will be taken at 20 cents per mile both for the steam locomotive and for the electric locomotive.

Appropriate *relative* figures for repairs and maintenance are $(10\times 2.5=)$ 25 cents per mile for the steam locomotive, and $(4\times 1.6=)$ 6.4 cents per mile for the electric locomotive.

As to capital outlay for locomotives, $45,000 for each steam locomotive can fairly be compared with $72,000 for the electric locomotive. This is a fair *ratio* and suggests a reasonable order of magnitude. In spite of the simplicity and strength of the electric locomotive, let us credit it with only the same life, in years, as the complicated and vulnerable steam locomotive and let us take the life as 15 years. Let taxes and insurance amount to 3 per cent. Consequently, as annual charges on the capital outlay for locomotives, we may fairly take $(5+4.6+3=)$ 12.6 per cent in each case. This comes to $5670 per annum for each steam locomotive and $9060 per annum for each electric locomotive. These figures reduce to

$$\left(\frac{567{,}000}{160{,}000}\right) = 35.4 \text{ cents}$$

per mile for the steam locomotive and

$$\left(\frac{906{,}000}{24{,}000}\right) = 37.8 \text{ cents}$$

per mile for the electric locomotive.

Thus for the five component costs which we have considered, the results are as follows:

	PER LOCOMOTIVE-MILE	
	Steam	Electric
I.—Fuel ..	$0.685	——
II.—Electricity.	——	$0.630
II.—Wages of locomotive crews	.200	0.200
IV.—Repairs and maintenance of locomotives.....	.250	0.064
V.—Interest, taxes, insurance and amortization. .	.354	0.378
Totals of above 5 items	$1.489	$1.272

These five items amount, for the 240,000 locomotive miles per annum, to the following annual outlays:

Steam........	240,000×1.489 = $357,000
Electric. .	240,000×1.272 = 306,000
Difference in the totals of the 5 items. .	$51,000

To illustrate the sensitiveness of the result on the prices of coal and electricity respectively, it should be noted that with coal at $2.80 per ton and electricity at 0.80 cents per kw-hr., the difference in the totals of these 5 items for steam and electricity increases from the above results of $51,000 to $102,000.

The wages of substation attendants and linesmen will only absorb a small portion—say $15,000—of the above balances, leaving the large remainder available to be applied to liquidating the capital outlay for substations and for feeders and contact conductors and for track structures and bonding.

No degree of exactness is claimed for the above cost comparison, but it *is* claimed that the results are very indicative of large commercial advantages in the electric operation of sections of main-line railways, especially in instances where electricity can be purchased at the substations at a cost of not much over one cent per kw-hr. It is often remunerative to large hydro-electric undertakings to supply electricity to railways at prices below one cent per kw-hr. at the substations. The dependence of the soundness of the proposition on the cost of coal and the price at which electricity can be obtained is indicated by the result to which allusion has already been made: that the saving, in the case examined, goes up from $51,000 per annum for coal at $2.50 per ton and electricity at one cent per kw-hr. to $102,000 per annum for coal at $2.80 per ton and electricity at 0.8 cent per kw-hr.

The calculations also show equally definitely that with coal at, say, $2.00 per ton and electricity at two cents per kw-hr. or thereabouts, it would be futile to consider electrification as a means of increasing the net earnings with traffic of this nature.

Consequently the merits of a proposal to electrify such a line may often be contingent upon the presence in the vicinity of a large system supplying electricity for miscellaneous power and lighting. From such a system the electricity required by the railroad could often be supplied profitably at less than one cent per kw-hr. delivered at the substations, as against a cost which might run up to two cents or more if the railroad had to provide its own power house for supplying exclusively the small quantity of electricity at poor load factor required for so sparse a service of trains.

Let us, however, return to the consideration of the case on the assumption that the railroad can purchase the required electricity at some such price as 0.8 cent per kw-hr. delivered at the substations.

The total quantity of electricity annually required at the substations in the above hypothetical case is

$$240{,}000 \times 63 = 15.1 \text{ million kw-hr.}$$

For an undertaking of this magnitude, the cost of substations, feeders and contact conductors, in fact, of all work, apparatus, buildings, structures and materials required for electrification, in addition to the 10 locomotives, would amount to a matter of only some $600,000 more or less. Of course the precise circumstances of each case would greatly affect this total.

It may have been observed that no reference has yet been made in this paper to the weight of the electrical apparatus constituting the motive power and control equipment of the locomotives. For the examples considered, there has been no occasion to introduce this factor. The weight of the complete electrical equipment for the 2400-volt system runs to a matter of only some 55 lb. per horse power of *continuous* capacity. In fact the electrical equipment of the Butte locomotive weighs only 53,000 lb. out of a total weight of 160,000 lb. Each 80-ton locomotive has a *continuous* capacity for maintaining a drawbar pull of 25,000 lb. at 15 miles per hour. This corresponds to a *drawbar* output of 1000 h.p. or an output *at the drivers* slightly in excess of 1000 h.p. This brings the weight down to some 50 lb. per horse power of *continuous* output *at the drivers*.

The significance of the low weight of electrical equipment is that there is ample margin to obtain the horse power capacity required at high speeds without exceeding the weight on drivers necessary for obtaining the required drawbar pull.

Electrification of a 96-Mile Single-Track Mountain-Grade Division of a Main-Line Railway

Let us now consider the electrification of a link in a main-line railway, consisting of a mountain-grade division 96 miles long. At certain seasons of the year there is experienced at this link a congestion of freight traffic of so severe a nature that it becomes necessary to divert to other routes of much greater length a large percentage of the available freight.[9] The division is single-tracked with 15 sidings at an average distance of six miles apart, thus dividing the 96 miles into sixteen sections of varying length but averaging six miles each. The character of the route is such that double tracking would involve enormous expense. This is often the case on mountain-grade divisions.

The trains negotiate an altitude of 3800 ft. in 48 miles and return to the original level in the remaining 48 miles. Thus the average gradient is

$$\frac{3800 \times 100}{48 \times 5280} = 1.5 \text{ per cent.}$$

The ruling gradient is 2.2 per cent. There are occasional 2.5 per cent gradients but these are so short that they may be dealt with as "momentum gradients" and are not determinants in arriving at the correct powering of the trains.

[9] While the extent of the freight congestion assumed in this example is doubtless extreme, the rapidly expanding freight business of the country is leading to conditions of this order of seriousness.

It is proposed that electric locomotives shall carry over this division trains of weights ranging from 900 to 1800 tons (exclusive of the weights of the locomotives), and that while ascending the average speed between stops shall be 12 miles per hour. Where the grade is in excess of the average value of 1.5 per cent, the speed will be less than 12 miles per hour, and for gradients of less than 1.5 per cent the speed will be in excess of 12 miles per hour. The range of variation will, however, be only of the order of from 9 to 15 miles per hour.[10] Ascending trains will be operated over the main track, and the number of stops will be reduced to a minimum. Descending trains will be operated at slightly higher speeds in order that they may be out of the way in the sidings when the ascending train arrives. Obviously on the basis of an average speed of 12 miles per hour, the 96-mile journey would require 8 hours were the ascending train to make no stops. On this *admittedly theoretical* hypothesis, and with trains in each direction simultaneously occupying alternate sections between sidings, the 96-mile division could contain simultaneously 8 trains travelling in each direction, or a total of 16 trains, and trains could be sent into the division from each end of the division at the rate of one per hour. Thus 24 trains per day could be passed over the division in each direction. This leads us to the (theoretically) limiting capacity of

$$48 \times 96 = 4600 \text{ train-miles per day.}$$

In practice, however, after making reasonable allowances for unequal distances between sidings, variations in speed due to varying grades and curves, delays at the terminals of the 96-mile division, inevitable stops even of the ascending trains, and other causes for irregularity, the practical limit of the capacity of the division may be taken as of the order of

$$(0.75 \times 48) \times 96 = 36 \times 96 = 3460 \text{ train-miles per day.}$$

This is on the basis that there shall be only $(36 \div 2 =)$ 18 trains instead of 24 in each direction per day.

Traffic of this intensity will, however, occur only during 100 days in the year. For the remaining 265 days, the freight to be transported will require only the equivalent of twenty-four 900-ton trains per day, or twelve 900-ton trains in each direction, whereas for the 100 days of dense traffic the 36 trains per day will each represent 1800 tons behind the drawbar.

Thus there will be transported annually over the division a total tonnage behind the drawbar amounting to $(100 \times 36 \times 1800) + (265 \times 24 \times 900) = 6,500,000 + 5,700,000 = 12,200,000$, or $96 \times 12,200,000 = 1,170,000,000$ ton-miles.[11]

Making reasonable allowance for the weight of the cars and for empty and lightly-loaded cars, we may take one-half of this load behind the drawbar as revenue tonnage. The paying load will thus amount to 6,100,000 tons per annum, or $96 \times 6,100,000 = 585,000,000$ ton-miles.

On the basis of an average rate of 0.75 cent per ton-mile the gross receipts amount to $585,000,000 \times 0.0075 = \$4,390,000$ per annum or $45,600 per mile of railway.[12]

The requirements of the railway as regards number and size of locomotives must be based on the seasons of dense traffic. On the ruling grade of 2.2 per cent an 1800-ton train will require a drawbar pull of $(2.2 \times 20 + 8) \times 1800 = 94,000$ lb.

Adding a further 36 per cent in order to have a safe margin for increased journal friction in cold weather, for adverse winds and for severe curves, we arrive at the value of $1.36 \times 94,000 = 128,000$ lb. as the drawbar pull which should be available when dealing with 1800-ton trains on this division. Providing a locomotive at each end of the train, each locomotive will require to have sufficient reserve capacity for exerting a drawbar pull, or push, of

$$\frac{128,000}{2} = 64,000 \text{ lb.}$$

On the basis of a coefficient of adhesion of 0.20, each locomotive must have a weight on drivers of

$$\frac{64,000}{0.20 \times 2000} = 160 \text{ tons.}$$

Thus so far as relates to the provision of the required tractive effort, the 160-ton Butte locomotives already described in this paper are appropriate for use on this 96-mile mountain-grade division.

The drawbar pull, when accelerating from rest (at the rate of one-tenth of a mile per hour per second) on the average gradient of

[10] A few passenger trains will be sent over the division every day. But to simplify the investigation, it will be assumed that these are taken into account by their equivalent in freight traffic.

[11] It is shown on the following page that the 1800-ton trains will require two locomotives and the 900-ton trains, one locomotive, consequently the annual locomotive-mileage is equal to $96 \times 100 \times 36 \times 2 + 96 \times 265 \times 24 \times 1 = 690,000 + 610,000 = 1,300,000$.

[12] It is recognized that this is a high figure, but it is consistent with the hypothesis of a congested link in an extensive railway system.

1.5 per cent, will be $(1.5\times20+10+10)\times1800=90{,}000$ lb., or only 69 per cent of the *maximum* drawbar pull (128,000 lb.) available with a coefficient of adhesion of 0.20. When desirable, an acceleration of over a quarter of a mile per hour per second may be imparted to an 1800-ton train on the average grade.

When working the line to its utmost capacity, i.e., with a descending train in every other length between sidings and an ascending train in each intermediate length between sidings (each train having a weight, exclusive of locomotives, of 1800 tons) there would be simultaneously traversing the division 16 trains and 32 locomotives. It has already been explained that practical limitations will cut this down, either as regards the number of trains simultaneously present in the division or as regards the maintenance of the journey speed of 12 miles per hour for the 96-mile run. The actual shortage will be due partly to each of these two factors. With due allowance for additional locomotives to be available in making up trains at the terminals before entering the 96-mile division, and for spare locomotives, there should be provided a total equipment of 48 locomotives of 160 tons each.[13] This total number of locomotives is determined upon to meet the requirements of the 100 days of dense traffic. A considerable percentage of the 48 locomotives will be in excess of the requirements of the remaining 265 days of the year and will be enforcedly idle.

When handling an 1800-ton train at a speed of 12 miles per hour on a 1.5-per cent grade, we have

$$\frac{12\times5280\times90{,}000}{60\times33{,}000}=2880 \text{ h.p. at the drawbar.}$$

This will be subdivided between the two 160-ton locomotives, and each will deliver 1440 h.p. at the drawbar, or

$$\frac{900+160}{900}\times1440=1700 \text{ h.p.}$$

at the rims of the drivers.

Each locomotive has eight motors (one on each of the eight driven axles); consequently the output per motor when ascending the 1.5 per cent grade at 12 miles per hour is $1700/8=213$ h.p.

Since this output of 213 h.p. is the average load, the work is seen to be well within the capacity of the equipment on the Butte locomotives, for on those locomotives each motor has a continuous capacity of 250 h.p. when cooled by the forced circulation of air through it.

In making up an estimate of the total annual traffic, we have arrived at the figure of 12,200,000 tons as the weight behind the drawbar passing annually over the division. Since we employ a 160-ton locomotive for every 900 tons, we shall have

$$\frac{12{,}200{,}000}{900}=13{,}600 \text{ locomotive-journeys}$$

over the division per annum,

$$\text{or } \frac{13{,}600}{48}=284 \text{ journeys per locomotive.}$$

Thus as an average for each one of the 48 locomotives we have a performance of $96\times284=27{,}200$ miles per annum.[14]

This is not to be taken as indicating an average mileage of $27{,}200/12=2260$ miles per locomotive for *each* of the 12 months in the year. On the contrary, during the months of heavy traffic this will be greatly exceeded and during the months of light traffic a considerable proportion of the locomotive equipment will be idle and the average mileage per month per locomotive will fall greatly below 2260 miles.

At the speed of 12 miles per hour $(96/12=)$ 8 hours would be occupied by the journey, and each locomotive would spend $286\times8=2288$ hours per annum on the 96-mile division. But what with the decreased speed due to delays and the large amount of time occupied at terminals in making up trains, each locomotive would be in service with its crew for $1.5\times2288=3440$ hours. On the basis of eight-hour shifts and two men per crew, and an average wage of \$6.00[15] per day, the wages per locomotive amount to

$$\frac{3440}{8}\times2\times6.00=\$5150 \text{ per annum,}$$

$$\text{or } \frac{515{,}000}{27{,}200}=18.9 \text{ cent per locomotive-mile.}$$

Repairs and maintenance per locomotive

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[13] With the mean value of 28 locomoti s (14 trains) simultaneously occupying the 96-mile section, there remain $(48-28)=20$ locomotives. With four undergoing repairs, we have 16 available at terminii, 8 at each end. Since these locomotives are double-ended, there will be much less time occupied than with steam locomotives in making up trains in readiness to be sent into the division.

[14] In the footnote No. 11, we have already arrived at the figure of 1,300,000 locomotive-miles per annum. We have $1{,}300{,}000/48=27{,}200$ miles per locomotive per annum, thus checking the above result in the body of the text.

[15] The crew of each locomotive will consist of an engineer and his mate. The latter accompanies the engineer on general principles relating to safety in the event that the engineer should be incapacitated from any cause. The engineer will receive a higher wage than this average of \$6.00 for the crew, and the mate will receive less than this average. The average figure of \$6.00 is high when taken in connection with the schedules at present in force, but its employment in this comparison is consistent with the purpose to favor steam-locomotive methods at all points where the reasonableness of the assumptions could be questioned

amount to $0.04 \times 1.6 \times 27{,}200 = \$1740$ per annum or $4 \times 1.6 = 6.4$ per cent locomotive-mile.

On the rough basis of \$450 per ton, we may take the price of each locomotive as $160 \times 450 = \$72{,}000$.

The 48 locomotives run to a total initial outlay of $48 \times 72{,}000 = \$3{,}460{,}000$.

Taking interest, taxes, insurance and amortization as aggregating 12.6 per cent on the investment for locomotives, these charges for each locomotive amount to $72{,}000 \times 0.126 = \$9060$ per annum.

(This is on the basis of interest at 5 per cent, taxes 1.5 per cent, insurance 1.5 per cent, and a life of 15 years.)

Thus we have, per electric locomotive per annum:

I.—Wages of loco. crews	\$5150
II.—Repairs and maintenance	1740
III.—Interest, taxes, insurance, amortization	9060
Total of above three items	\$15,950

For the 48 locomotives, this comes to a total of

$$48 \times 15{,}950 = \$766{,}000.$$

Now let us estimate the amount of electricity consumed by the locomotives. On the ascent, the power averages 2880 h.p. at the drawbar or 3400 h.p. from the motors.

The average consumption by the locomotives works out at

$$\frac{3400 \times 0.746}{0.87} = 2920 \text{ kw.}$$

During the ascent, electricity is drawn from the line only during $(48/12=)$ 4 hours, notwithstanding that the ascent is accomplished in a greater time than this.

The energy consumed during the ascent is

$$4 \times 2920 = 11{,}700 \text{ kw-hr.}$$

No return of energy to the line will be credited to the locomotives during the descent; on the contrary, an allowance of 500 kw-hr. will be made for occasional applications of power.

Energy consumed by locomotives during descent = 500 kw-hr.

Total consumption of energy by locomotives for 96-mile journey with 1800-ton train,

$$11{,}700 + 500 = 12{,}200 \text{ kw-hr.}$$

For the 900-ton trains, the consumption per journey will be

$$\frac{12{,}200}{2} = 6100 \text{ kw-hr.}$$

There are $100 \times 36 = 3600$ journeys per annum with 1800-ton trains and $265 \times 24 = 6360$ journeys per annum with 900-ton trains.

Thus the total consumption at the locomotive is

$3600 \times 12{,}200 + 6360 \times 6100 = 44{,}000{,}000 + 39{,}000{,}000 = 83{,}000{,}000$ kw-hr. per annum.

Increasing this by 25 per cent (i.e., by 21,000,000 kw-hr.), to 104,000,000 kw-hr. per annum to allow for terminal movements and for heating of locomotives and as a margin of safety, and taking at 0.93 the annual efficiency from the substations to the trains, we obtain for the output from the substations

$$\frac{104}{0.93} = 112 \text{ million kw-hr. per annum.}$$

The annual overall efficiency of the substations may be taken as 78 per cent. Consequently the input to the substations is

$$\frac{112}{0.78} = 144 \text{ million kw-hr. per annum.}$$

On the basis of a price, as delivered to the substations, of 0.70 cent per kw-hr. the outlay for electricity is

$$144{,}000{,}000 \times 0.0070 = \$1{,}010{,}000 \text{ per annum.}$$

Per locomotive, this works out at

$$\frac{1{,}010{,}000}{48} = \$21{,}000.$$

or

$$\frac{2{,}100{,}000}{27{,}200} = 78 \text{ cents per locomotive-mile.}$$

As to the overhead contact line, the rail bonding and the feeder copper, these will be covered liberally by an outlay of \$8500 per mile. Allowing for sidings, the total outlay will be \$900,000.

Finally, there will be required four substations, each for an annual output of 28,000,000 kw-hr.

On the basis of a load factor of 0.25, the *maximum* load on each substation will be

$$\frac{28{,}000{,}000}{8750 \times 0.25} = 12{,}800 \text{ kw.}$$

The *average* load per substation will be only some

$$\left(\frac{28{,}000{,}000}{8750}\right) = 3200 \text{ kw.}$$

These substations will cost, complete, with step-down transformers and motor-generators, some \$160,000 per substation or \$640,000 for the four substations.

Taking interest, maintenance, taxes, insurance, amortization, and labor for attendants, and linemen, as amounting to 16 per cent[16] on this outlay of (900,000+640,000=) \$1,540,000 we arrive at a charge of

$$(0.16 \times 1.540,000 =)\ \$246,000 \text{ per annum.}$$

or

$$\frac{246,000}{48} = \$5130 \text{ per locomotive.}$$

or

$$\frac{513,000}{27,200} = 18.8 \text{ cents per locomotive-mile.}$$

Thus for those annual outlays which are other for electric working than they are for steam working, we have:

Loco. wages, repairs and maintenance, interest, taxes, insurance, amortization	\$766,000 per annum
Electricity	1,010,000 per annum
Substations and distributing system	246,000 per annum
Total	\$2,022,000 per annum

Now how does the case stand with steam? Let us assume that a 250-ton Mallet locomotive can handle a load of 600 tons behind the drawbar over this division with the same speed when in motion as the 160-ton electric locomotive with its 900-ton load.[17] Then when, as at times of densest traffic, it is desired to carry freight in 1800-ton trains, we shall require three 250-ton Mallets as against two 160-ton electric locomotives.

The average load at the drawbar, if equally subdivided amongst the three Mallets is

$$\frac{2880}{3} = 960 \text{ h.p. per Mallet.}$$

The drawbar pull is equal to

$$\left(\frac{960 \times 33,000 \times 60}{12 \times 5280}\right) = 30,000 \text{ lb.}$$

This corresponds to an output from the cylinders of

$$\frac{(600+250) \times 960}{600 \times 0.75} = 1810 \text{ i.h.p.}$$

The fuel will be Western lignite of a calorific value of 11,000 B.t.u. (4.32 h.p-hr.) per pound and the consumption will be five lb. per i.h.p.

The coal consumption for a speed of 12 miles per hr. and for 600 tons behind the drawbar thus amounts to

$$\frac{1810 \times 5}{12} = 755 \text{ lb. per locomotive-mile.}$$

But this result is arrived at on the basis that there is no wasteful consumption during stops. Unlike the electric locomotive, however, several stops will be necessary for taking on water and for coaling, and the consumption during the ascent will be increased to at least 850 lb. per locomotive-mile, or

$$48 \times 850 = 40,800 \text{ lb. for the ascent.}$$

The descent will occupy some 5 to 7 hours. While the power required for propulsion will be negligible for most of the descent, nevertheless, steam must be maintained in the boilers, and also, owing to the high frictional-resistance of Mallet engines, power will be required for all grades materially lower than the average value of 1.5 per cent. Let us take the coal consumption as 400 lb. per hour, or (6×400=) 2400 lb. for the 48-mile descent.

Thus the total coal consumption for the locomotive for the 96-mile journey comes to

$$40,800+2400=43,200 \text{ lb.}$$

This should be increased by 20 per cent to cover the coal burned by the switching engines and also by the Mallets during terminal movements before entering and after leaving the 96-mile division, bringing the total to

$$1.20 \times 43,200 = 52,000 \text{ lb.}$$
$$= 26 \text{ tons.}$$

This is an average of

$$\frac{52,000}{96} = 540 \text{ lb. per locomotive-mile}$$

for the 96-mile journey.

At \$2.40 per ton, we have a full cost of

$$\left(\frac{540}{2000} \times 240\right) = 65 \text{ cents per locomotive-mile.}$$

Of course it is to be understood that the terminal operations are not executed by Mallets but by switching locomotives. But to simplify the calculations, the equivalent outlay is taken in terms of Mallets.

Attention must now be drawn to the consideration that with the delays inherent to steam locomotive operation, even on the favorable assumption that the speed with three 250-ton steam locomotives and an 1800-ton train may, when running, be taken equal to the speed of two 160-ton electric locomotives and an 1800-ton train, nevertheless, the running time for the 96-mile journey (together with the increased time consumed in making up trains at terminals with single-ended and cumbersome steam switching engines as compared with double-ended and simple electric locomotives), will certainly

[16] The criticism may be raised that this \$246,000 should be considered in detail. To do so would only introduce uninteresting calculations. The item is relatively so small that it can consistently be dismissed without further comment than to point out that it includes an allowance of sor \$50,000 for wages of substation attendants, inspectors and linemen.

[17] This is crediting the Mallets with a higher speed for such loads than they can maintain. Nevertheless it is desired to err on the side of favoring the steam locomotive whenever there is room for divergence of opinion.

be at least 50 per cent greater. Thus for the 100 days of dense traffic when the division is worked to its utmost capacity, the train mileage is cut down to two-thirds of that obtained with electric operation The limiting capacity of the line is thus reduced to

$$\frac{2}{3}\times 6{,}500{,}000+5{,}700{,}000$$
$$=4{,}300{,}000+5{,}700{,}000$$
$$=10{,}000{,}000 \text{ tons.}$$

or

$$96\times 10{,}000{,}000=960{,}000{,}000 \text{ ton-miles.}$$

Again taking one-half as revenue load and crediting it with an average rate of 0.75 cent per ton-mile we ascertain the gross receipts to be

$480{,}000{,}000\times 0.0075=\$3{,}600{,}000$ per annum, $37,500 per mile of railway.

We have seen that for 600 tons behind the drawbar of each locomotive, the coal consumption to be debited to the entire journey works out at 540 lb. per locomotive mile.

This is

$$\frac{540}{300}=1.80 \text{ lb. per revenue ton-mile,}$$

or

$$\frac{1.80}{2000}\times 480{,}000{,}000=432{,}000 \text{ tons per annum.}$$

At $2.40 per ton, the annual outlay for fuel amounts to

$$2.40\times 432{,}000=\$1{,}040{,}000.$$

The large amount of time required for cleaning, overhauling, repairing, adjusting and generally looking after the welfare of the steam locomotives renders it very liberal to credit each steam locomotive with an annual performance of

$$\frac{27{,}200}{1.50}=18{,}100 \text{ miles}$$[18]

as against each electric locomotive's 27,200 miles per annum.

On the other hand, during the 265 days of light traffic it will be fair to estimate that one steam locomotive shall haul a 900-ton train at a slower speed, instead of hauling a 600-ton train at the higher speed at which an electric locomotive hauls a 900-ton train. Since during these 265 days the line is not worked up to its physical limitations, the disadvantage of this plan is chiefly confined to the greater outlay for wages per locomotive-mile. No greater outlay for wages on this score will, however, be debited against the steam locomotive in this comparison.

The total steam locomotive mileage during the 100 days of heavy traffic is

$$96\times 100\times 24\times 3=690{,}000 \text{ miles.}$$

During the remaining 265 days the steam locomotive mileage amounts to

$$96\times 265\times 24\times 1=610{,}000 \text{ miles.}$$

The total steam locomotive mileage per annum is thus

$$690{,}000+610{,}000=1{,}300{,}000$$

Consequently we must provide

$$\frac{1{,}300{,}000}{18{,}100}=72 \text{ Mallet locomotives.}$$

Each weighs 250 tons and may be taken as costing $45,000.

Thus for the outlay for locomotives we have

$$72\times 45{,}000=\$3{,}240{,}000.$$

Allowing, as with the electric locomotives, 12.6 per cent to cover interest, taxes, insurance and amortization, we arrive at an annual charge of

$$0.126\times 45{,}000=\$5660 \text{ per locomotive}$$

or

$$\frac{566{,}000}{18{,}100}=31.3 \text{ cents per locomotive-mile.}$$

Each of the 72 locomotives makes

$$\frac{1{,}300{,}000}{96\times 72}=188 \text{ journeys per annum.}$$

Were only (96/12 =) 8.0 hours occupied by the 96-mile journey, then each locomotive would spend

$$188\times 8=1504 \text{ hours per annum}$$

on the 96-mile division. But there must be taken into account the decreased speed due to delays during the journey and also the great amount of time consumed in making up trains at terminals. This handicaps operations with single-ended steam locomotives much more than with readily and promptly operated double-ended electric locomotives. It will be reasonable to assign to each steam locomotive an annual period of

$$2\times 1504=3008 \text{ hours}$$

of service with its crew. The crew of the steam locomotive will consist of an engineer and a fireman working on eight-hour shifts. On the basis of an average wage of $4.50 per day (the engineer receiving *more*, and the fireman *less* than this average), the outlay

[18] This works out at an average of 18,100/365 = 50 miles per day averaged over the entire year. This figure is higher than that for any Mallets of which I have records, when operating on severe mountain-grade divisions.

for wages for each steam locomotive amounts to

$$\frac{3008}{8}\times 2\times 4.50=\$3380 \text{ per annum,}$$

or

$$\frac{338,000}{18,000}=18.7 \text{ cents per locomotive-mile.}$$

It will be noted that in estimating the wages for each Mallet, it is assumed that only one fireman will be required. However, we have already seen that 40,800 lb. of coal will be burned during the 48-mile ascent. If this ascent is accomplished in 5 hours, the coal consumption amounts to 8200 lb. per hour; if in 6 hours, 6800 lb. per hour. It is often maintained that *two* firemen should be provided when it is required to fire such great hourly quantities of coal.

Repairs and maintenance per locomotive amount to

$0.10\times 2.5\times 18,100=\$4250$ per annum.

(This is on the basis of $10\times 2.5=25$ cents per locomotive-mile.)

Thus per steam locomotive per annum we have

I.—Wage of locomotive crews	$3380
II.—Repairs and maintenance	4250
III.—Interest, taxes, insurance, amortization	5660
Total of above three items	$13,290

For the 72 locomotives we have

$72\times 13,290=\$956,000.$

Bringing together the annual outlays which should be compared with those previously set forth as relating to equivalent operation by electricity we have

Loco. wages, repairs, maintenance, interest, taxes, insurance, and amortization	$956,000 per annum
Coal	1,040,000 per annum
	$1,996,000 per annum*

But, whereas the electrical outlay of $2,022,000 per annum was associated with a revenue of $4,390,000 per annum leaving a difference of $2,368,000 per annum to be applied to the outlays common to both systems and to reserves, the corresponding steam outlay of $1,996,000 per annum is associated with the reduced revenue of only $3,600,000 per annum leaving a difference of only $1,604,000 to be applied to residual outlays and to reserves.

$$\frac{1,604,000}{2,368,000}=0.68.$$

Thus the residual amount with steam is only 68 per cent of that with electricity.

It will be agreed that the correct basis for estimating the commercial results to accrue from electrical operation is to compare all those items which are affected by the use of electricity instead of steam. This is, however, inconsistent with the retention of the forms which have become customary in analyzing the results of steam operation. Consequently as of probable interest, the locomotive operating expenses per locomotive mile are tabulated below.

	Operating Expenses in Cents per Locomotive-Mile	
	Steam	Electric
Fuel	65.0	0
Electricity	0	78.0
Repairs	20.0	5.6
Wages	18.7	18.9
Engine house expenses	3.5	0
Lubricants	0.9	0.5
Stores	0.6	0.3
	108.7	103.3

These figures only apply to the particular 96-mile mountain division which has constituted the subject of our analysis and to the particular prices employed for coal ($2.40 per ton) and electricity (0.70 cent per kw-hr.).

For the electric proposition there is an average load of 900 tons behind the drawbar for every electric locomotive. But from the data previously given we see that the average load behind the drawbar for the steam locomotive is only

$$\frac{960,900,000}{1,300,000}=740 \text{ tons.}$$

Consequently to reduce the locomotive operating costs to comparable terms let us take as a standard of reference 100 tons behind the drawbar. We then have steam locomotive operating costs per mile

$$=\left(\frac{108.7}{7.40}\right)=14.7 \text{ cents per 100 tons behind}$$

drawbar.

Electric locomotive operating costs

$$=\left(\frac{103.3}{900}\right)=11.6 \text{ cents per 100 tons behind}$$

drawbar.

* No charge is made to cover outlays for round-houses, water tanks, structures for coal stores and other works incident to steam locomotive operation and not required when electric locomotives are adopted.

Let us look at the costs per locomotive-mile per total train-mile and per 100-ton-mile behind the drawbar for the 1800-ton train which we have more particularly investigated. This required three 250-ton Mallets or two 160-ton electric locomotives, bringing up the total train weights in the two cases to (3×250+1800=) 2550 tons and (2×160+1800=) 2120 tons respectively.

The results are set forth in the following table:

OPERATING EXPENSES IN CENTS PER MILE

	Per Steam Locomotive	Per Elec. Locomotive	Per Steam Train (3 Locomotives)	Per Elec. Train (2 Locomotives)	Steam Operation Per 100 tons behind draw-bar	Electric Operation Per 100 tons behind draw-bar
Fuel or elec	65.0	78.0	195.0	156.0	10.8	8.7
Repairs...	20.0	5.6	60.0	11.2	3.3	0.6
Wages......	18.7	18.9	56.1	37.8	3.1	2.1
Engine house expense...	3.5	0	10.5	0	0.6	0
Lubricants..	0.9	0.5	2.7	1.0	0.2	0.1
Stores..	0.6	0.3	1.8	0.6	0.1	0.1
Totals..	108.7 per loco. mile	103.3 per loco. mile	326.1 per train mile	206.6 per train mile	18.1 per 100 ton-miles behind the drawbar	11.6 per 100 ton-miles behind the drawbar

ELECTRICITY APPLIED TO THE MANUFACTURE OF SUGAR

By P. S. Smith

Foreign Dept., General Electric Company

This article outlines the processes followed in the modern "central" for the production of refined sugar from the raw cane; and lays stress on the imperative demand for the most efficient form of mechanical operation, consequent upon the rising cost of producing raw sugar and the decreasing price at which the finished product can be sold. In meeting the demand, the system which will win out is the one in which the fuel bill for the power plant is cut down to the minimum; and this viewpoint puts the electric system in its most favorable light, as it should be possible to raise all the steam for a good turbo-electric station from the refuse cane which is a by-product of the mill. For the rest the article deals succinctly with the suitability of the electric drive for operating the various machines in the mills.—Editor.

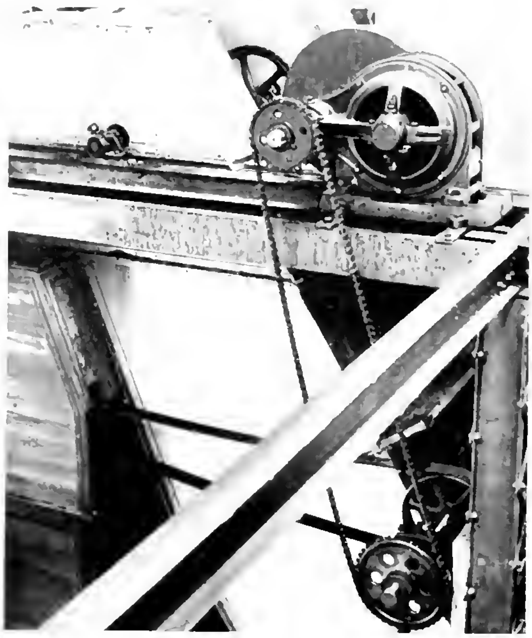
The conversion of the juice of the sugar cane into sugar is an industry which has existed for many centuries. The primitive methods which were once used are slowly giving way to the advance in scientific power application which other industries have experienced, although even now there exist in certain localities small outfits which can hardly be dignified by the title of mill or factory. These consist of a pair of mill stones, the lower one being imbedded in the ground while the upper is turned round and round by slowly plodding oxen. The cane, being fed between the stones, is ground to a sort of pulp from which the juice is collected into large open iron kettles and boiled down over fires of the cane refuse. The result, an unattractive looking mass composed of the unseparated molasses and sugar, is commonly called in Cuba "raspadura," and is used as sugar by the poorer classes or wrapped in leaves and sold as candy to children. These crude "bull mills" are rare, however, and only to be regarded as a curious relic of the industry in its earliest stages, for the production of sugar on a commercial scale is carried on in mills equipped with powerful machinery and employing skilled engineers and chemists to watch over the details which are so essential to the quality and amount of sugar obtained.

The frontispiece to this issue showed the ox-teams at work in the sugar plantation, and the cane being loaded on to the ox-carts for transportation to the railway siding. This picture shows the ox-carts delivering the loads of cane to the railroad at the property of the San Manuel Sugar Company, Las Delicias, Cuba

During the grinding season the machinery must be kept in operation for twenty-three hours a day, or more, to avoid the losses occurring with a shut down of even short duration. The engineering staff is held responsible for the continuity of service of all apparatus, and its attention is, in addition, called to the solution of other problems which are of paramount importance. These problems arise from the need of increasing the overall efficiency of the mills in order to offset the rising cost of milling raw sugar coupled with the decrease in the market price of the refined product. In 1876, the price of Cuban sugar at the mill was about eleven cents per pound, while since 1900 it has averaged less than three cents. This is getting so close to the actual cost of production that the varying of either

This is a view of the sugar mill and power house of the San Manuel Sugar Company, Las Delicias, Cuba. The raw cane is delivered direct into the "central" by the railroad, and is there subjected to a succession of processes of extraction and refining, in all of which electricity is very profitably employed. The power house is shown on the right of the picture, and derives the bulk of its fuel supply from the "bagasse" or cane from which the juice has been extracted

Handling the cane at the central. The hoist shown here (San Manuel Company) is operated by a 30 h.p. induction motor

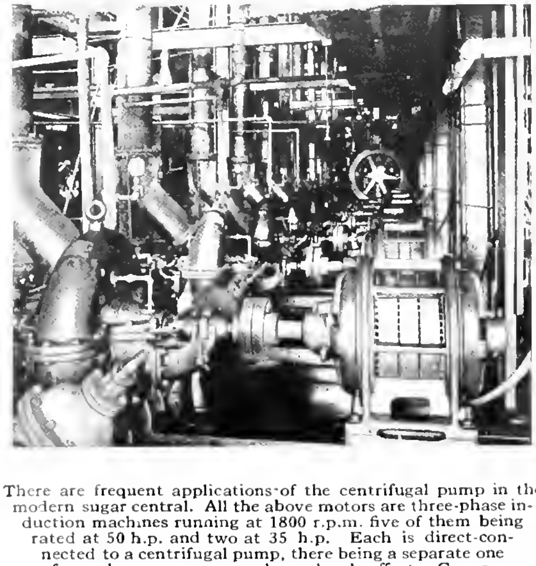


Electrically-operated elevator in the San Manuel central driven by a 15 h.p., 900 r.p.m. back geared induction motor, with chain drive to shafting. This shafting is belted to a double sugar elevator cost or price by even a small fraction of a cent will bring any mill not equipped with the most modern appliances to the financial danger line or even to the point of no profits. The cost of cane and labor have both been increasing and there is little reason to expect any change in this tendency. Therefore, maintenance of satisfactory profits must be looked for only through manufacturing economies.

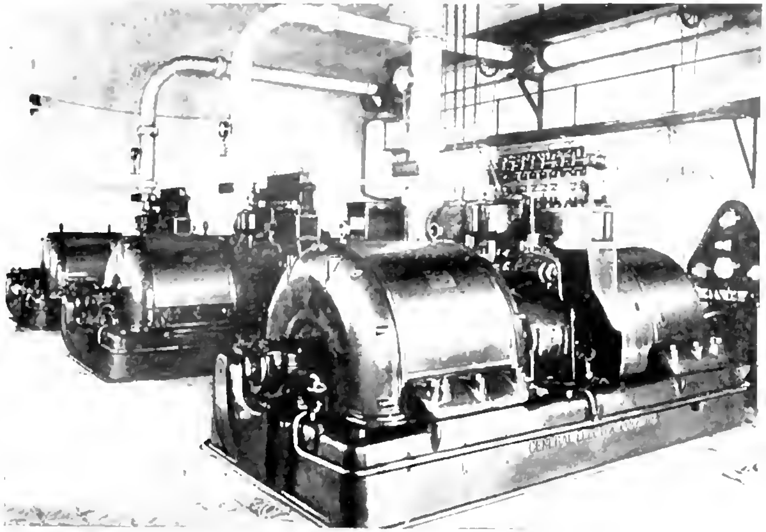
Under the present methods the power plant of the sugar mill consists of a large number of boilers from which the steam is piped to engines driving the various machines scattered all over the mill. The "bagasse" or cane from which the juice has been extracted is used as fuel. This, however, with the steam-engine drive in average mills is not sufficient for the total heat units required and the remainder have to be supplied from coal or wood, which becomes, especially in the larger mills, a source of considerable expense as will be seen in the following calculation. Estimating the weight of bagasse to be five times that of the sugar produced and taking a large mill, e.g., one producing 90,000,000 pounds of sugar per season, we would have bagasse amounting to 200,000 long tons. If we assume that this is seven-eighths of the fuel required, the mill would have to buy the equivalent of 28,500 tons of bagasse. As five tons of this material are equal to one of coal this means 5700 tons of coal, which at $7.50, a conservative price for coal at a Cuban factory, would cost $42,750. That the purchase of this extra fuel is, in general, unnecessary has been conclusively proven. As early as 1892, Prof. L. A. Becuel in a paper, read before the Louisiana Sugar Chemists' Association, stated: "It appears that with the best boiler plants—those taking up all the available heat—by using this heat economically the bagasse can be made to supply all the fuel required by our sugar houses."

The elimination of unnecessary fuel expense is one of the reforms which is most sought after by sugar mill owners. This can hardly be brought about, however, while the steam-engine is still the means of furnishing direct power, as too many of the heat units are wasted in condensation of steam in the pipes, in the leakage at pipe joints, and in the gross inefficiency of the small engines, of which many are used. The loss due to leakage and condensation may at first seem trivial, but it must be remembered that the main, intermediate, and small piping in a steam-driven mill is so complex and extensive that its initial cost may well be in the neighborhood of one-third that of the entire mill.

The 15 h.p., 900 r.p.m. induction motor shown above performs a variety of services in handling the sugar. Through back-gearing, a chain drive, and various bevel gears and friction sprockets, it operates a sugar conveyor, massecuite conveyor, sugar mixer, etc.

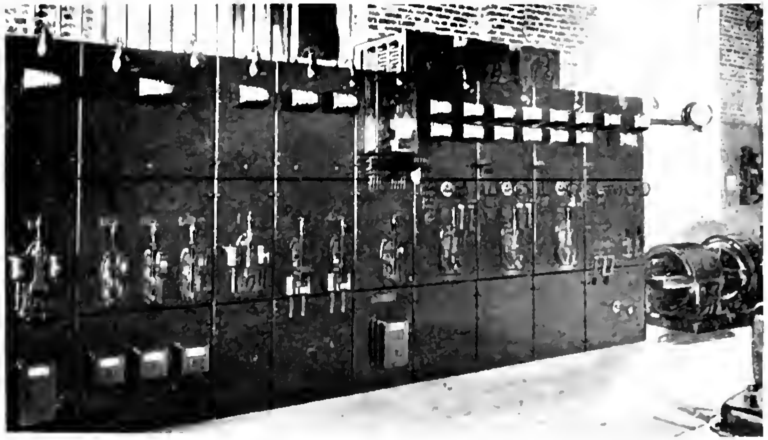


There are frequent applications of the centrifugal pump in the modern sugar central. All the above motors are three-phase induction machines running at 1800 r.p.m. five of them being rated at 50 h.p. and two at 35 h.p. Each is direct-connected to a centrifugal pump, there being a separate one for each vacuum pan and quadruple effect. Capacity 1400 gallons, 1800 gallons and 2000 gallons per minute

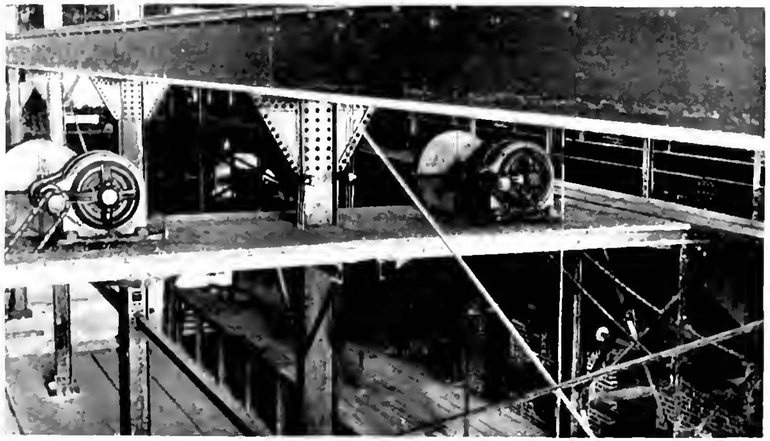


Installation of three 1000 kw. Curtis turbo generators running at 3600 r p.m. and delivering current at 440 volts, 60 cycles for power and lighting loads in the San Manuel Company's plant. The San Manuel installation was designed for electrical operation, and is now completing its second successful grinding season

As usual, one of the conspicuous advantages of the electric method of operating sugar centrals is the ability to install electric drive in the machine shops, repair shops and carpenter's shops, attached to the plant. "You only pay for what you use," and auxiliaries are operated only as long as is actually necessary



Another interior view of the main power station of the San Manuel Company, showing the generating and distributing panels. Three 1000 kw. turbo-generators are at present in operation. The above board contains the panel for the control of the outgoing feeder to the Chaparra substation

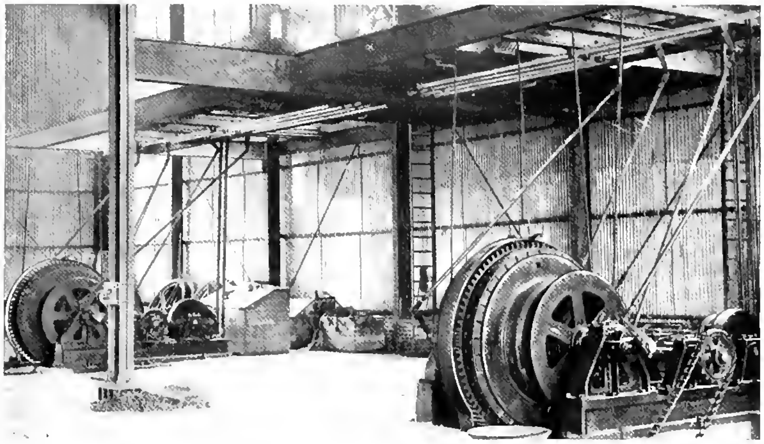


Raising steam from the refuse of production. The "bagasse" is used as fuel in the steam electric plant, and the above picture shows two 15 h.p., 900 r.p.m. motors driving, through back gearing and chains, the "bagasse" feeders corresponding to the boilers on each side

Also, on many plantations, the water supply is so far from the mill that a separate steam boiler plant has to be erected to furnish power for the pumping engines, and the cost of coal and attendance forms a considerable item in the total expenses.

These are but a few of the conditions existing in the steam-engine-driven mills which can be improved by the substitution of the more efficient electric drive, as is being proven by many up-to-date mills which are today enjoying an electric power installation with its ease of control, minimum of expense, and unsurpassed reliability of operation.

Electricity is equally adaptable for equipping an entirely new mill or for remodeling one which is now using steam. In either case, the beneficial results obtained are practically in direct proportion to the extent to which it is employed.



Another hoisting equipment at the San Manuel central. These two Lidgerwood hoists are each driven by a 37 h.p., 1200 r.p.m. induction motor

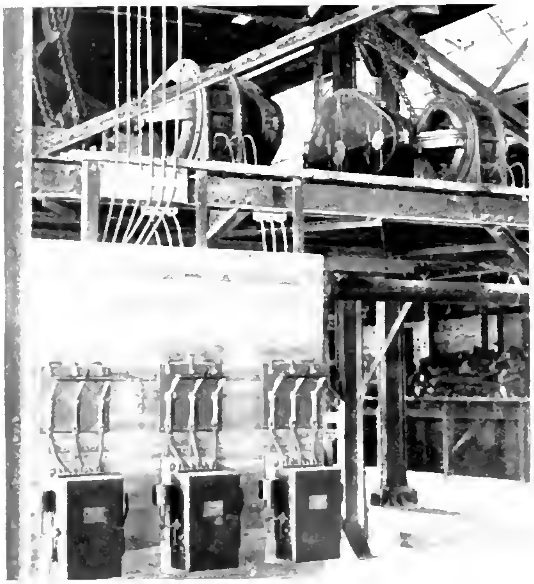
In addition to operating some 1500 h.p. in motors at Las Delicias and lighting the factory and adjacent town, the turbo plant there furnishes electric service to an allied "central" at Chaparra located some three miles away. The above cut shows the Chaparra substation which handles the distribution service at this second mill

A recent Cuban "ingenio" or mill laid out for electrical operation is that of Las Delicias at San Manuel. This mill, which has a capacity of 400,000 bags of sugar per year (320 pounds per bag), is just completing its second successful grinding season. Its electrical equipment consists of three 1000-kw. Curtis turbines, direct-connected to 60-cycle alternating-current, 440 volt, three-phase generators, switchboard, transformers and substation. In addition to operating some 1500 horse power in motors at Las Delicias and lighting the factory and adjacent town, power is furnished from this plant to an allied central* at Chaparra about three miles away.

While these centrals were originally designed for an electric equipment and may be arranged in a slightly different manner from older ones which were laid out for steam drive, the latter can be changed over at an expense amply justified by the advantages gained. The cost of such change-over could be estimated only upon detailed examination of the central by

* This name is given to the headquarters plant in which the refining operations are performed.

an engineering specialist. Experience seems to show that, where complete electrification is made, the resulting economies will pay for the equipment in a time, which, though varying



Another view of the apparatus which carries the waste "bagasse" to the boilers, showing the extreme simplicity of the electric control. The motors themselves are located some distance from the ground; while all that is necessary to bring the handles of the compensators within easy reach of the floor level is a few feet of cable

with local conditions, is never great. In cases where much coal is burned, it is even profitable to scrap the old engines and accessories when a market for them is not readily apparent.

The machines which are now being successfully motor-driven consist in part of the various conveyors, hoists and pumps, crystallizers, bagasse feeders, centrifugals, sewing machines and furnace blowers, beside the carpenter and machine shops. In the majority of old mills, the motors can be substituted directly for the engines, using the same pinions and bases, thus reducing the expense for accessories to a minimum. The centrifugals require special frame-work with direct-connected motor but these have been developed and in successful service for a long time. The electrification of the crushing rolls has not been generally adopted as yet, but will undoubtedly be taken up in the near future.

Polyphase induction motors of the squirrel cage armature type are adapted to nearly all of the foregoing machines, thus making a power installation of unequalled reliability, simplicity, and economy. As these are three of the most important factors in successful sugar mill operation today, it places no tax on the imagination to look forward to the time when all profit paying sugar mills will be driven entirely by electricity. Many of the operations in the sugar central—conveying, hoisting, pumping, mixing, and so on—are well illustrated in the accompanying pictures, which make up a fairly complete story of the sugar business, including also the gathering of the cane on the plantation, and its transportation to the mills. The photographs illustrate various parts of the plant of the San Manuel Sugar Company at Las Delicias, Cuba, to whose operations reference has already been made above.

An adjunct to the sugar central. Molasses or "miel" tank and pumping station at the plant of the San Manuel Sugar Company, Las Delicias, Cuba

MOTOR TRUCK ADAPTABILITY AND ITS RELATION TO OPERATING EFFICIENCY

By P. D. Wagoner

President General Vehicle Company, Long Island City

The adaptability of the truck to its work is of prime importance, and the greatest present need is the right truck for the right place. The useful field of the gasolene and electric truck must be recognized, and the peculiar advantages of each type frankly conceded. Those who look for a type war are going to be disappointed. The General Vehicle Company— noted for years for their electrics—are now going into the gasolene business as well, in order to place themselves in position to meet *all* the road-transportation requirements of any mercantile concern. They have secured the importer's rights for the German-built *Mercedes* gasolene truck and its exclusive manufacturing rights in this country. President Wagoner's article gives a specification of the truck and indicates what it is capable of doing. —Editor.

The motor truck, so long hampered by tradition and countless economic difficulties, is now on the way to a two-fold commercial success. Thousands of users are making it pay them, and this stimulates its manufacture at what will soon be a fair profit. It is to motor truck adaptability and scientific operation that business men are now turning their thoughts, and they could direct their energies into no more helpful channels with respect to the general mercantile situation.

Fig. 1. Storage Battery Truck Used in the Service of a Tool Manufacturer. Power propelled vehicles are able to easily overcome bad road conditions, such as snow, etc.

Just at present motor truck operation is greatly hampered by lack of standards in gauging efficiency. For centuries the horse wagon, while improving as to type, has been limited in scope by the animal that drew it. Succeeding generations have loaded and unloaded merchandise or raw material in much the same laborious way. Those who sought for a guiding principle in accelerating the speed of the loaded vehicle were hindered in numerous ways by tradition, by the architect, by street congestion, rush seasons and weather conditions. It was not until the horse could be weeded out by a machine equally elastic that a remedy became possible.

Into a condition already chaotic, the motor truck manufacturer brought his product and sought a hearing. He had to contend with prejudice, indifference and in some cases pathetic ignorance. His was the task, not of selling a self-propelled machine to take the place of a worn out, inferior one; but of selling an improved machine to displace a four-footed industrial unit having a time-honored monopoly of the entire field which it served.

Fig. 2. The Electric Truck is Widely Employed by Express Companies on Account of Its High Economy on Frequent-stop Runs

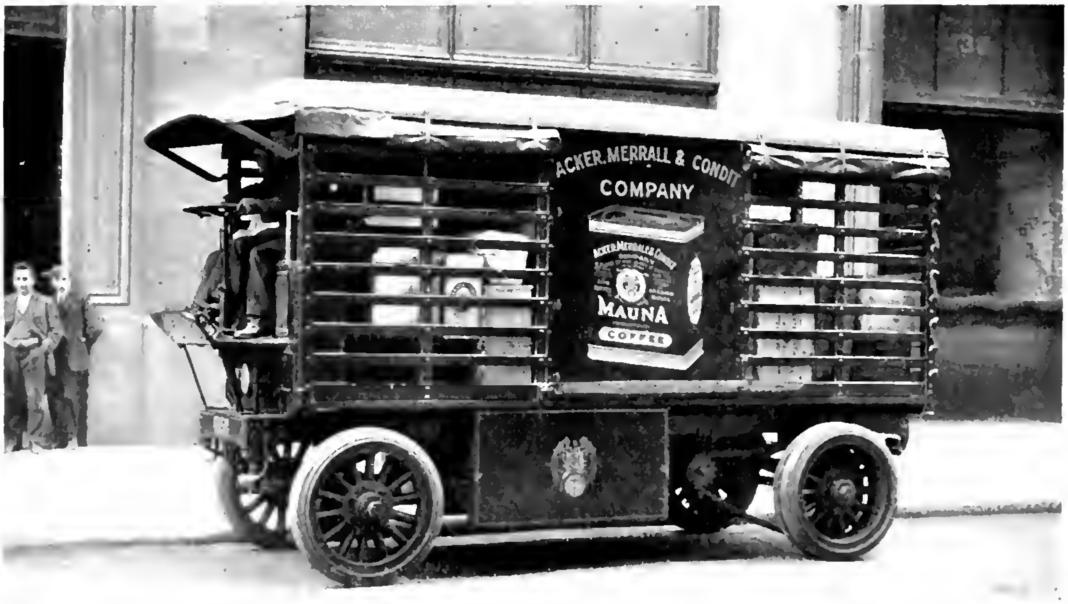


Fig. 3. Well Designed Electrically Propelled Vehicles Render a Great Service to Both the Wholesale and Retail Trade

It is obvious that, in seeking for standards by which to gauge operating efficiency, the motor truck manufacturer could profit little from what may be called horse wagon practice. There were too many variables in route making, load units and other factors such as loading platforms and shipping room methods. It was necessary to begin at the bottom and build up new principles based on motor truck performance. But motor truck performance also varied—especially so over a period of twelve or more months. So the manufacturer at first made little progress; and he might have found no workable solution of the problem but for developments which were the outcome of his early efforts to establish a better working basis of determining operating efficiency.

Since 1909, four things have been slowly percolating through the minds of the business men of the country. *First*, that the motor truck is not so much an automobile as it is a self-propelled, trackless machine designed especially for road transportation. *Second*, that a properly designed and well constructed machine is the only safe investment. *Third*, the operating end of motor trucking should take precedence over all else, once the machine is installed. *Fourth*, other things being equal, the responsible pioneer manufacturer having ample capital as well as practical operating knowledge, is the best source from which to obtain both the truck and the co-operation.

Accordingly, the year 1913 finds us with at least a working hypothesis in solving the problem. The results obtained by watching the performance of the trucks installed ten years ago (in the case of the Vehicle Equipment Co., 12 years ago) have been priceless. The endless experiments covering every type of vehicle in scores of cities both here and abroad, have settled, beyond question, the relative fields of the electric and gasolene types. The express companies, the brewers, department stores, wholesale grocers, and many retailers, as well as the public utility corporations, have gone into the matter exhaustively, and have vindicated to their own satisfaction the deductions and claims of reputable electric truck sponsors. At the same time they have established, beyond question, the superiority of the gasolene truck in its economic field.

The adaptability of the motor truck to its work is of prime importance. Financially speaking, a firm would better stick to horses, even in this era of high prices, than to buy motor trucks, no matter how good, which are not adapted to the work in question. It has been demonstrated that the firm which approaches the question of motorizing with an open mind, but resolved to take no false step, is usually wise in its decision to test the relative economies of trucks of various capacities, before buying, say, even 50 per cent of its needed equipment. It is true that a wholesale grocer might buy a 2-ton or 3½-ton truck with little danger of not being able to utilize, to good advantage, a truck of either capacity, because in the large number of trucks in this service, these capacities predominate. A careful study of his needs, however, might develop that on one important route where flour in barrels was the principal item involved, 5-ton trucks would be most economical; that for transfers to retailers a 2-ton truck was ideal; but that in his particular case there was a field also for the 1-ton truck with its higher speed and greater mileage, as a medium for special delivery. Another grocer might find that nine 3½-ton trucks were just what he needed to displace all horses and secure the greatest relative efficiency.

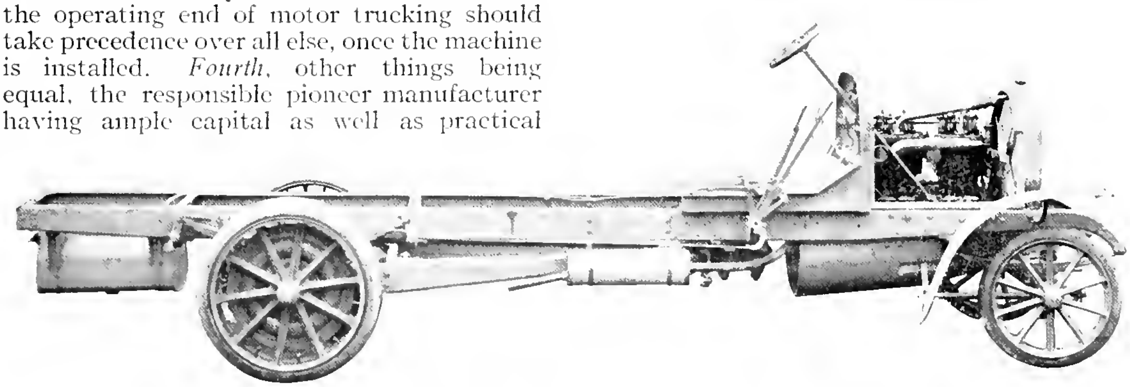


Fig. 4. Chassis of a Gasolene Truck of Mercedes Design; Metal Wheels Used Throughout

It is this adaptability and its relation to general efficiency which recognizes the respective fields of the electric truck and the gasolene truck, and concedes each type certain advantages in its field. Those who look for a type war are going to be disappointed. There will undoubtedly be fierce competition, because if some gasolene truck manufacturers had their way, they would keep the electric on hauls under five miles in length, and doubtless some who make electrics will also endeavor to invade the field of the gasolene truck; but there is room for both and there is need for both types at the present time.

Fig. 5. A Daimler Mercedes Gasolene Truck with Trailer as Used by a Berlin Coal Company

There is therefore ample reason why manufacturing firms who have in the past dealt exclusively with the production of the electric vehicle should now turn their attention to the manufacture of gasolene trucks. In the first place, many large corporations and merchants require both types, and while they may have the utmost confidence in the electric product of some one manufacturer and have given expression to this confidence by investing in it to the limit of their electric truck needs, they have heretofore been obliged to go elsewhere to buy, in some cases, from three different manufacturers, in order to provide machines of the right capacities for their long hauls. The need for both types grows as all-motor delivery systems multiply.

As far as the General Vehicle Company was concerned, this general situation was foreseen several years ago; and, in our search for the best engineering designs upon which to manufacture a gasolene truck to meet the demands of the American market, we turned our attention to Europe. The writer, in company with the factory manager and chief engineer, spent three months continuously studying European conditions and designs.

Fig. 6. Another Instance, this one with a Brewing Concern, of the German Policy of Using a Trailer in Connection with a Gasolene Mercedes Truck

Every kind of motor truck was investigated and hundreds of users were interviewed; and we arrived at the decision that the design best fitted for service under American conditions was provided in the Mercedes vehicle. Not only was this truck giving excellent results over a long period of years, where road conditions were favorable for heavy haulage; but, in certain mountainous and rural districts where road conditions are fully as unfavorable as we have here, it was giving from six to ten and even twelve years exceptional service. Its record in cross-country work compared very favorably with shorter hauls on perfect roads. We succeeded in securing the right to import German manufactured Mercedes commercial vehicles and the exclusive manufacturing rights in the United States. The American built Mercedes in design and construction and performance; but, from 1899 on, Daimler commercial vehicles were awarded the highest honors. Trucks for military purposes followed in 1901, and in 1903 Daimler industrial trucks for use in the agricultural districts also won success. In 1908 Daimler trucks were subsidized by the German government for army transport service. As early as 1902 Daimler motors were installed in the auxiliary boats of the Imperial Navy, and today motors of from 6 to 100 horse power are used in that

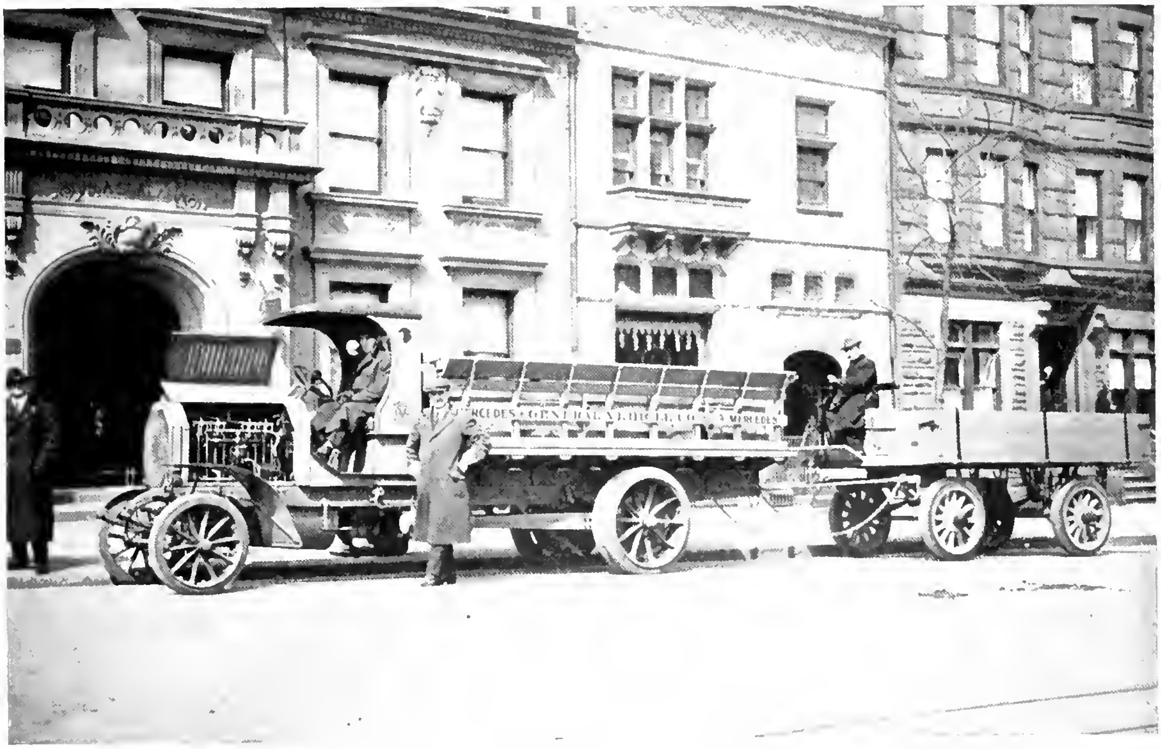


Fig. 7. A General View of the Mercedes Truck of the General Vehicle Company as Used in America

truck will be a replica of that of German manufacture, and will be manufactured from the drawings of the *Daimler Motoren Gesellschaft.*

Gottlieb Daimler built and ran his first Mercedes automobile in 1886, or 27 years ago. His first invention in 1882 resulted in the introduction of permanent ignition on paraffin motors. He was the first to construct high-speed combustion engines of light weight in proportion to the power developed. As years went by, the name Daimler became identified with the best in automobile practice. Not only did Mercedes passenger cars excel service. Small wonder that when Gottlieb Daimler died in 1902 the Association of German Engineers erected a monument to him as the father of the automobile.

A brief description of the Mercedes truck illustrated on this page may be interesting to REVIEW readers. It has a useful load capacity of 6 tons, and the trailer 4 tons. The wheel base is $169\frac{1}{4}$ in., the tread $60\frac{5}{8}$ in. The total length of chassis is 21 ft. 5 in. The weight of chassis with tires, gasolene, and oil is 6380 lb. Two 4-cylinder, 4-cycle motors are interchangeable on this chassis. The standard motor is of 35 brake horse power at 850 revolutions per minute. (The cylinders are 4.25 by 5.90 inches bore and stroke.) The larger motor is of 45 brake horse power at 800 revolutions per minute. Both motors are provided with governors, which are built into the crank case and cannot be tampered with, though easily inspected. There are two complete and independent sets of brakes—one on rear wheels, one on transmission. The transmission provides four speeds forward and one reverse. The drive is of the internal gear and pinion type, which permits the use of a forged steel rear axle. The wheels are entirely of metal, and the frame of pressed steel. Compare the weight of the average American 5-ton gasolene truck which is around 9000 lb. with the 6-ton Mercedes at 6380 lb., and you have one factor in favor of the latter as an efficient cross-country truck.

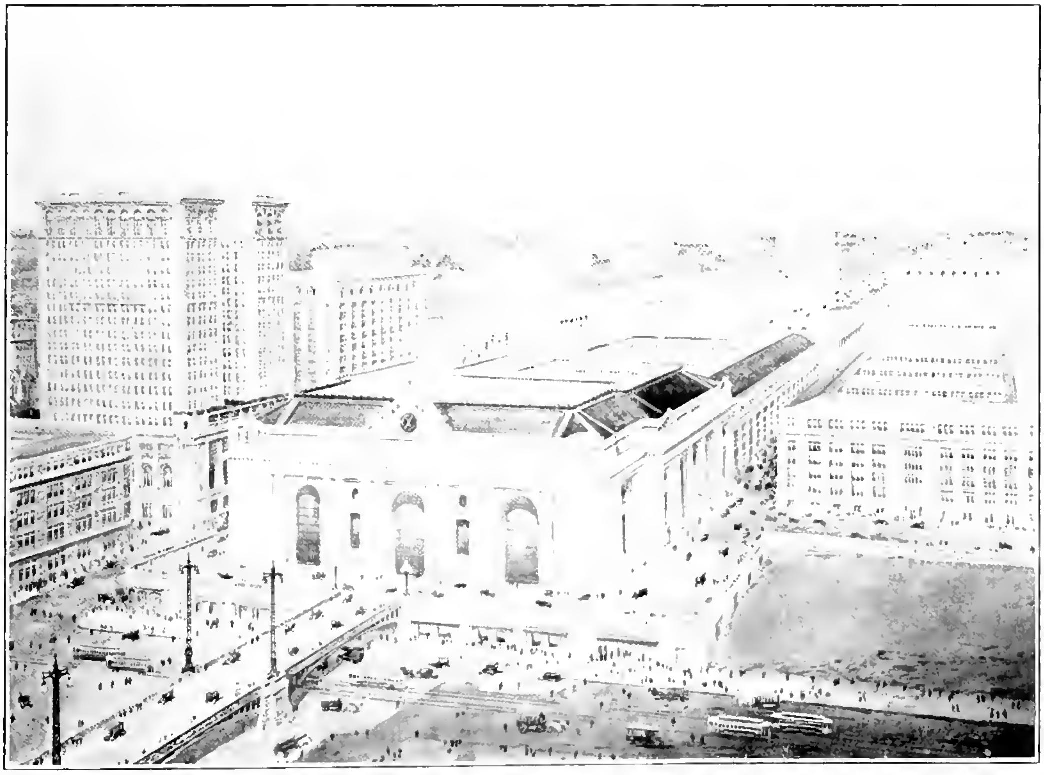
As trucking with motors becomes more and more of a science, it is certain that the initial cost of motor trucks will become less of a bugbear to at least the large buyer. Operating efficiency is largely a matter of careful routing and intelligent care. It is true the driver has often been an uncertain quantity, but this problem no longer greatly concerns the owner of the electric; and, in the case of the gasolene truck, it pays to utilize machinists or other mechanics and pay them good wages. The use of a gasolene truck presupposes the utilization of its greater radius of action and higher speed, and when it is cutting down local express bills or doing other work which is outside the realm of either electrics or horses, its greater earning power can well support a thoroughly competent driver-mechanician.

Fig. 8. A Hill-Climb Test by the Truck and Trailer Shown in Fig. 7

It is an undisputed fact that to the firm which has gone at the matter rightly, ten trucks can be cared for as cheaply as six, and this ratio increases when you get above thirty. In the matter of part renewals, we can hardly hope for a proportionate saving. Tire cost, however, can be greatly reduced by a little forethought, and one firm I have in mind has evolved a method of getting the last bit of energy out of practically every plate in a battery. The engineer in charge puts the new battery on the long hauls, changing it to a truck with a shorter daily mileage as it weakens. By the time the rated mileage is reduced 50 per cent, the battery is driving a truck which only needs to make about 14 miles per day to cover its route; and, by adding a few comparatively good plates from his other partially condemned batteries, he will often get a (lead) battery life of from 18 to 22 months as against 12 months by less scientific users. This is but an example of cutting maintenance costs in the case of the electric.

Gasolene truck costs can be reduced by systematic routing, by careful driving and also by keeping the truck busy. Sometimes a gasolene truck that will show a small profit with 9 hours' work, will treble this profit with a 14-hour day, or two short shifts. Special crate bodies which can be loaded and placed inside the original panel or slat body are also important time-and-money savers, and should be used much more than they are. Proper loading platforms are also very essential in avoiding delays in loading and discharging.

But the crying need of the hour is the right truck for the right place. Adaptability as a factor in performance has not received the attention it should. A $5000 truck can be a round peg in a square hole, just as much as an executive or a workman can; and the fact that it doesn't fit burns up dollars for the user. If operating efficiency is to reach the high plane that it should, we must have adaptability and durability placed before initial cost, type or line of business.



Warren and Wetmore, Architects. Grand Central Terminal, New York City.

MECHANICAL REFRIGERATION AND ICE MAKING FROM A CENTRAL STATION POINT OF VIEW

By E. F. Tweedy

Commercial Engineer of the New York Edison Co.

This article, which is the first of two that have been prepared by the author for the Review on the subject of mechanical refrigeration, was written principally to show the great opportunity offered by this power load in the building up of the yearly load-factor of a central station, and how the manufacture and sale of ice by a small station may make all the difference between success and failure. The most valuable part of the article to the electricity supply company contemplating the manufacture of ice as a revenue-producer consists of a carefully prepared table covering the items of investment, daily capacity, yearly output, manufacturing cost, selling price, percent net return on the investment, etc., of a score of ice-electric manufacturing plants. Other very important material to the central station comprises data relating to the power consumption and the maximum power demand per ton of ice manufactured. By way of showing the extent to which refrigeration is employed in the trades, the physical and thermal characteristics of two of the more important applications (ice cream and fur storage) are taken up and discussed in detail. The second article, which will appear in an early issue, will take up the thermal characteristics underlying refrigeration and describe the generating machines used and the methods of applying the cold.—Editor.

Mechanical refrigeration and ice making are receiving a considerable amount of attention at the hands of central station managers and engineers at the present time. While motor-driven refrigerating machines have long been recognized as affording a very desirable form of central station load, it is only within the past few years that any very active steps have been taken towards securing this class of business.

When it comes to the question of ice making, the manager of a central electric light and power station has the choice of two alternatives. He may either sell electrical energy for the operation of motor-driven ice machinery to a concern engaged in the business of making and selling ice, or he may elect to manufacture the ice himself as a supplementary process to that of generating and selling electrical energy. The latter course has been followed by a very considerable number of central stations in this country, but the stations which have thus undertaken the manufacture of ice are, with a few exceptions, of relatively small size. Several of our larger central stations are now attacking this ice making problem along the lines first mentioned, viz., by selling electrical energy for the operation of ice making machinery to concerns engaged in the manufacture and sale of ice.

In the case of the small central station, the manufacture of ice as a side line possesses many attractive features. The investment in real estate, buildings, and steam equipment may be largely shared by the two manufacturing processes. A considerable portion of the plant labor may be likewise divided between the two, with the result that the operating costs, as a percentage of the gross income, are often materially reduced, and the net earnings largely increased. Before considering this phase of the subject further, some statistics will be given relative to the manufacture of ice in this country. This will be followed by the presentation of certain data bearing upon combination ice making and central station plants, and the balance of the article will then be devoted to mechanical refrigeration, including ice making by means of motor-driven compressors, as a field for central station service.

To give some idea of the present magnitude of the ice manufacturing business in this country, it is only necessary to mention that there were 2000 plants engaged primarily in the manufacture of ice in the United States in 1909, which was the time of the last census of manufactures. These plants employed over 21,000 persons and utilized approximately 318,000 horse power. The combined capitalization of these plants amounted to over 118 million dollars, or nearly 60,000 dollars per plant. The amount of ice manufactured by these plants aggregated nearly 13 million tons valued at over 42 million dollars. These figures relate only to those plants which were primarily engaged in the manufacture of ice. Other plants, which were engaged primarily in the manufacture of products other than ice,—and combination ice-electric plants would be included in this category,—produced an additional 1½ million tons. At the present time the annual output of manufactured ice in the United States is probably in excess of 20 million tons, or something over one-half of the total amount of ice that is consumed. In New York City, the consumption of ice is about 6 million tons annually at the present time. Of this total, about 40 per cent, or 2½ million tons, is natural ice, the balance being the manufactured product. As the present population of Greater New York is approximately 5 million, the consumption of ice per capita is, roughly, $1\frac{1}{4}$ tons, or some three or four times the per capita consumption of the United States as a whole.

While the majority of the combination central station and ice making plants in this country are located in the southern states, where natural ice competition does not exist to any extent, they are by no means confined to the warmer portions of the country, as will be evident from a glance at the adjacent map (Fig. 1), which shows the approximate distribution of the combination ice-electric plants in this country at the present time It will be seen that there is apparently quite a field for manufactured ice, even in those sections of the country where natural ice might be expected to be plentiful and cheap. This is unquestionably the result of a growing recognition of the fact that ice produced under conditions which are controllable from a sanitary standpoint is inherently safer for public consumption than ice taken from bodies of water which are usually located in close proximity to cities or towns where they are frequently exposed to dangerous pollution.

In Table I, some data is presented upon a number of combination ice-electric plants located in various parts of the United States. The data appearing in this table have been compiled from a number of sources, chiefly from articles upon central station ice making which have appeared from time to time in the *Electrical World*.

The investment per ton of ice making capacity is seen to vary from about \$1000 to \$2000, with an average for the plants as a whole of about \$1200. The amount of ice made per year per capita of population shows a considerable amount of variation. For plants located as far south as Florida, Texas, and Oklahoma, the per capita output reaches as high as 1 to $1\frac{1}{2}$ tons, but for the plants farther north the amount of ice made usually ranges from one-third to one-half of a ton per capita of population. The average for all of the plants, for which the pe capita output is given in the table, is 0.57 tons. The population served per ton of ice making capacity varies from a minimum of 130 to a maximum of 500, with an average for all of the plants of a trifle over 300.

Only four of these plants operate throughout the entire year, and one of these operates at a greatly reduced output during five months of the winter season. From four to seven months appears to be the usual period of operation, although this is governed largely

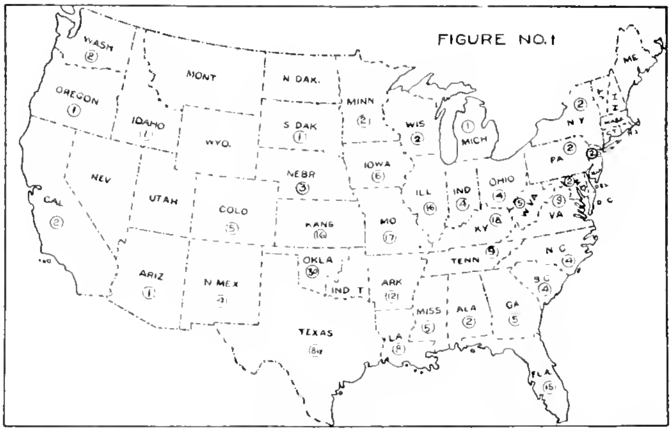


Fig. 1. Map showing the number and location, by states, of the combination central station and ice making plants operating in the United States

by the demand for ice, the size of the ice making plant, and the amount of storage capacity that is provided. There is a considerable difference of opinion among the operators of these combination plants as to whether it is better to provide a plant large enough to meet the summer demand, with little or no storage capacity, and operate the plant only during the warm months when ice is needed, or to provide a smaller plant, with sufficient storage capacity to meet the summer demand, and then operate the plant during a considerable portion of the year. The majority of those who are operating combination plants, and who have expressed their views upon the subject, are apparently in favor of providing sufficient storage capacity to keep the ice plant in operation throughout a large part of the year, as by so doing the business can be better systematized and the plant labor more efficiently employed. This plan requires a smaller investment in ice machinery, although this saving is offset to a greater or less extent by the additional cost of the necessary storage space.

While the majority of the plants shown in Table I deliver at least a portion of their output to the retail trade, there are a few plants shown which sell their output at wholesale

TABLE I
COMBINATION CENTRAL STATION AND ICE MAKING PLANTS

Location of Plant	System of Refrigeration Used	Rated Capacity in Tons of Ice Per 24 Hrs.	Storage Capacity in Tons	Months Operated During Year	Ice Plant Investment (Dollars)	Population Served	Tons of Ice Made: Total Year	Tons of Ice Made: Per Capita	Average Cost per Ton (Dollars)	Average Selling Price Per Ton	Per Cent Net Return Ice Investment	Remarks
Latitude of Topeka, Kansas	Absorption	10		4	17,500	3500	1100	0.31	2.95 * 1.15 † 4.10	6.36	13.0	* Includes delivery. † Fixed charges, including interest, depreciation, taxes, etc.
Missouri	Do.	10		1	20,000	3600	1000	0.28	3.34 * 0.76 † 4.10	6.40	12.5	* Labor and fuel. † Insurance, taxes, and depreciation (5% on gross income).
Latitude of LittleRock, Arkansas	Compression system steam-driven	25		5	10,000	8000	1000	0.50	2.00 * 2.50 † 4.50	6.50	20.0	* Plant expenses. † Includes delivery and overhead charges.
Kewanee Illinois	Do.	30		12		15,000	3488	0.23	1.36 *	2.75 †		* Exclusive of fixed charges — fuel, wages, supplies, etc. only. † Sold to dealer or shipped out of town.
Williamson, West Va.	Do.	10		12		5000	1451	0.29		4.00 *		* For 8 months—$3.60 during balance of year.
Oklahoma	Do.	12			17,000	4000				7.40	23.0	
Latitude of Omaha, Nebraska	Do.	10	75	4	10,000	3500	1200	0.34	1.29 †	6.25 *		* $9.00 retail; $4.00 from platform wholesale. † Stated to include fixed charges, but this is probably incorrect.
Kansas	Do.	15	1000	4	22,700 *	2300	2800	1.22	1.35 (1) 2.01 (2) 3.36	4.28	11.3	* Includes ice storage space costing $6000 (1) fuel, labor, supplies, etc., (2) depreciation, delivery, etc. (delivery costs $1.30 per ton).
Western City	Do.	60		6 to 8	60,000	30,000			1.00 *	3.60 †		* Approximate cost of manufacturing. † Wholesale.

Northern Illinois	Absorption	20		6	21,600	6347	2000	0.32		6.00		
Illinois		7	20	5	10,000	3000	1000	0.33	2.00 *	4.00 †	20.0	* Stated to include manufacturing and overhead costs. † Wholesale.
Kentucky	Compression system steam-driven	15	36	5	9,500	3000			2.00 *	5.00 (1) 8.00 (2)	37.9	* Fuel, labor, etc. (1) Wholesale. (2) Retail.
Florida	Absorption system using exhaust steam	10		12	12,000	1700	1700	1.00	4.12 *	6.00 (1) 10.00 (2)	41.6	(1) Wholesale. (2) Retail. * Manufacturing and overhead charges.
Near Washington, D. C.	Compression system steam-driven	10	50	6	9,000	1800	1000	0.56	2.25 *	5.00 (1) 9.00 (2)		(1) Wholesale. (2) Retail. * Fuel, labor, etc.
Tennessee		20	200	7	15,000 (1) 3,000 (2) 2,000 (3) 1,000 (4)	5000	3000	0.60	2.60 *	3.00	9.5	(1) Ice machinery, freezing tanks, etc., (2) Addition to building, (3) Delivery wagons, (4) Storage space. * Includes interest, depreciation, etc.
Northern Texas		10		6	16,000 *	2000	2000	1.00	2.74 (1) 2.16 (2) 4.90	6.00 †	13.7	* Purchase price as "going concern," (1) Cost of manufacturing, (2) Overhead and delivery costs. †$4.00 Wholesale; $9.50 retail.
Near Omaha, Nebraska		21		7 *	25,000	8000	2700	0.34	1.92 †	3.00	12.0	* Remaining months at reduced output. † Includes interest.
Northern Texas		4	6	6	5,000	1200	700	0.58	3.60 *	7.71	57.6	* Includes interest, depreciation, etc.
Latitude 40° near Mississippi River		10		6	10,000	2000	600	0.30		4.00 (1) 9.00 (2)		(1) Wholesale. (2) Retail.
Oklahoma		10	300	6	10,500 (1) 600 (2) 1,006 (3)	1300	2000	1.54	1.25 *			(1) Refrigerating machinery. (2) Wagons and teams. (3) Storage space. * Evidently exclusive of fixed charges.

only from the station platform. A price of three to four dollars per ton is frequently obtainable when the ice is sold in this manner, while the retail price obtained for ice delivered generally runs from eight to ten dollars or more per ton. As the delivery of ice usually involves considerable expense, to say nothing of trouble and annoyance, the majority of those who are operating combination plants now seem to favor the selling of their product wholesale at the station platform to a local dealer, allowing the latter to assume the burden of delivering the ice to the consumer.

The addition of ice making equipment to the average central station supplying a small town or city is, in the great majority of instances, a decidedly profitable investment. In many instances, central stations in some of the smaller communities could not be operated at a profit were it not for the ice making part of the business. About two years ago the *Electrical World* sent out inquiries to nearly 300 central stations whose activities were known or believed to include the manufacture of ice. Of the central stations replying, 136 reported that they were manufacturing ice, and in reply to the question, "Has the combination plant proved satisfactory?" 130, or over 95 per cent, responded in the affirmative, twenty-four taking occasion to express enthusiasm at the results obtained. Two replied "fairly satisfactory," while only four answered "unsatisfactory." The distribution of these plants, in accordance with the size of the town or city in which they were located, is of interest:

Population of Town or City	Per Cent of Total Number of Plants From Which Replies Were Received
Under 2500	34.8
2501 to 5000	34.8
5001 to 10,000	19.5
Over 10,000	10.9
	100.0

In undertaking the manufacture of ice, the central station manager has the choice of several different methods of ice making. He may choose between the absorption and compression systems, and, if he should decide upon the latter, there is still the question of steam or electric-driven compressors. There is also the alternative of making plate or can ice, and, if the latter is to be made, whether raw or distilled water shall be used. A large majority of the existing combination plants are using the compression system with steam-driven compressors, although quite a number of plants are making use of the absorption system. Great claims are now being made for the latter system as regards the possible use of exhaust steam from the generating engines. While it may be practicable to do this in certain cases, notably where low-temperature cooling water is available, the fact remains that very few absorption plants are being operated by means of exhaust steam at the present time. When operated by means of live steam, this type of plant shows little if any economy over the steam-driven compression plant, except when temperatures much below those employed in ice making are required.

The reason why so few combination plants are using motor-driven compressors at the present time is due to the fact that almost all of these plants manufacture can ice, and the belief has been almost universally held, until quite recently, that distilled water must be used for ice making with the can system. With a steam-driven compressor the exhaust from the engine is condensed, and, after being freed more or less completely of oil, it provides a supply of distilled water from which the ice is made. A few motor-driven plants have been equipped with multiple-effect evaporators, by means of which distilled water may be obtained for ice making with a relatively small consumption of live steam. It can be confidently stated, however, that distilled water is not necessary for the production of clear can ice at the present time. Several processes are now available by means of which raw water may be used for producing perfectly transparent can ice, and, in the writer's opinion, it is only a question of time when practically all ice made by the compression method will consist of raw water frozen by means of motor-driven compressors.

Probably few persons outside of those who are brought into actual touch with refrigerating work have any idea of the rapid development which has taken place during the last few years—and which is still taking place—in the field of mechanical refrigeration. Not only is mechanical refrigeration rapidly replacing ice as a medium for cooling in many lines of industry, but it is finding many new applications for which the use of ice would be entirely impracticable. A few of the more important applications of mechanical refrigeration met with in central station work will be briefly considered.

Ice Cream Making

The wholesale manufacture of ice cream was first undertaken in this country in the early fifties, and the industry has now reached tremendous proportions. With the exception of Canada, which ranks next to this country in the production of ice cream, the only other countries where the wholesale manufacture of ice cream is carried on are England, Australia, Mexico, and Argentine; and in these countries the output is comparatively small. In other parts of the world, the industry has undergone little or no development.

It is estimated that the factory output of ice cream in the United States during the year 1912 amounted to 124 million gallons. This output of ice cream does not include that made by the retail dealers, nor that made by and consumed in hotels, restaurants and clubs, nor at soda-water fountains. It has been estimated that these additional sources of production amounted to 30 million gallons, making the total output of ice cream in the United States during the year 1912, 154 million gallons. Based on an estimated population of 95 million people, this output would provide approximately 6½ quarts for every man, woman, and child in the United States. The retail value of this 1912 output, or the amount of money expended by the American people in gratifying their taste for this popular dish, has been placed at about 217 million dollars, based upon an average retail price of 35 cents per quart. This is equivalent to a per capita expenditure of approximately $2.30. According to the census of manufactures for 1909, there were only 25 industries in the United States at that time in which the value of the yearly products was in excess of the value of the ice cream output of 1912. Practically all of the electrical machinery, apparatus, and supplies turned out in the United States in 1909 could have been purchased by the money spent by the people of the United States for ice cream during the past year. These figures will perhaps convey some idea of the present magnitude of the ice cream industry.

Prior to some eight or nine years ago, the use of ice and salt for freezing and hardening ice cream was universal, but, during the past few years, mechanically refrigerated brine has very largely replaced the old ice and salt method, particularly where ice cream is made in any considerable quantity. It is estimated that there are now some 525 refrigerating machines in this country operating in plants which are engaged in the manufacture of ice cream.

Mechanical refrigeration is made use of in the ice cream industry in one of three ways: first, it may be used only for freezing, hardening and storing the ice cream; second, it may be employed simply for the manufacture of ice, the freezing, hardening, and storing of the ice cream being accomplished by the old ice and salt method, or by the use of brine refrigerated by means of ice; third, it may be used directly in the manufacture and storage of the ice cream and, in addition, in the production of the ice required in the shipment of the finished product. The method first mentioned is employed in those places where the ice cream is consumed upon the premises where it is manufactured, such as in department stores, restaurants, clubs, hotels and at soda-water fountains, etc. This method requires the purchase of ice for packing when it becomes necessary to ship the product, but it is frequently employed even under these conditions when the amount of ice cream made is small. The second method is employed when the manufacture of ice may be viewed as the primary process, the output of ice cream being considered more or less as a by-product. The third method is the one which is now usually employed in the larger ice cream factories, unless ice for shipment can be purchased at an extremely low price.

When the ice required for shipping is made by the ice cream manufacturer, the refrigerating problem becomes somewhat complicated, due to the fact that the requirements for ice making and for ice cream making are quite different. The manufacture of ice is most efficiently accomplished with a brine temperature of some 15 to 18 deg. F. The hardening of ice cream is best accomplished with a brine temperature in the neighborhood of 0 deg. F., and an even lower temperature than this is frequently employed. When a single compressor is used for both purposes, with a suction pressure sufficiently low to provide a brine temperature suitable for the hardening of the ice cream, the compressor output is materially reduced and its efficiency considerably lowered, while only about 10 to 20 per cent of the entire refrigerating capacity is actually needed for the ice cream making process itself.

While a few ice cream manufacturers have installed two separate refrigerating systems—one for the manufacture of ice, and the other, of much smaller capacity, for the freezing and hardening of the ice cream—the more usual way of meeting this problem is to provide a separate brine tank of smaller capacity in circuit with the freezers and setting tank, and to circulate the brine in this circuit more rapidly than that circulated through the ice making tank. By this means it has been found possible to maintain the former brine circuit at a temperature of 10 deg. or more below that of the brine employed for ice making.

While there are several different types of ice cream freezers upon the market, the majority of them are quite similar in principle to the old domestic ice and salt freezer with which we are all familiar. One of the latest types, however, known as the "continuous type" of freezer, is radically different in principle. The mixture is fed in at one end and is moved through the machine by revolving disks within which the brine is circulated, and is discharged at the other end of the machine.

In the manufacture of ice cream, what is known as "swell" occurs, this being the term applied to the increase in volume which the mixture undergoes during the freezing process. This increase in volume results almost entirely from the incorporation of air into the mixture during the period of freezing. The degree to which this occurs depends largely upon the viscosity of the cream from which the mixture is made. As the viscosity of cream increases very considerably for several hours, from the time of its separation and after that at a slower rate for several days, especially if kept cool, it is very necessary to hold the raw cream at a low temperature for some time preceding its use. The rate of freezing also has an important bearing upon the amount of swell. Extensive experiments made by the Vermont Agricultural Experiment Station show that the expansion in volume takes place during a drop in temperature of only a few degrees, and that if the cream is frozen too rapidly, not enough time is available, while passing through these few degrees of temperature, for the proper amount of swell to take place. It was found that the ordinary mixture of cream and sugar used in ice cream making is too thin to retain any appreciable amount of air until it reaches a temperature of about 34 deg. F., when it begins to foam up slowly and then to increase gradually in volume until a temperature of about 29 deg. F is reached. At this point the temperature remains constant for a short period, while the latent heat of the cream is being extracted. At 28 or 27 deg. F., the frozen product is ready to remove from the freezer. The cream is not frozen hard in the freezer, but is removed in a condition which permits of its being poured, the consistency usually being about that of condensed milk.

After the cream is removed from the freezer, it is packed in cans or other containers and placed in a hardening room or tank. There are several different methods of hardening: one is to place the cream in cans which are kept immersed in a tank filled with brine; another method is to have brine drip upon the cans in which the cream is packed; while the latest method is to place the containers upon shelves in a room which is maintained at a temperature of about 0 deg. F. The air in this room is usually kept in circulation by means of a fan, so that a uniform temperature will be maintained throughout. It usually takes about five or six hours to thoroughly harden ice cream, although it is sometimes done in a shorter period of time.

Theoretically, one ton of refrigerating capacity is required to convert about 12 gallons of the liquid ice cream into the hard commercial product per hour. The actual number of gallons of the finished product that can be turned out per hour per ton of refrigeration, depends, of course, upon the amount of swell that takes place, upon the efficiency of the refrigerating system that is used, and, to some extent, upon the kind of ice cream that is being made. For a given quantity of output, ices require considerably more refrigerating capacity than is needed for ice cream.

Motor-driven ice cream making plants provide a very desirable form of central station load. The consumption of electrical energy throughout the year varies almost inversely as the output of the average central station, as is shown in Fig. 2. The curve for ice cream making is the mean of a number of plants, and it shows the monthly consumptions of current expressed as percentages of the total amount of current consumed during the year. Similar curves are shown in Fig. 2 for some other refrigerating loads that are commonly met with in central station practice. The heavy full-line curve shows the monthly outputs of a certain large central station expressed as percentages of the total yearly output. A comparison of this curve with the refrigerating load curves will make it evident why mechanical refrigeration affords such a desirable form of load for central stations. The consumption of electrical energy in an ice cream making plant which does not manufacture any ice for shipment will ordinarily run from 300 to 500 watthours per gallon of ice cream made, with an average of about 400. The annual consumption of energy per ton of refrigerating capacity will usually range from about 3500 to 4500 kilowatt-hours.

The Cold Storage of Furs and Fabrics

While the cedar chest, camphor gum and tar paper still provide the chief means of defence against the ravages of those insects which prey upon furs and woolen fabrics during certain seasons of the year, the practice of placing furs and other garments in cold storage during the summer months is becoming more general each year in our larger cities where such cold storage facilities are available.

The first storage warehouse to undertake the cold storage of furs, carpets and other fabrics, was apparently that of the American Security and Trust Company of Washington, D.C., which first provided cold storage facilities for those classes of goods about twenty years ago. Subsequently, the manager of the cold storage department of that company, in conjunction with the Bureau of Entomology of the United States Department of Agriculture, carried on a series of extremely interesting and valuable tests in order to determine the effects of various temperatures upon the larvæ of the moth and beetle.

As a result of these investigations, it was found that any temperature below 45 deg. F. was sufficient to prevent the larvæ of both the moth and the beetle from doing any damage to furs and fabrics, although the larvæ were capable of sluggish movement at temperatures as low as 42 deg. F. Below 40 deg. all movement is suspended and the larvæ become entirely dormant, while at about 45 deg. activity of the larvæ begins and increases with each degree of temperature up to about 55 deg., when a normal condition of activity is reached. It was also found that it was when the insects in question were in the larval condition that they cause the damage to the furs and fabrics, inasmuch as the grease and animal juices in the fibre and wool serve as food for the larvæ of both the moth and the beetle while these insects are passing through this stage of their existence. It was found that the larvæ of both of these insects could withstand a temperature as low as 18 deg. F. for a long period without harmful effects, and that they changed back from a dormant to an active condition when the temperature again became normal. If rapidly exposed to considerable variations in temperature, however, the vitality of these insects is found to be considerably reduced. It was found that the miller and beetle were soon killed when subjected to temperatures below 32 deg. F., and that they gradually died if exposed to temperatures between 32 and 40 deg. F. While these investigations

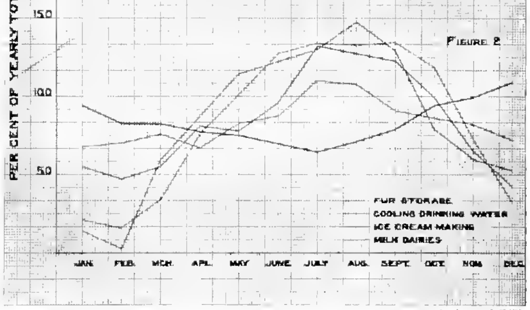


Fig. 2. The broken line curves show that the monthly consumption of energy taken by various types of refrigeration plants is the inverse of the monthly output of a central station, which is illustrated by the full line

show that cold storage rooms for the preservation of furs and fabrics may be maintained at 40 deg. with perfect safety, the temperatures most commonly carried range from 20 to 26 deg. F. At these lower temperatures the furs retain a fresh and glossy appearance, and the flexibility of the skins is preserved as a result of a lessening of the evaporation of the natural oils which they contain.

There are two different methods of applying mechanical refrigeration to the cold storage of furs and fabrics. One of these methods is known as the direct system and the other as the indirect. In the direct system, refrigerating coils—either arranged for direct expansion or for the circulation of brine—are placed within the storage room itself, being mounted upon the side walls or ceiling, or upon both. In the indirect system a bunker space is provided outside of the storage room, and the refrigerating coils are located in this room. Ducts connect this bunker space with the storage room, and the air is circulated through these ducts by means of a motor-driven fan. The latter system possesses several advantages over the former, particularly in that the coils are kept out of the space in which the furs and fabrics are stored. When brine coils are placed within the storage space, there is always the possibility of the coils leaking, with consequent damage to the goods in storage. The indirect system has the further advantage of freeing the storage space of the moisture which collects as frost upon the piping and which melts and drips from the pipes when the temperature rises above the freezing point.

The operation of a modern fur storage plant using central station service will be briefly described as typical of the large number of these plants which are now in operation. Not only are all of the more prominent furriers operating such plants, but practically all of the department stores are now equipped with storage facilities of this kind.

The plant referred to is in operation for about eight months out of the year, usually from about March 1st to November 1st. The storage vault contains approximately 60,000 cubic feet and about 15,000 fur garments of various kinds are in storage during the summer months. The ammonia expansion pipes are located in a cooling room which contains approximately 2700 cubic feet. A system of ducts connects this room with the cold storage vault in which the furs are stored, and the air is kept in circulation by means of a blower operated by a $4\frac{1}{2}$ h.p. motor. Brine is allowed to trickle over the ammonia pipes for the purpose of keeping them free from frost, and the circulation of this brine is effected by means of a 1 h.p. motor-driven centrifugal pump. During the winter months this refrigerating plant is not operated, as there are few furs in storage, and the outside air is sufficiently low to maintain these furs in a satisfactory condition. During this period the blower circulates the outside air through the vaults, which are thus maintained at a temperature of about 10 deg. above that of the outside air. After the plant is first started up in the spring, and until it is shut down in the fall, the temperature in the storage vaults is never allowed to rise above 32 deg. F. During this operating period the average temperature is approximately 20 deg. F., ranging from 26 deg. in the early morning to about 14 deg. just before the plant is closed down in the afternoon. From 6 P.M., when the operation of the plant is ordinarily discontinued, until 8 the next morning, when it is usually started again, the rise in temperature is about 12 deg. F. On Monday mornings, after the plant has been shut down over Sunday, the temperature is generally in the neighborhood of 32 deg. F.

While the two foregoing applications of motor-driven refrigerating machines have been described in some detail, it will be impossible in the confines of a single article to more than mention a few of the numerous other applications of motor-driven refrigerating machinery now in common use. Among the more important of these may be mentioned fish and meat markets, dairies, florists, and restaurants. Motor-driven refrigerating plants for cooling drinking water are now frequently met with in our large office buildings, while air cooling, although not done to any extent as yet, offers promising possibilities in the way of a refrigerating load.

Ice Making

As previously stated, several of our larger central stations are now selling electrical energy for ice making. The rate at which such energy is being sold is extremely low on account of the high load-factor which obtains. The rate is based in most cases upon the use of current during "off-peak" periods only, the contract of one particular company specifying that it "shall not be required to stand ready to supply any electricity between the hours of 4 and 8 P.M. from November 1st to March 1st."

The consumption of electrical energy per ton of ice produced usually varies from 50 to 70 kilowatt-hours, including the operation of the compressors, the auxiliary apparatus, and the lighting of the plant, although figures as low as 40 kilowatt-hours have been claimed during certain periods of the year when the condensing water was at a low temperature. The maximum demand, where the plant is of 75 tons capacity or over, usually runs about 2.3 kilowatts per ton of ice making capacity, of which nearly 70 per cent is required for the compressor alone, the balance being used in the operation of the various auxiliaries. The yearly load-factor of a motor-driven ice making plant in the latitude of New York or Chicago will probably average in the neighborhood of 55 or 60 per cent.

Reference has already been made to those processes by means of which ice may be made from raw, or undistilled water. There are a number of such plants either now in operation or in course of construction. In one particular plant of 120 tons capacity located in Chicago, water from Lake Michigan is converted into transparent ice, and the only coal required is that necessary to produce sufficient distilled water to fill the cores left in the center of the cakes when the impurities are withdrawn, which amounts to only some 10 or 15 per cent of the weight of the ice. With the multiple-effect evaporator, the amount of boiler steam that it is necessary to generate in order to produce a given amount of distilled water is very small. In one plant producing 120 tons of raw water ice per day, about one ton of coal is burned daily in the fire box of the evaporator, which is equivalent to an output of 120 pounds of ice for each pound of fuel.

ELECTRIC *versus* GAS LIGHTING FOR MOTORCYCLES

By L. C. Porter

Edison Lamp Works, Harrison, N. J.

The application of electricity to automobile lighting (and incidentally to engine cranking and gear shifting) has been productive of such satisfactory results generally that the possibility of its service in connection with motorcycle lighting naturally suggests itself. The limiting factors here, of course, are weight and bulk; but from the experiments conducted by the author, the problem does not appear to present any material difficulties. In fact, it was found, after a careful search for a suitable battery and lamp, that a satisfactory electric lighting outfit for motorcycles could be evolved which, as regards weight and dimensions, was more desirable than the gas equipments that are now almost wholly in use. Besides the advantages of simplicity, convenience, and a reduction in weight and space occupied by the equipment, the road tests and laboratory measurements demonstrate the decided superiority of electric lighting in the prime requisite, *illumination.*

—Editor.

The popularity of electric lighting that has made such rapid strides on automobiles has extended to the motorcycle field. These small, but speedy machines require a powerful headlight; one which is reliable and safe. Ease in manipulating the lighting unit is as much desired by the motorcyclist as by the more fully equipped autoist. It is estimated that there are now in use, in this country, some 500,000 motorcycles, and this year's production will probably increase this figure by 125,000. Many of these machines are frequently used during the evening, and most of them are at present equipped with gas lights of one form or another.

In reporting these tests, the subject will be treated in three parts:

General advantages of electric lighting.
Road tests.
Laboratory tests.

General Advantages

Due to a wide difference of opinion among riders no definite rule for the requirements of the motorcyclist can be made, but many miles of riding over all kinds of roads and under various weather conditions has convinced the writer that he has a good understanding of the general requirements of a motorcyclist.

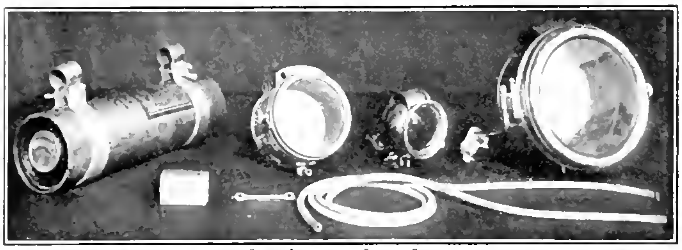
Motorcycles are driven as fast, frequently faster, than automobiles, which fact alone demands a powerful headlight for safe operation. It is necessary for the motorcyclist to see the road as clearly, and nearly as far ahead as the driver of an automobile. It is not necessary, however, for him to see so great a width of road; a headlight covering 6 to 10 feet in width is ample.

A machine equipped with electric lights carries with it numerous advantages which tend toward increasing the comfort of the rider. Two open gas flames, one a few feet ahead and the other a few feet back of two and one-half gallons of gasolene are not very safe, especially in case of accident. With electric lighting, the difficulties of lighting and extinguishing are reduced to the simple turn of a switch. There is no gas tank key to lose; there are no damp matches to wrestle with or shield from the wind. Any rider who has been unfortunate enough to get a puncture on a country road at night will never forget the difficulty experienced in locating and patching the hole by what little light was thrown back of the gas headlight. With electric lighting it is a simple matter to rig up a trouble lamp which can be easily and safely moved around to any desired spot.

Electric lights also permit the use of a small speedometer lamp, electric horn, and other useful accessories—great conveniences—making night riding as satisfactory as day. With compressed gas, there is always a possibility of the tank running empty in places where it is difficult to refill it. On the other hand, there is hardly a country village where dry batteries cannot be obtained. They will operate the electric lights very satisfactorily for many hours, until a place is reached where it is convenient to recharge the storage battery.

The intensity of electric headlights remains practically constant, while to obtain the same result with gas it is necessary to keep continually opening the gas cock as the pressure decreases.

The weight of the lighting equipment is also to be considered. The lighter the machines, the less the wear on tires, etc.



1 2 3 4 5 6 7

Fig. 1. A 4-Inch and a 6-Inch Gas Motorcycle Headlight, and the Necessary Gas Apparatus to Operate Either

1–Gas tank
2–Matches
3–Gas tank key
4–4 In. headlight
5–Tubing
6–Tail light
7–6 In. headlight

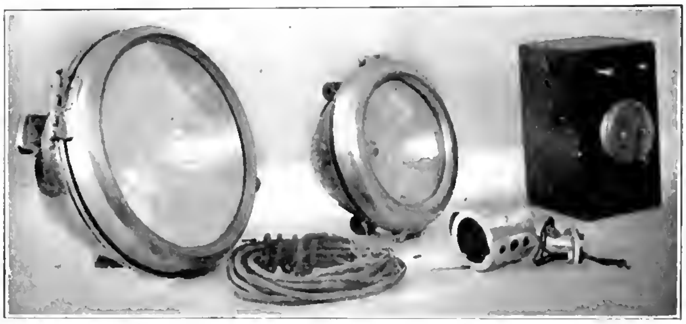
Figures are given later in this discussion which show that the electric equipment is lighter. No electric motorcycle lights were found on the market, but several automobile types can be easily adapted to motorcycle use. Small gas tail lamps can be easily converted to electric by replacing the gas burner with an electric lamp.

The question of current supply is one which for some time delayed the electric lighting of motorcycles. There are, however, several makes of unspillable storage batteries now on the market for this purpose. These are of two types, 4 and 6 volt. The 4-volt batteries are more compact and lighter than the 6-volt, but it is the writer's opinion that the use of a 6-volt battery is well worth the extra space and weight. It enables the use of 6-volt lamps, which can be purchased at almost any garage or electric supply house, while many of these places do not carry 4-volt lamps. One concern has an electric generator for motorcycles on the market; another is working on a combination low tension magneto and storage battery for this purpose. Storage batteries of approximately 10 ampere-hour capacity, 4 or 6-volt (preferably 6) are ample for a week's service, riding every evening, provided a little care is used and the light turned off when not in actual service. This is comparable with the service of a compressed gas tank, operating a $\frac{1}{2}$ cubic-foot headlight burner and a $\frac{1}{8}$ cubic-foot tail light.

Road Tests

Three electric lamps of varying filament concentration but of equal candle-power were placed on the motorcycle, one at a time, and used for headlights at low and high speed, over rough and smooth roads. It was found that the lamp with extreme concentration gave too narrow a beam for satisfactory riding; the bent-back-loop filament, or one of little concentration, gave a beam which covered a great deal more of the road than was necessary; while the screw type, or auto headlight filament, came the nearest to meeting the requirements. It was determined that from 6 to 10 feet of the road should be lighted for satisfactory work. The writer also found that for the best results the center of the beam should be directed on the road 25 feet ahead of the machine.

Having determined the type of filament which gave the most satisfactory results, the next step was to determine the size of lamp necessary. In order to make a thorough study of the subject, various oil, gas and electric equipments were purchased and tried out on an Indian motorcycle under severe conditions. It was found that oil lamps were out of the question for motorcycle use. Even when mounted on the fork of the front wheel they did not give suffi-



1 2 3 4 5

Fig. 2. A $4\frac{1}{2}$-Inch and 7-Inch Electric Headlight, and the Necessary Equipment to Operate Either

1–7 In. headlight
2–Wire
3–$4\frac{1}{2}$ In. headlight
4–Tail light
5–Battery

cient illumination for even slow riding. A well known gas lamp, consisting of a combination lamp and generator, was also tried. It was found that while the light given was sufficient for slow riding, at any speed above 10 miles an hour the beam was not powerful enough to enable the rider to discover obstacles on the road in time to avoid them. Riding on rough roads or striking a bump on an ordinary road would jar down such an excess of water into the carbide that a rush of gas would be generated so great as to make the flame roar, lose its luminosity, and endanger the mirror.

The only satisfactory gas equipment was found to be a headlight operated from compressed gas. With this equipment two sizes of headlights were used, one consisting of a 4 in. Mangin mirror back of a 1/4 cubic foot burner, and the other a 6 in. Mangin mirror back of a 1/2 cubic foot burner. These headlights, with the necessary equipment to operate either, are shown in Fig. 1. It was found that the 4 in. headlight was satisfactory for general urban use, but when it came to high speed work or country roads, the light was hardly powerful enough to be satisfactory. The 6 in. headlight gave an excellent light; however, the flame was so far from a point source that the light spread not only over the road,

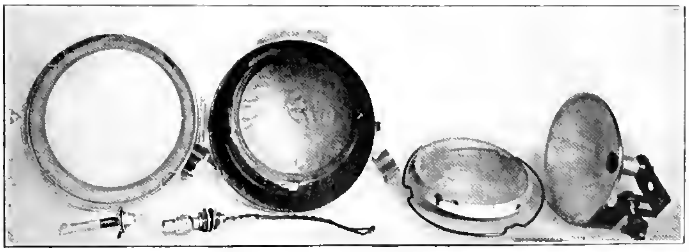


Fig. 3. Gas Lamp Ready for Converting to Electric—with Electrical Apparatus

1–Gas burner
2–Electric socket
3–6 In. gas lamp casing
4–Mangin mirror and retaining wire
5–Parabolic reflector and bracket

but over the ditches as well. If the same volume of light could be concentrated into a beam covering but 6 or 10 feet of the road and be of greater intensity, a much more satisfactory light would result. This is exactly what is accomplished by the electric headlight.

In these tests both parabolic reflectors and Mangin mirrors were used. Lamps of 2, 4, 6, 8, 10 and 16 c-p. were tried. It was found that for slow riding, 2 c-p. lamps furnished sufficient light. For rough roads or high speed work, the 8 c-p. lamps were found to be amply powerful. For general

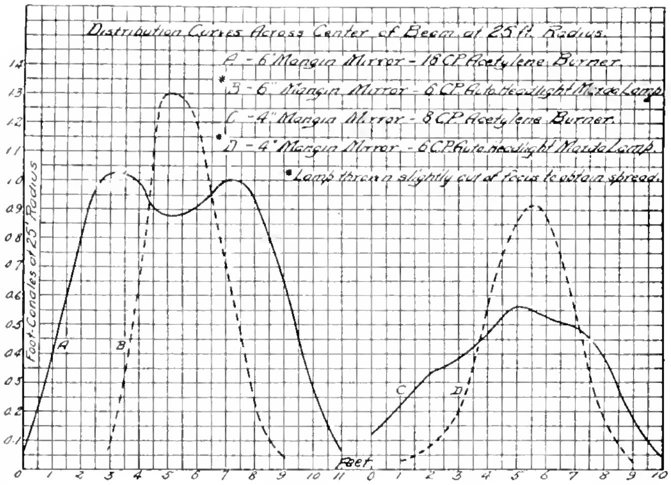
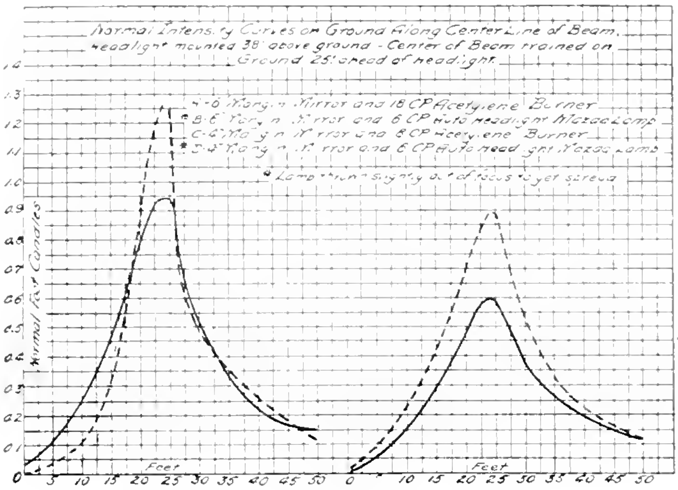


Fig. 4. Curves Showing the Difference of Intensity and Distribution Across the Center of Beam, at 25 Ft. Radius, Thrown by Two Sizes of Gas and Electric Headlights, Using Mirror Reflectors

use, the best lamp was found to be 6 c-p.

There are many gas headlights in use on motorcycles today. In order to determine the possibility of converting these to satisfactory electric lamps, the gas burners in two gas lamps (one equipped with a 4 in. and the other with a 6 in. Mangin mirror), were replaced by lamp sockets. The 6 c-p. screw type filament lamp was used in each case. It was found that with this lamp located at the focus of the reflector, a very powerful but very narrow beam was obtained—one which was too narrow for safe riding. When the lamp was located between the focal point and the mirror, a good spread was obtained, but there was a dark spot in the center of the beam. When, however, the lamp was located a short distance ahead of the focus, a very satisfactory beam was obtained. With both the 4 in. and the 6 in. headlights, beams were obtained which were decidedly better than the gas beams. They were more powerful, and while not having so great a spread, were sufficient for comfortable riding, at the same time being very steady. The 4 in. headlight was found to be sufficiently powerful for



A–Full line curve
B–Dotted curve

C–Full line curve
D–Dotted curve

Fig. 5. Curves of Normal Intensity on Ground Along Center Line of Beam from Two Sizes of Gas and Electric Headlights Using Mirror Reflectors

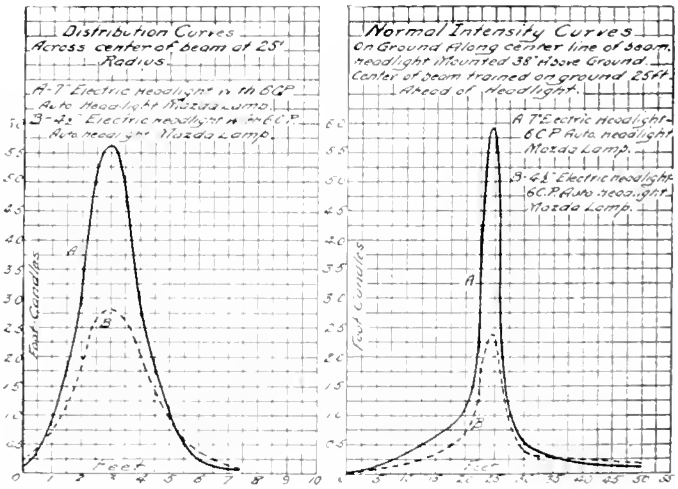
ordinary use, but as with the gas, the 6 in. light was required for high speed or rough roads.

A search was made for an electric headlight for a motorcycle, but none was found. However, two electric headlight lamps were obtained from automobile apparatus. One consisted of a 7 in. parabolic reflector and casing, used as a small auto headlight; the other of a 5¼ in. reflector [only 4½ in. being effective, due to the door covering the edge of the reflector] used for an auto side light. Both of these headlights are illustrated in Fig. 2. The 7 in. reflector equipped with the 6 c-p. lamp mentioned above made a most excellent headlight. It was much more powerful than the 6 in. gas lamp and had ample spread; in fact, this lamp was more powerful than necessary. Equipped with a 2 candle-power lamp, it gave very satisfactory light. The converted side lamp also gave good service.

One prominent manufacturer makes a 6 in. parabolic reflector complete with bracket and lamp socket for converting gas to electric light. This is illustrated in Fig. 3 together with the other parts involved in the conversion. Gas headlights having a 6 in. or larger mirror can be converted to excellent electric headlights by removing the gas burner and mirror, and replacing them with this reflector. This can be done in a few minutes with a pair of pliers. The gas burner is removed from the casing by simply unscrewing the base unit. The mirror is removed by pulling out the piece of stiff spring brass wire shown in Fig. 3. The reflector and bracket can then be inserted and held in a similar manner to the old gas burner. If the rider does not care to purchase the reflector outfit, however, the gas burner can be replaced by an electric socket, obtainable at almost any auto supply house. Such a socket is shown in front of the lamp casing in Fig. 3.

Laboratory Tests

In order to obtain some comparative figures on gas and electric lighting for motorcycles, photometer tests were conducted on both. The gas lamps used were equipped with a 6 in. Mangin mirror and ½ cubic foot burner and a 4 in. Mangin mirror and ¼



Distribution curves across center of beam at 25 ft. radius

Normal intensity curves on ground along center line of beam

Fig. 6. Curves Showing Characteristics of Beam Projected from a 7-Inch and a 4½-Inch Electric Headlight, Employing Parabolic Reflectors

cubic foot burner. Acetylene gas was supplied to these lamps from a compressed gas tank. The flame was turned up as high as it would go without roaring.

The candle-power of the two gas burners alone was measured and then distribution curves were taken. An examination of the data and curves A and C, Fig. 4, shows that the candle-power of the $\frac{1}{2}$ cubic foot burner is 18, while that of the $\frac{1}{4}$ cubic foot burner is 8. The distribution across the beam at 25 ft. shows wide spread with maximum intensities of 1.03 and 0.56 foot-candles. The curves show that the beams are a little uneven. After these, curves were taken from the headlights with the gas burners replaced by the 6 candle-power tungsten lamp. The lamp was thrown sufficiently far ahead of the focal point to give good spread. These curves, B and D, Fig. 4, show that the beam thus obtained is even, and while the spread is not so great as the gas, the beam covers a sufficient amount of the road for safe riding and has a higher intensity than the gas in the center, i.e., directly in front of the motorcycle reaching 1.3 and 0.92 foot-candles.

In order to determine the intensity of light that would be thrown on a stone, the side of a hole, or other obstruction in the road at various distances ahead of the machine, photometer readings were taken on a plane 38 in. below the headlight (the height of the light above the ground when mounted on motorcycle handlebars) with the center of the beam directed on the ground 25 ft. ahead of the light. These readings, curves A and C, Fig. 5, show the normal illumination on an obstruction in the road, from 5 to 50 ft. directly in front of the machine.

Next, similar tests were conducted on the two sizes of electric headlights, each being a parabolic reflector equipped with a 6 candle-power tungsten lamp, one having an effective surface 7 in. in diameter, and the other $4\frac{1}{2}$ in. Curves A and B, Fig. 6, show that the 7 in. lamp has a spread (6 to 10 ft.) sufficiently great for satisfactory riding and throws a beam of nearly five times the intensity of the 6 in. gas or 6 in. gas converted to electric. The $4\frac{1}{2}$ in. electric lamp also has good spread, and is more powerful than the small gas or gas converted lamp.

Fig. 7. Illumination Given by a 6-Inch Gas Headlight, Showing Stones 25 and 50 Ft. Ahead

Fig. 8. Illumination Given by a 6-Inch Gas Headlight Converted to Electric, Showing Stones 25, 50 and 100 Ft. Ahead

Photographs which were taken of the road illumination given by various gas and electric equipments, are shown in Figs. 7, 8 and 9.

The weights of the various apparatus were found to be as follows.

Gas

6 in. gas headlight and brackets...	4 lb. $13\frac{1}{2}$ oz.
4 in. gas headlight and brackets...	2 lb. 7 oz.
Tail lamp and brackets........	$11\frac{1}{2}$ oz.
Compressed gas tank...........	9 lb. $13\frac{1}{2}$ oz.
Rubber tubing.............	5 oz.
Gas tank key.............	$\frac{3}{4}$ oz.
Total with 6 in. lamp......	15 lb. $12\frac{1}{4}$ oz.
Total with 4 in. lamp......	13 lb. 6 oz.

Electric

7 in. headlight and brackets	4 lb. 6 oz.
$4\frac{1}{2}$ in. headlight and brackets	3 lb. 10 oz.
Tail lamp and brackets	5 oz.
6-volt, 10 amp-hr. battery	$11\frac{1}{2}$ lb.
4-volt, 10 amp-hr. battery	7 lb. 9 oz.
Wire	4 oz.
Switch	1 oz.
Total with 7 in. lamp and 6-volt battery	16 lb. 8 oz.
Total with 7 in. lamp and 4-volt battery	12 lb. 9 oz.
Total with $4\frac{1}{2}$ in. lamp and 6-volt battery	15 lb. 12 oz.
Total with $4\frac{1}{2}$ in. lamp and 4-volt battery	11 lb. 13 oz.

The space occupied by the various equipments was also measured, and found to be considerably less for the electric outfit, the storage battery occupying about one-half the space required by the gas tank. The headlight occupied nearly the same space; the electric tail light considerably less.

Fig. 9. Illumination Given by a 7-Inch Electric Headlight, Showing Stones 25, 50, 100 and 200 Ft. Ahead

Conclusions

As a result of the tests, the writer draws the following conclusions: Electric lighting is very satisfactory; it enables the user to obtain a powerful headlight, giving a steady beam, no matter how rough the road; the beam does not fall in intensity, as does that of a gas lamp, which requires continual opening of the valve; no matches are required, and there is no gas tank key to lose; the lamp can be easily focused to give a long, powerful beam for country use, or a wide spread at lower intensity in the city. Electric lighting can be controlled by the simple turning of a switch; it enables the use of a small tail lamp, a speedometer lamp, and a trouble lamp, the latter being of great service; it enables the use of a small electric horn; the storage battery can, if necessary on a long trip, be temporarily replaced by dry batteries, which are obtainable anywhere.

The operation of electric lighting is very much more convenient than that of gas. The space occupied is less, meaning a neater equipment. Very satisfactory electric outfits can be obtained with little trouble and but slight expense where gas is now in use, by simply replacing the gas headlight burner with a 6 candle-power electric lamp and socket, the gas tail light burner with a $\frac{1}{2}$ candle-power tungsten, and the gas tank by a small storage battery. Where new outfits are purchased even more powerful headlight lamps can be obtained.

CAUSES OF VOLTAGE VARIATION IN THE OPERATION OF LIGHTING SYSTEMS

By J. J. Sullivan

Edison Lamp Works, Harrison, N. J.

The maximum degree of satisfactory service is obtained from a lamp when it is burned at its highest efficiency, and for this condition an unvarying "label" voltage is the principal requirement. This article states in a clear and brief manner the causes of unsatisfactory voltage supply and points out where in the system, from generator to lamp, the sources of trouble occur.—Editor.

The importance of operating lamps at high efficiency has frequently been pointed out. The relation that exists between lamp efficiency and operating conditions is primarily a matter of voltage. It will be found that in a large majority of central station systems wrong voltage conditions exist, the causes of which may lie (1) in plant operation, (2) in the distributing system, and (3) in the wrong selection of lamps for the socket voltage.

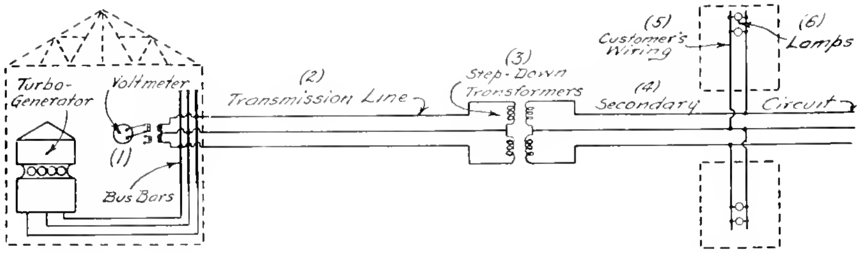


Fig. 1. Diagram of Distributing System with Possible Causes of Wrong Voltage Indicated

Plant Operation

In stations employing slow speed prime movers belted to high speed generators, a fluctuation in voltage may be found. In all stations where the prime movers are belted to the generator, any belt slipping produces periodic changes of voltage, the degree of which varies with the belt slip. In modern stations very little voltage trouble can be charged against the generating apparatus, owing to the excellent design of the governors, whereby almost constant speed is maintained.

Switchboard instruments are very often responsible for wrong voltage conditions. Chief among these is the station voltmeter. The voltmeter is the judge of the lighting service and if it reads incorrectly it will have a detrimental effect on central station revenue and service. Error in the voltmeter reading may be due to one of two causes: (1) the instrument may be out of calibration, and (2) the potential transformer that supplies the voltmeter may be overloaded. Potential transformers are designed to carry a load of 50 watts; and to them are connected the voltmeter, the potential circuit of the wattmeter and the power-factor meter. Sometimes it happens that a pilot lamp or gauge lamp of 60 watts or more is connected to a potential transformer, thus overloading it. A potential transformer so loaded delivers a decreased voltage at the secondary terminals to which the voltmeter is connected. Overloading a potential transformer consequently causes the voltmeter to read incorrectly.

Distribution System

Voltage drop in the distributing system is due to two causes, ohmic resistance and load. The voltage drop in transmission systems varies with the length of the conductor; i.e. the greater the distance of transmission the greater the voltage drop for a given sized conductor. The diameter of a conductor must be large enough to transmit the load at a voltage drop not exceeding 2 per cent. The greatest losses in the transmission of energy are cases of primary line drop. As the greatest drop is caused at the period of peak load, it is of the utmost importance that voltage readings be taken during this period, which is generally between 5 and 10 p. m.

Wrong voltage conditions are very often produced by step-down transformers. Sometimes the ratio of transformation is incorrect, thereby producing wrong voltage conditions on the secondary circuit, but in the majority of cases it will be found that the transformers are overloaded, as there is a great tendency to add new customers to existing transformers until they become overloaded. The secondary circuit itself may present wrong voltage conditions, due to insufficient copper to carry the necessary load. Besides the voltage drop in the secondary circuit, there is a further drop in the customers' premises, as there is a tendency to add more lamps to the circuit without increasing the amount of copper.

A very common cause of wrong voltage conditions is in unbalanced three-wire systems. In plants supplying three-phase alternating current, or three-wire direct current, excessive voltage drop may exist, due to unbalanced load. If the load on one phase becomes greater than the other, the voltage on the loaded phase decreases, while that on the other may be increased. This may be due (1) to an unequal distribution of the number of lamps on each side of the system, (2) to the installation of a constant current transformer with its constant current lighting system on one phase, and (3) to the installation of alternating current motors.

Lamp Voltage

In general, it will be found that lamps are ordered with a label voltage from 2 to 4 volts higher than the socket voltage of the installation. This is one of the principal causes of the wrong voltage conditions in lamp operation and is called under-voltage burning.

Voltage Surveys

In carrying out voltage surveys, it is important first of all that the central station voltmeter be calibrated to read correctly and that the voltage at the busbars be maintained constant by an attendant or automatic regulator. Voltage drop on the primary lines can be obtained only by taking voltage readings at different points along the line. It can be calculated if the length and diameter of the conductor and the current transmitted are known. The drop in the secondary circuit can be obtained by taking voltage readings as near the secondary of the transformer as possible, and at intervals along the line to the end thereof. If the secondary voltage drop is found to be 4 or 5 per cent it is an indication that the line is overloaded. The drop in the customers' wiring can be obtained by taking voltage readings at several sockets with all the lamps lighted, and then taking voltage readings at the same sockets with the lamps turned off. If the voltage drop exceeds 2 or 3 per cent, it is an indication that the customers' wiring is insufficient to carry the current. The operation of large motors on lighting circuits should be discouraged, and it is advisable that the power load be separated from the lighting load. Lamps should be inspected to see that their label voltage corresponds with the voltage of the circuit. Diagrammatically, Fig. 1 shows the different parts of the central station distributing system and the causes of wrong voltage

EUROPEAN VS. AMERICAN PRACTICE IN LIGHTNING ARRESTERS

By E. E. F. Creighton

Consulting Engineer, General Electric Company

Practice in lightning arresters in Europe and America has developed along somewhat different lines. In America some of the European practice has been used. In Europe a considerable number of arresters, especially of the aluminum cell type, have been installed; some of which have been built in America, and others in Europe—probably most of them in Europe. The aluminum arrester was developed entirely in America by the author. Its success depends much on the care in manufacture, especially if charging resistances are not used. The same degree of satisfaction has not been found in Europe as in America; and this has apparently produced there a wave of preference for the resistance type of arrester. The object of the present paper is to compare the several forms of arresters that are used in Europe, and not in America; and the term "European practice" is convenient to cover this field as distinct from the practice used in America. The paper deals with lightning arresters, specifically, and no other forms of protective apparatus, such, for example, as are used in selective switching and line protection.—Editor.

In order to compare European and American practice, an endeavor will be made below to describe the difference in the several features involved in the apparatus. The American practice has been worked out mostly by a small group of engineers with excellent research facilities, and consequently it is very much more clearly defined and more consistent than European practice. The term "European Practice" is used as a convenience to cover all the various arresters in use there and not in America. Some of the European engineers have expressed their aversion to horn gaps without series resistance as strongly as has been done by American engineers. They stand for a series resistance and much of it. Other European engineers

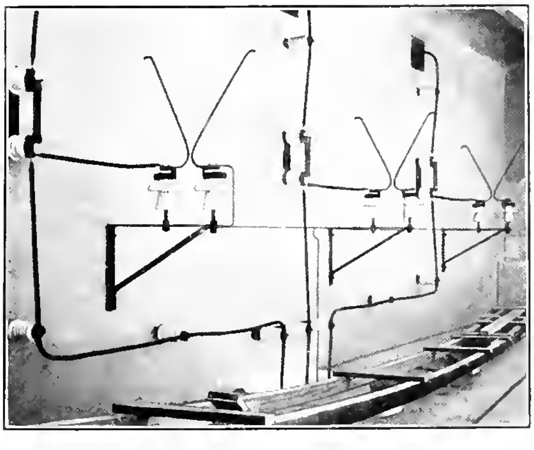


Fig. 1. Main Horn Gaps and Fuses of a European Type Lightning Arrester Installation Located in Mexico

advocate the use of aluminum arresters. Still others, in the minority, favor none of these practices but advocate the use of condensers. In both Europe and America there are a few freak devices advocated for protection. These dreams belong to the land of poets. The claims can not be substantiated scientifically and need no serious consideration in this article. The writer is naturally much more familiar with American practice as a whole, although he has conducted investigations on every form of European device herein treated.

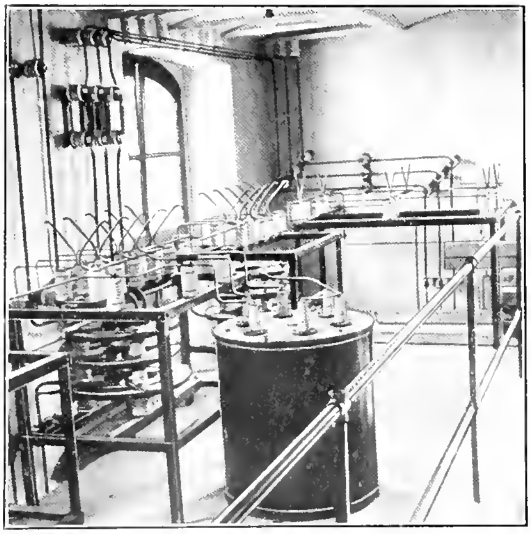


Fig. 2. Main Floor Arrester Equipment of the Mexican Plant. Multiple horn gaps and choke coils at the left, delta connected horn gaps at the right, and oil tank containing resistance in the foreground

European Practice

Nearly all the familiar features of European practice are involved in an installation of a 13,200 volt arrester in Mexico, and we have therefore selected this installation for discussion. Photographs of the arrester are reproduced here. The practice involves the following elements:

First: Horn gaps from each phase to ground. These gaps have a comparatively large gap setting and there is no resistance placed in series.

Second: Delta-connected horn gaps with comparatively large settings connected line to line without series resistance (although series resistance might be employed).

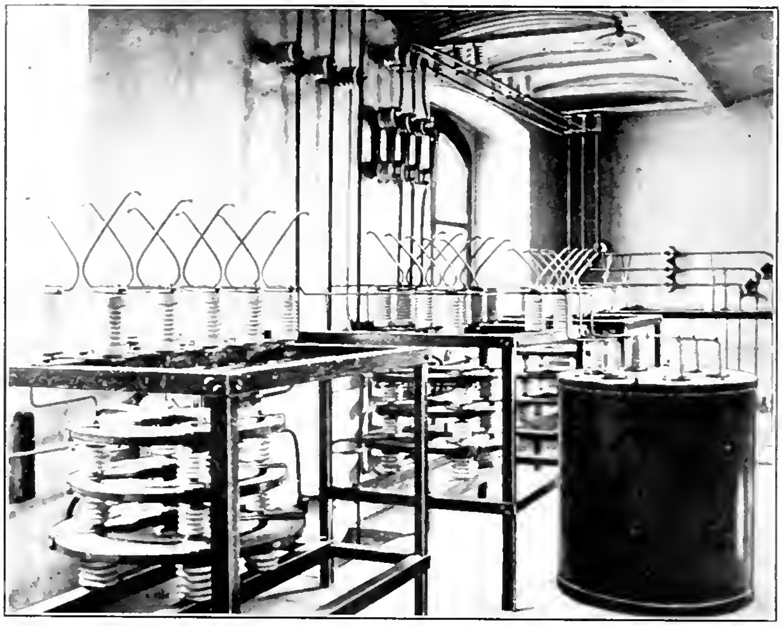


Fig. 3. A Nearer View of the Equipment Shown in Fig. 2

Third: Y-connected horn gaps with moderate settings and with enough resistance in series to limit the dynamic current to a range of 3 to 12 amperes, according to the judgment of the designer. It is usually considered that the best design of the resistance is that of wire immersed in oil. Water boxes have, however, been used, and in a few cases, composition resistance of different kinds.

Fourth: Multiple horn gaps connected between a number of series choke coils in the line. The apparent object of this multiple horn is to catch the maximum peak of potential, no matter where it occurs along the inductance offered by the choke coils. Another way of stating this condition is to say that the taps on the choke coils correspond to different frequencies on the line.

Fifth: The water jet lightning arrester. This lightning arrester consists of a solid stream of water which connects each line to ground. There is in the circuit of this water jet an ammeter which registers the very low current that is sent through the water, usually about 0.1 amp.

Sixth: There is another form of lightning arrester not shown in this particular Mexican installation. It consists of electrostatic condensers placed between line and ground. The chief advocates of the condenser protector use glass tubing as an insulator.

The first five of these elements are illustrated in the accompanying photographs. Fig. 1 is a photograph of the main horn gaps, which are located in the second story of the building. In the circuit between each entrance lead and the horn gaps a fuse is placed.

In the background of Fig. 2 may be seen the horn gaps connected delta on the circuit.

The oil tank in the middle, and the multiple horn gaps and choke coils on the left are a little more clearly shown in Fig. 3. Of the group of horn gaps in the left of the picture, consisting of five pairs, there is one which connects directly from the line to one of the resistances in the oil-filled tank at the right of the picture. The other four gaps are

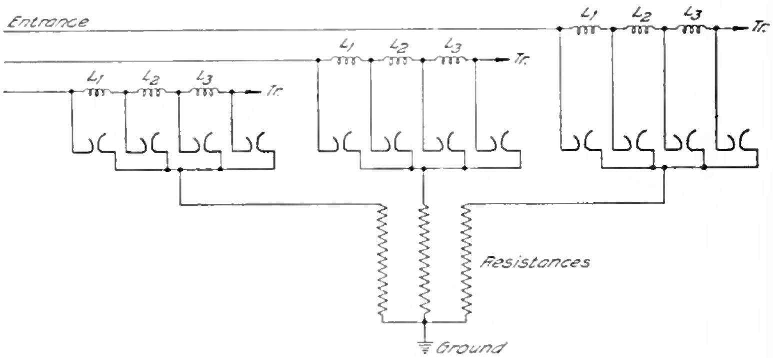


Fig. 4. Diagram of Circuit Connections of Apparatus Illustrated in Figs. 2 and 3

tapped off from the choke coils, of which one set of three are shown in the rack underneath the group of horn gaps already described. The circuit connections are illustrated in Fig. 4. Just to the left of the disconnecting switches in Fig. 3 the three leads from the entrance in the second story pass vertically down through the floor to the basement.

In the basement of the building the water jet lightning arresters are placed. A general view is shown in Fig. 5. At the upper central part of this picture is shown an ammeter which registers continuously the leakage current through the water jets to ground. A tank with three pipes projecting down from it is shown at the upper part of the picture. The tank is fed by a pipe which is partially visible

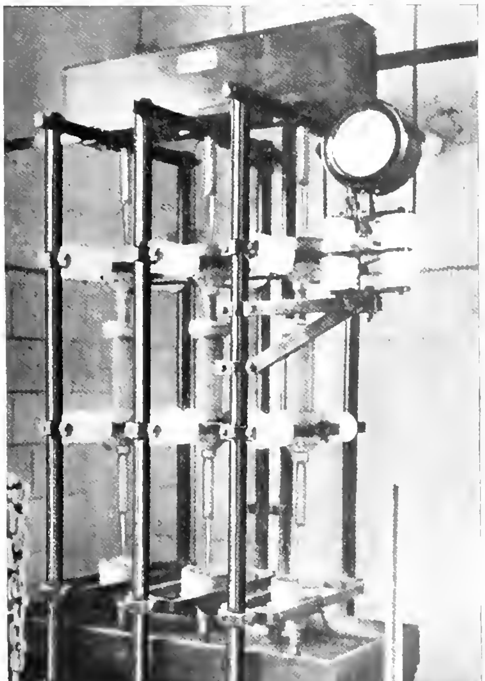


Fig. 5. Complete View of Water Jet Arrester with Indicating Ammeter, Located in the Basement of the Mexican Plant

in the picture. In this case it was not necessary to pump the water because a running stream was available. It was necessary only to maintain the level of the water in the tank. The water jet passes into three receptacles of insulated metal, each of which is connected to a phase. The water then flows in another stream from the line receptacle into a common tank shown at the bottom of the picture.

Fig. 6 shows a nearer view of the arrangements of two intermediate receptacles and two water jets.

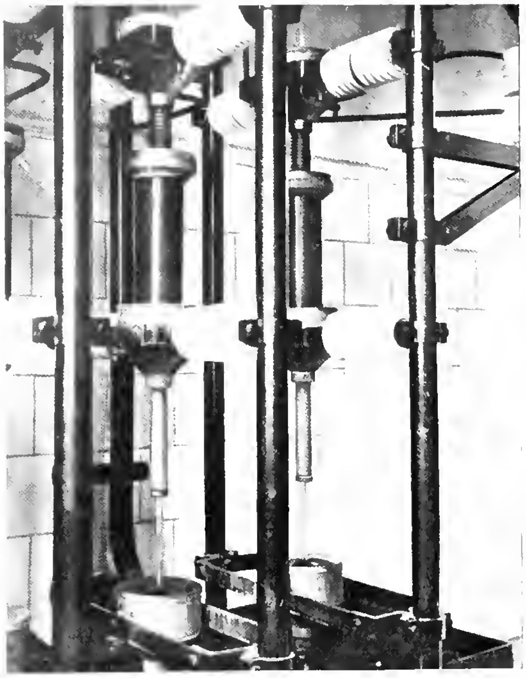


Fig. 6. Near Partial View of the Water Jet Arrester

Fig. 7 shows the diagram of connections of all the protective devices. These pictures, as already stated, cover the general practice used in Europe, except for the glass condenser. The usual form of this condenser is that of long glass tubes closed at both ends. The plates on these tubes are so arranged as to give no appreciable edge effect where corona is liable to take place. The property which gives protection seems to be entirely that of electrostatic capacity.

American Practice

The American practice in the protection of power circuits consists in the main of three devices: First, the aluminum arrester; second, various forms of the multigap arrester; and third, surge protectors and high frequency absorbers. The essential theoretical features of the aluminum arrester are shown in Fig. 8.

Fig. 9 is a picture of a typical installation of aluminum arresters for 13,200 volt circuits.

This picture is to be compared to the Mexican installation shown in Figs. 1 to 7 inclusive.

Fig. 11 shows the connections of the standard multigap arrester for medium and low voltages.

Fig. 12 is a photograph of the compression chamber arrester, which is the latest development of the multigap arrester reduced to its simplest form and lowest cost of manufacture.

In the matter of surge protectors the practice has been well developed but is not yet in wide use anywhere. It was necessary to eliminate high potential disturbances on the line before it was possible to determine definitely the need of a surge protector, although surge protectors had been used. The subject of high frequency absorbers is brought up at the present time more as a matter of pointing out its relations to arresters and its particular functions rather than to compare it with European practice.

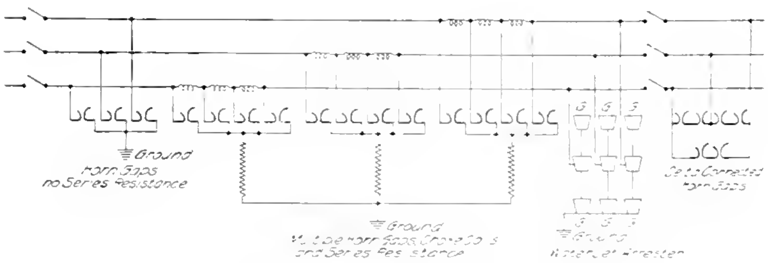


Fig. 7. Complete Diagram of Connections of the European Protective Apparatus Used in the Mexican Plant

Space Occupied by Arresters: American and European Practice

The subject of space occupied by electrical apparatus in general is receiving the critical attention of engineers. The cost of housing apparatus is considerable and, even with compact apparatus, there is a tendency to place the apparatus outdoors. The most obvious criticism of the complete horn gap practice, as shown in the pictures of the Mexican installation, is that of the space occupied, and consequently the cost of housing. This installation of horn gap arresters is for only 13,200 volts and the horn gaps are very much closer together than they could be if used outdoors. There are at least two reasons for this, first, in outdoor installations a considerably greater spacing between pairs of horns must be allowed in order to prevent arcs from one horn gap being blown into another by currents of air; second, the skirt type of insulator must be used in outdoor installations to keep dry surfaces between line and ground.

As the matter stands, an idea of the relative space of the European and American installations can be gained by comparing photographs of Figs. 1, 2 and 5 with the American type of aluminum lightning arrester shown in Fig. 9. While the European apparatus occupies three floors and is necessarily spread out over a large floor area, the American installation is confined to one floor and occupies an approximate space of 7 ft. by 3 ft. with a height of 8 ft. An estimate of the relative volumes is given diagrammatically in Fig. 10. The ratio of volumes is 10 to 1.

If space is going to be saved by the European practice in lightning arresters it must be saved apparently by not using certain forms of arresters. In many cases only part of the complete installation has been used as lightning arrester protection. A criticism of each part will be made further on.

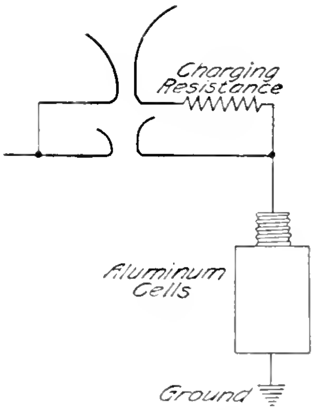


Fig. 8. The Essential Theoretical Features of an Aluminum Arrester

Comparison of Costs of Arrester Installations

In comparing the two installations as already described it is evident that the aluminum arrester will have the lower cost. Although the actual horn gaps may not be intrinsically expensive, their installation by inexperienced men makes the labor item high. Arresters that can be completely built in the factory by men who are making thousands of them have a minimum of labor cost in their construction. The labor of installation is usually less also because the construction has all been done in the factory. There are some parts which are the same in both European and American arresters. An aluminum arrester contains a metal tank and a large quantity of oil, which are duplicated in the resistance-horn gap arrester. The American practice includes the rod form of resistance, which may be considered as equivalent in cost to the wire resistance used in the European practice. This leaves the difference in cost in the part of the arrester located in and about the tank in favor of European practice, since the aluminum cones have no equivalent in European practice. However, when it comes to the horn gaps American practice is simplified to the use of a total of three sets of horn gaps having two gaps per phase. The European practice, shown in the Mexican installation, includes 21 horn gaps, which will be of very materially greater expense than the American horn gaps. In addition twelve choke coils have been used. It might be considered unfair to compare the American practice of using three choke coils with the European practice of using twelve choke coils. Some of the European engineers make greater claims for the four choke coils per phase than can be accomplished by a single choke coil. The necessity for the use of the twelve choke coils may very properly be questioned, although there is no doubt that certain things can be accomplished with four choke coils per phase that cannot be accomplished with a single choke coil per phase. This subject of choke coils will be treated in more detail further on. As the matter stands the European practice calls for four flat-wound choke coils per phase, which have a relatively much greater cost than the single choke coil used in American practice. In the American practice both the flat type choke coil and the solenoid type are in current use, one group of manufacturing engineers favoring one type, and another group favoring the other.

Fig. 9. Complete Three-Phase American Type Aluminum Arrester with Charging Resistance for a Non-Grounded Neutral Circuit

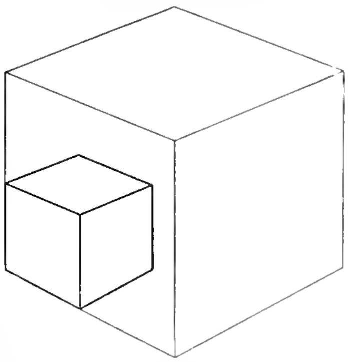


Fig. 10. Diagrammatic Representation of the Volumetric Space Required by an American Arrester (small cube) Contrasted with that Required by the Equivalent European Arrester (large cube)

In addition, the European practice calls for water jet arresters, which in themselves have a very considerable cost, and in addition there is often the operating expense of the running water. Taking into account the cost of the apparatus plus the cost of housing, the complete European practice in horn gap arresters is much more expensive than the corresponding American practice using the aluminum arresters.

A Critical Expression of the Value and Use of the Different European Arresters

In comparing the details of European with American practice, each subdivision of European practice will be criticised in sequence to bring out its good and bad points, and later, to show its relations to American practice, where nearly all the features are involved in one compact form. The six subdivisions under which we will consider the subject are: (1) Y-connected horn gaps without series resistance; (2) delta-connected horn gaps without series resistance; (3) Y-connected horn gaps with medium values of resistance in series; (4) the use of vertical horn gaps connected between a number of series choke coils in the lines; (5) the water jet lightning arrester; and (6) condensers as protectors. This discussion will be followed by a brief summary of European practice and a comparison with American practice. The present instalment will take up the first of the foregoing six subdivisions, while a consideration of the remaining five, together with the summary, will appear in the following issue of the REVIEW.

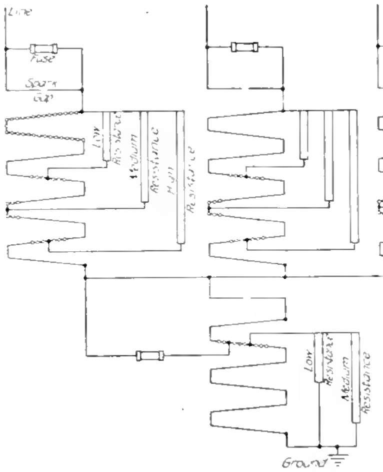


Fig. 11. Diagram Showing the Standard Connections of a Medium and Low Voltage Multigap Arrester

First: Y-Connected horn gaps without series resistance:

It is technically inadvisable that horn gaps without series resistance should come into operation except for extremely high and dangerous potentials. In consequence, the gap setting is usually very large. Just how large it should actually be is somewhat regulated by attending conditions, and exactly the best value is usually unknown. For illustration, if the horn gap without series resistance is the only arrester used, the gap setting must be considerably below the dielectric strength of the insulation of the apparatus, if good protection is to be obtained. Frequent lightning discharges approaching in potential the dielectric strength of the insulation of the apparatus will in general cause successive deterioration of the insulation. Although the horn gaps with the large setting would apparently be giving protection, the damaging effects would not be known until some later period. Therefore, the engineer who determines the gap setting for these horn gaps should know the characteristics of the insulation that is to be protected, and should set the horn gaps within the disruptive voltage that is safe for the insulation. It is sufficient to say that no operating engineer could be in a position to determine this gap setting, because it is only with the greatest difficulty in the laboratory that the characteristics of the different materials in resisting disruptive discharges can be determined. The user or designer of such an arrester must set the gap at a length which corresponds to not much more than double the line to line voltage. If, on the other hand, the horn gaps without series resistance are used in their normal manner, that is, as emergency relief for other horn gaps having limited series resistance, then the main horn gaps can be set much higher, and will give the desired protective conditions. In that case the horn gaps with series resistance relieve the line of all the minor abnormal charges.

Having considered the matter of protection, the next subject will be that of the effects of the operation of horn gaps without series resistance. If two or three of these horn gaps are caused to spark over simultaneously, there results on the system a dead short circuit. The minimum time occupied by the short circuit arcs to rise on the horns, unaided by any blowout device, may be taken as one second. The time is often considerably more, especially if the arcs strike back. One second, however, is sufficient to throw out of step nearly all synchronous apparatus. One second of short circuit is also sufficient to start the operation of an inverse time limit relay with the usual setting, if such relays are used in the station. The short circuit arc may often hold long enough to cause time limit relays to operate oil switches. In every case when the short circuit arcs cause a tripping of the oil switches, an undesirable interruption of service results. In other words, interruption of service frequently results from the operation of horn gaps without series resistance. This is a beggarly solution of an important problem.

From a standpoint of mechanical strains, a short circuit on electrical apparatus is exceedingly undesirable. As the amount of power on a system is increased, these mechanical strains become more and more formidable. Short circuits have been known to tear transformer coils to pieces, and mingle the turns in one mass. Even under the best conditions of mechanical construction, it is undesirable to place excessive mechanical strains on coils that are necessarily held by insulating material of comparatively weak mechanical strength.

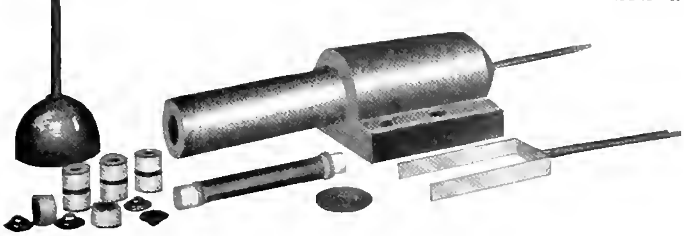


Fig. 12. Exploded View of Compression Chamber Arrester

On the favorable side of the horn gap without series resistance, it may be stated that the absence of series resistance allows an unobstructed flow of the lightning current from line to ground, which is so essential in cases of direct stroke. It should be noted, however, that this relief comes into existence only after the potential has risen to a value high enough to jump a large gap setting, which is already in the region of danger for the apparatus. Furthermore, the action of the dielectric spark lag of this large gap allows the lightning charge to run along the conductors beyond the gap into the apparatus. The impact of this charge which goes into the station apparatus is not relieved by the discharge of the horn gap. The charge that goes into the apparatus comes to its maximum potential, and the current reverses in direction before the charge can flow out to the horn gap. If the horn gap has now been bridged the charge can flow to ground, and the horn gap thus relieves the insulation from a second impact. Plain horn gaps thus may be considered simply as an emergency device which should be called into use only on rare occasions when the conditions are so bad that none of the other protective apparatus suffices.

In order to decrease the time of short circuit during the operation of the horns, fuses have been used in series with the horn gaps in some cases. These series fuses have advantages and disadvantages. First of all, an advantage lies in the fact that a fuse can be used which will clear the circuit much quicker in general than the horn gaps alone. Since the fuse wire does not have to carry power current, a wire of small diameter may be used. On the other hand, such horn gaps are brought into use mostly by the presence of a storm directly over the station, and in such a contingency there is liable to be a second heavy discharge near the station before the fuse can be replaced. If there were no other way of solving this problem, horn gaps alone, or horn gaps with fuses, might be temporarily acceptable.

Oscillations set up by operations of horn gaps without series resistance: It has already been stated that when two or more horn gaps discharge, a short circuit occurs with a resultant heavy current surge. This heavy current surge does not, in general, involve potentials very much above normal. Usually the potential is far below normal. When, however, the short circuit arc is interrupted there is a possibility of high potentials resulting. If the short circuit current gradually diminishes to zero no resultant high potentials will be induced. If, however, due to some accidental condition of air currents or explosive action of the arc at the horns, the heavy current is suddenly extinguished, there will result a high electromotive force in the generating apparatus. The initial value of electromotive force will be distributed throughout the generating or transforming apparatus, in direct proportion to the inductance of the parts of the apparatus. For example, each coil will generate an electromotive force depending upon its inductance. An exact value of electromotive force is found by multiplying the inductance by the rate of change of current. It is found, in general, that this electromagnetic kick from the apparatus and intervening circuits will seldom cause harm because an arc can be reestablished at the horns. In fact, damage by surges resulting from the interruption of a short circuit have not been distinguished from the effects of mechanical strain between the wires of the coils. If a breakdown occurs between turns, it is often impossible to determine whether it was due to a mechanical movement of the wires—a crushing together by the electromagnetic forces—or an actual potential strain. So far as the first impulse is concerned, the experimental evidence indicates very little chance of damage by excessive potential. The greater possibility of damage comes from the oscillations which follow the interruption of the short circuit arc. Should these oscillations not strike a frequency which resonates with some part of the circuit, the possibilities of damage from high frequency potentials is relatively small. There is one important feature in regard to short circuit conditions, and that is the tremendous energy which is stored up in the electromagnetic field of the short circuit. This energy is considerably greater than the energy stored up in a line in the form of an electrostatic charge induced from a lightning cloud. The difference between the two, however, is usually counterbalanced by the fact that the lightning charge has the greater power.

The greater danger from surges when horn gaps without series resistance are used comes from the possibility of having one gap only discharging to ground. It happens not infrequently that lightning will cause a single gap to discharge. This has been shown many times by telltale papers in the gaps of lightning arresters. If a single horn gap arcs to ground there exists the most vicious form of arcing ground, that is to say, an arcing ground with a gradually varying length of arc. If resonance on the line is to be caused by an arcing ground, the varying arc length gives the most favorable conditions for producing it. The oscillations set up by these arcing grounds are usually more dangerous to insulation than lightning itself. How much arcing will take place when a single horn discharges to ground will depend upon the total capacity of the system. If the total length of line is comparatively small the capacity to ground will be correspondingly small, and there will not be enough current from the capacity of the lines to maintain an arc at the horn gap. As the total length of line increases, the capacity current will increase correspondingly, and the arc at the horns will become correspondingly larger. Strange to say, the possibility of damage does not increase directly with this value of capacity current. The possibility of damage passes through a maximum for a given length of line and a given circuit, and for any further increase in the circuit the possibility of damage diminishes, although the arc at the horns becomes of larger volume. This is due apparently to the fact that the natural frequency of the system is continually decreasing as the capacity is increased, and there is less liability that the lower frequency will fall in resonance with a localized frequency of a transformer or transformer coil. If the combination of power reactances and other inductances in the circuit bring the natural frequency of the total circuit within the range of the fundamental frequency of the generator or its harmonics, another danger region will be reached for the value of current in the arcing ground. It should be noted that there is always more or less of single arcing ground effect, even when two or more horns discharge simultaneously. The three horns have currents which are out of phase with each other, and naturally the arcs will be extinguished successively. This will leave one arc to be extinguished after the others have been extinguished, and will thus be a single arcing ground. It might be well here to answer the question that is often brought up:—How may we have an arc at the horn without setting up bad oscillations? When the current from a single phase to ground is limited by resistance so that it is less than the full grounding current, then the phase which is arcing to ground will not be reduced to zero potential. As a matter of fact, a considerable fraction of the total grounding current of one phase to ground may pass over a horn gap without greatly diminishing the potential of that phase toward ground. This condition results from the fact that the electromotive force drop across a resistance is at right angles to the electromotive force drop across a series condenser, and therefore, a considerable decrease in resistance can take place before the potential across the condenser, which is the capacity of the other two-phase wires, diminishes.

QUESTION AND ANSWER SECTION

The Q. and A. Section has been started with the sole object of increasing the practical usefulness of the REVIEW; and in order that it may be made of real value, we invite correspondence from any of our readers who are looking for information on any technical matter in the field covered by this magazine, and which they think we can furnish.

Where possible the answers to such inquiries will be the work of this office; where desirable we shall obtain our authority from that engineering or commercial party in the General Electric Company's organization best fitted for handling the particular subject. We hope our readers will not hesitate to avail themselves of the expert engineering opinion which should be made available through this section of the REVIEW. Information on matters of general importance and interest will be published here; questions of interest solely to the querist will be handled by mail.

Sketches should accompany questions in all cases where this is necessary to give us complete and accurate information on the point at issue. Scale drafts will be made up here from correspondent's rough pencil sketches Questions must be accompanied with the name and address of the sender, although these will not necessarily be for publication, and should be addressed to the Editor, Q. and A. Section, GENERAL ELECTRIC REVIEW, Schenectady, N. Y

FREQUENCY-CHANGER SETS

(51) What are the relative advantages or disadvantages of synchronous motor-driven and induction motor-driven frequency-changer sets for tying-in two systems, each of about equal capacity but several times larger than the frequency-changer sets: first, when the sets are not reversible, second, when the sets are reversible?

We have gone to considerable pains to obtain a useful written discussion of this question; but have found, of course, that, while there is no lack of operating experience concerning synchronous motor-driven sets, there is comparatively little known of the behavior of induction motor-driven units, used for tying together two a-c. systems of different frequency and considerable capacity, and possessing the flexible reversing feature. We shall greatly appreciate receiving advice along this line from any of our readers in the operating field whose work has brought them into actual contact with such cases; up to the present we have found no one who has had to handle the situation. We have nevertheless received some very interesting letters on the behavior, and general suitability, of synchronous motor-driven frequency-changer sets, giving us the results of the experience of a number of prominent operating men, as well as their *opinions* regarding the manner in which the induction motor sets are *likely* to operate. Mr. Sprong, of the Brooklyn Edison Company, not only gave us his own views at considerable length, but also very kindly put us in touch with the operating staff of several other companies. To him and to them we owe our very warmest thanks for the service they have done us; and we hope that we may be able to publish here the views of other engineers who have studied this frequency-changer question. There is no doubt of its importance in the lighting field to-day.

Mr. Severn D. Sprong advised us that he was handicapped by the indefiniteness of the question; and that, although on the lines of the Brooklyn Edison Company there were frequency-changer sets of both these classes, i.e., some driven by induction motors and some by synchronous motors, the conditions were not such as would provide the basis of any complete answer to the question.

"The problem seems to assume two independent generating systems, one of 25 cycles and the other of 60 cycles. These are to be tied together by frequency-changer sets, and the question seems to be which type of motor would be preferable. With a synchronous set, the only commercial speed giving proper frequency at both ends of the set is 300 r.p.m. with a 24-pole 60-cycle machine, and a 10-pole 25-cycle machine. Such a set will obviously transfer energy from either system to the other. On the other hand, an induction set should preferably be of 375 r.p.m.—the 60-cycle generator having 20 poles and the induction motor 8 poles. At synchronism, this would give 25-62½ cycles, thus allowing sufficient excess frequency on the 60-cycle end to make up for the slip of the induction motor. Such a set of modern design will run at about 25-61 cycles; and, of course, will transfer energy from the lower to the higher frequency under these conditions, but will not reverse until the 60-cycle end reaches about 64 cycles to allow for positive slip.

While the Brooklyn system has never had to meet the double-system condition and it is extremely rare in practice, I did, however, have experience with this problem while with the United Electric Light & Power Company of New York City. The United Company had a 60-cycle steam generating station, and operated it in multiple with the 60-cycle end of induction motor-driven frequency-changer sets, supplied with 25-cycle current from the Waterside stations of the New York Edison Company. These frequency-changer sets were in sizes of 500 and 1000 kw. each, and the motor had a wound rotor with slip rings and a regulating grid resistance for speed control through a range of about 4 per cent. However, it was never required that the frequency-changer sets reverse, that is, transfer energy from the 60 to the 25-cycle systems; and, therefore, we had no means of knowing how they would operate under such conditions. In the regular way they did operate with entire satisfaction and gave no trouble whatever from the fact that two primary systems were tied together through the frequency-changer sets. The 60-cycle steam generator capacity was about two to one in ratio to the frequency-changer sets.

Speaking generally, I would not hesitate to supplement a 60-cycle generating system by means of induction motors. Under these conditions, and provided the motor has a liberal regulating range, there is no difficulty in bringing the set up to synchronism and adjusting for full-load at such speed as may be required. The frequency-changer sets will gradually equalize with the 60-cycle system and carry their share of the load without too frequent adjustment. With synchronous sets, however, the problem would be quite different, and I believe would offer serious difficulties in every day operation if the two systems were of relatively large capacity compared with that of the frequency-changer sets. I refer, of course, to the fact that they would act as an inflexible mechanical lock between the two systems, requiring that the latter be synchronized when tying together rather than that the one machine of the frequency-changer set be synchronized with the system. A possible solution of this is perhaps offered in using a synchronous motor having unusually heavy field grid winding, so that it might be brought up to the point of synchronizing with the generator end without excitation, and then very slowly bringing up the field on the motor so as to gradually bring the two generating systems together. The objection to this is that it would require rather high talent in the operating department. This, of course, the larger companies have available; but as a substation proposition for relatively small customers the condition would be somewhat beyond the capacity of the operators found in such locations."

It was at the instance of Mr. Sprong that we wrote to the Pacific Gas and Electric Company, San Francisco, the Connecticut River Transmission Company, and the Power Construction Company, Shelburne Falls, Mass. Our replies from these companies gave us some interesting information in regard to the reversible operation of the synchronous motor sets; but did not provide much encouragement regarding the suitability of induction machines for frequency-changing service. Mr. J. P. Jollyman, Engineer of Electrical Construction to the Pacific Gas and Electric Company, wrote us:

"A few years ago we were using two 4000-kw. synchronous motor frequency-changer sets. These sets were normally fed from our 60-cycle transmission system which had a total generating capacity of about ten times the capacity of the two frequency-changers, and fed into a 25-cycle system which was also supplied by other generating apparatus of more than the capacity of the frequency-changers.

The operation of these sets presented no difficulties whether working normally or reversed. The sets held in step remarkably well even under very severe load changes. Both the motors and the generators were provided with amortisseur windings on the revolving fields, and the sets were self-starting, using either machine. No other special features were included in the construction of the sets. With the synchronous motor we were able to control the power-factor of the load taken from the transmission system in such a manner that the voltage of the transmission system was undisturbed by varying loads. When running reversed the motors acted in every respect as synchronous generators, and an exact control of the voltage of the power delivered to the 60-cycle system was obtained.

Neither of these results could have been obtained had the sets been induction motor-driven. Irrespective of the amount or direction of the load transferred the relative frequencies of the systems remained in exactly the same ratio. Had induction motor sets been used the ratio of the frequencies would have changed with changes in the amount or direction of the power transferred, on account of the slip of the induction motors.

Whether induction or synchronous motor-driven frequency-changer sets would be the most suitable for use in feeding from a certain system to another certain system would depend upon the special characteristics and requirements of the systems involved. A careful study of the conditions under which the sets would operate, together with a consideration of the characteristics of the two types of sets, would enable the engineer to choose the most suitable type. The synchronous motor frequency-changer is analogous to two gears running in mesh, and the induction motor-driven set to two pulleys connected with a belt. The gears will transmit power with an exact speed ratio; the pulleys and belt will permit a certain amount of slip, depending upon the amount of load."

Mr. J. B. Mahoney, Superintendent of the Hydro-Electric Power Department of the Connecticut River Transmission Company, Shelburne Falls, Mass., wrote us in regard to the operation of two sets installed in one of the substations of his company located near the Lancaster Mills, at Clinton, Mass. These sets supply power to the latter property, and consist each of a 12-pole, 1880-kw. synchronous machine coupled to an 8-pole, 1770-kw. synchronous machine, running at a speed of 600 r.p.m.

"Each set has its own exciter and induction motor for starting purposes on the same shaft. They are used for converting our 60-cycle current to that of 40 cycles for use in the mills. Inasmuch as we sell the Lancaster Mills Company both primary and secondary power, we do not operate these sets in parallel on the 40-cycle end, but use one solely for primary power and the other for secondary. This allows us to keep our records separate and distinct.

The Lancaster Mills have a modern installation of reciprocating steam engines held in reserve for emergency purposes. We have on a number of occasions run this plant in parallel with our system, with very satisfactory results. When the sets are used for this purpose the 40-cycle ends are tied in with the steam plant, and brought up to speed from rest, with the engines. Synchronizing is then done on the 60-cycle end, where are also the automatic switches. This scheme of starting has worked entirely satisfactory; and, as we do not use the steam plant often enough to warrant the expenditure of installing synchronizing apparatus on the 40-cycle end, we have never gone to this expense. There are no special engineering features included for this purpose, and the results obtained are entirely satisfactory.

As to the relative advantages or disadvantages of synchronous motor-driven and induction motor-driven frequency-changing sets for tying in two such systems as you mention, I believe all the advantages are in favor of the synchronous motor set. The synchronous motor set not only offers the advantage of power-factor regulation, which is a very important factor, but also the superior advantages of running both systems more flexibly in the interchanging of current at different periods of the year, and the benefit of considerable help in emergencies when a breakdown occurs. Neither of these advantages can be obtained, of course, with an induction motor set, unless one system can run either above or below its normal speed, when it might be possible to use the induction motor as an induction generator. This, of course, would be rather unsatisfactory.

We are now engaged in installing three 3000-kv-a. synchronous motor sets in one of our substations to be used for converting three-phase 60-cycle current to single-phase 25-cycle. When this installation is completed it will shut down a steam turbine plant now used for supplying single-phase 25-cycle current. We expect to hold the steam plant in reserve for low-water or emergency purposes, at which time the steam plant will operate in parallel with our system. Later we intend to install waterwheels direct-connected to these sets, after which the sets will then be used as double-current generators, i.e. single or three-phase generators. In fact, there will be a number of combinations which we can obtain, rendering a very flexible service between both systems."

We also wrote Mr. Arthur E. Pope, Electrical Engineer of the Power Construction Company, of Shelburne Falls, Mass., in regard to the installation of a couple of frequency-changer sets at the plant of the Boston and Maine railroad company for the electrification of the Hoosac tunnel. He wrote us:

"The sets which were purchased for this development are not to be used in just the way you suggest: that is, they do not form a connecting link between two large systems of approximately equal capacity, but rather between the large 60-cycle systems of the Connecticut River and New England Power Companies, and the single steam station at Zylonite.

The usual operation of these sets will be in converting from 60 to 25 cycles, and ultimately each set will be connected directly to a waterwheel shaft and operated as a double generating unit. Synchronous motors were selected in this instance for several reasons, among which are the benefit of the corrective effect of the motor on the 60-cycle system, and also the stability of the large 60-cycle system in maintaining the frequency of the tunnel service during high momentary overloads.

The sets are arranged for reverse operation although it is not expected that such operation will be customary. The only special features for taking care of such operation consist of duplicate kilowatt-hour meters with ratchets, and reversing switches for the indicating meters where required. It has been assumed that the sets can always be started from the 60-cycle side, and no duplicate starting arrangement has been provided. The question of the capacity of the individual machines is taken care of in this instance by the nature of the service. In other words, when converting from 60 to 25 cycles the conversion is from three-phase to single-phase, and the capacity of the set is approximately 3000 kv-a. In case the operation of the set is reversed the 25-cycle current will be taken at three-phase, which would increase the capacity of the 25-cycle machine to an extent which would permit of the full capacity of the 60-cycle machine being developed.

I can see no advantage of induction motors being used between two large systems other than the general flexibility of connection which they would supply, and the comparative ease of connecting the systems together. A disadvantage of this scheme would be the fact that the transfer of load from one system to another, in amount equal to the normal capacity of the set, would require the two systems to be operating at frequencies several per cent from normal. I believe that in a majority of cases this variation from the normal frequency would be very undesirable from an operating point of view. The heavy lagging effect of such a connection on the system is also a disadvantage which I think is very often given too little consideration.

As to the use of synchronous motor sets under the conditions stated, I believe that this would depend largely upon the operating characteristics of the systems involved. On systems where the present speed regulation is good, I believe that no trouble would be experienced except at times when one system dropped its frequency to a considerable extent, due to a bad short-circuit. At such times, of course, the action of the set would be to attempt to carry the entire system, and the set would have to be protected by time limit relays. Some relief of this sort would also be necessary on an induction set, although the resultant overloads would not of course be nearly as severe in the latter case.

As our frequency-changer station has not yet gone into commission, I am unable to base any of the above observations upon operating facts. The question is certainly an interesting one, and I should be pleased to hear if you are able to locate any system which has been through the mill of operation under the conditions stated."

BREAKDOWN OF NEEDLE AND HORN-GAPS

(52) Do the potential breakdown values of horn-gaps bear any definite relation to the needle-gap striking distances given in the A.I.E.E. Standardization Rules? If not, please give the horn-gap striking distances for a range of from 20,000 to 100,000 volts.

There is no definite relation between the spark-over potential of a needle-gap and that of a horn-gap In general, for a given gap the spark potential of a horn-gap is considerably greater than that of a needle-gap. The spark-over potential of a horn-gap depends upon the shape and size of the horns. These vary so much in practice that it is impossible to give any general table for spark potential, and this must be determined for any given type of horns by actual test.

R.H.M.

TRANSFORMER REGULATION

53 In the Question and Answer Section of the March REVIEW the answer to Question No. 5 gave a formula for obtaining transformer voltage regulation. Some difficulty has been experienced as to how to apply this formula. Please explain in further detail, and work out a concrete example.

The formula referred to is

$$\%\ IR\ p + \%\ IX\ w + \frac{(\%\ IX\ p - \%\ IR\ w)^2}{200}$$

in which, % IR = total resistance drop due to load current expressed in per cent of rated voltage, % IX = total reactance drop due to load current expressed in per cent of rated voltage, p = power-factor ($\cos\theta$), and w = wattless-factor ($\sin\theta$).

Explanation: Measure the ohms resistance of each winding, high tension = R_1, and low-tension = R_2.

Calculate the voltage drops due to the resistance by multiplying the separate resistances by their respective currents (R_1I_1 and R_2I_2).

Let the high-tension voltage = E_1
and the low-tension voltage = E_2.

Per cent resistance drop in the high-tension

$$= \frac{R_1I_1}{E_1} \times 100.$$

Per cent resistance drop in the low-tension

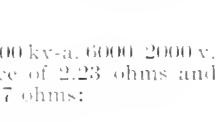
$$= \frac{R_2I_2}{E_2} \times 100.$$

Total per cent resistance drop (% IR to use in the regulation formula) is

$$\left(\frac{R_1I_1}{E_1} \times 100\right) + \left(\frac{R_2I_2}{E_2} \times 100\right)$$

Measure the impedance volts of the whole transformer. This is done in the usual manner of short-circuiting the terminals of one winding and measuring that e.m.f., which, when applied to the other winding, will cause normal load current to flow. Ordinarily, the low-tension side is short-circuited and the impedance volts (ZI) measured on the high-tension side. Knowing the total impedance and resistance drop (ZI and RI) in the transformer, it is a simple matter for one to obtain the per cent reactance volts to substitute in the regulation formula.

$$XI = \sqrt{(ZI)^2 - (RI)^2}$$



Per cent total reactance volts $= \frac{XI}{E_1} \times 100.$

These per cents of resistance and reactance volts substituted in the regulation formula, along with the self-evident values of p and w, give the per cent regulation.

Example:

Take the transformer H-60-100 kv-a. 6000/2000 v. having a high-tension resistance of 2.23 ohms and a low-tension resistance of 0.167 ohms:

H.T. current $= \frac{100{,}000}{6000} = 16.7$ amps.

L.T. current $= \frac{100{,}000}{2000} = 50$ amps.

H.T. resistance drop $= 2.23 \times 16.7 = 37.2$ volts.

$$= \frac{37.2 \times 100}{6000} = 0.62 \text{ per cent}$$

L.T. resistance drop $= 0.167 \times 50 = 8.35$ volts

$$= \frac{8.35 \times 100}{2000} = 0.417 \text{ per cent}$$

Total resistance drop, due to load current, expressed in per cent of rated voltage = 0.62 + 0.417 = 1.037 per cent. Impedance drop on the high-tension side by measurement is 182 volts.

This is the ZI of the triangle.

The RI is 6000 × 1.037 per cent = 62.3 volts.

Total reactance drop, due to load current, expressed in per cent of rated voltage is

$$XI = \sqrt{182^2 - 62.3^2} = 171 \text{ volts}$$

$$= \frac{171 \times 100}{6000} = 2.85 \text{ per cent}$$

Assuming load to be of 80 per cent power-factor

$p = 0.8$ and $w = \sqrt{1.0^2 - 0.8^2} = 0.6$

$$\text{Per cent regulation} = (1.037 \times 0.8) + (2.85 \times 0.6) + \frac{[(2.85 \times 0.8) - (1.037 \times 0.6)]^2}{200} = 2.55$$

E.C.S.

POWER-FACTOR

54 What would be the power-factor of a generator under short circuit, e.g., in the drying out of a generator with a concentrated winding and one with a distributed winding?

The power-factor of a synchronous generator operating under short circuit is a very indefinite quantity—indefinite because the reactive component of pressure existing under this condition is not a certain quantity. This component can be only roughly estimated.

Certain standard methods of estimating indicate that the power-factor of machines having a concentrated winding (which is usually found on high-voltage machines with small pole pitch) is about 0.1 when operating under short circuit; and the power-factor of machines having distributed windings is about 0.2 when operating under this condition. That is, in the latter case the reactive component is considerably smaller, compared with the effective resistance component, than in the former.

R.E.D.

HUNTING

(55) Considerable annoyance has been caused in a certain generating station by the synchronous vibration, under certain conditions, of the governor upon a driving engine and the automatic voltage-regulator of the connected generator. The difficulty was overcome by altering the natural period of vibration of the governor, through a change in its bearing. It is now desired to learn if there is any method whereby the likelihood of such hunting can be predicted for a proposed installation?

There is no means of determining this information other than by direct trial. This fact, however, is not really detrimental on account of the very rare occurrence of the conditions necessary to promote such hunting, and also the ease with which the trouble can be overcome. Only one or two other instances of such pulsation have been known and in each case the trouble was eliminated by a change in the engine governor, such as to make it slower or quicker to respond.

H.A.L.

GENERAL ELECTRIC REVIEW

Published Monthly by the

GENERAL ELECTRIC COMPANY'S PUBLICATION BUREAU

Manager, M. P. RICE   Editor, JOHN R. HEWETT   Associate Editor, B. M. EOFF
Assistant Editor, E. C. SANDERS

Subscription Rates: United States and Mexico, $2.00 per year; Canada, $2.25 per year; Foreign, $2.50 a year, payable in advance. Remit by post-office or express money orders, bank checks or drafts, made payable to the *General Electric Review*, Schenectady, N. Y.

Entered as second-class matter, March 26, 1912, at the post office at Schenectady, N. Y., under the Act of March 3, 1879.

VOL. XVI., No. 9 SEPTEMBER, 1913

CONTENTS

We show two examples of spectacular illumination in this issue; one on the cover, the other on this page. It would seem that the art of spectacular illumination is developing rapidly and is likely to take its place among the great attractions on festival occasions. The beautiful illuminating effects secured by the use of searchlights and color schemes at Niagara Falls in 1907 and the Hudson-Fulton celebration in 1909 will long be remembered by all who saw them. We understand that even these spectacular performances are to be far surpassed at the World's Fair to be held at San Francisco in 1915 in celebration of the opening of the Panama Canal, and we shall hope from time to time to show our readers some of the results secured.

GENERAL ELECTRIC REVIEW

THE PATHS OF PROGRESS

Familiarity breeds contempt, and constant association with any one class of work too often leads to a distorted perspective of conditions, whether these conditions be of progress or of retrogression. So it is not unusual to find those who are absolutely unimpressed by spectacular achievements, and, indeed, the marvels of yesterday so soon become the commonplace of today, that it is not rare to find some who doubt we are progressing.

The progress of science in general, and particularly the engineering sciences as applied to the useful services of man, has been so rapid, and our minds have been so engaged in bringing about notable accomplishments, that we hardly pause to consider the multitude of things done by machinery today that were either left undone, or else were done less well by other means, but a few brief years ago.

Engineering, both electrical and mechanical, has made such strides along the paths of progress that the problems faced today are not so much can this or that be done, but rather which of several methods can best perform the work under consideration; and the predominating feature which settles these points is more and more becoming one of economics. The cry for greater efficiency has well nigh become the keynote of the age, and this would seem to indicate that we have progressed to the stage where the elimination of waste is an absolutely essential feature, whether it be in man or in machinery of his making. This of itself is a most marked sign of progress, as an increase in efficiency must necessarily await a certain soundness in development. This searching for an increase in efficiency or curtailment of waste is among the chief problems of the scientific and engineering world.

There are two main reasons why the scientist and engineer must work hand in hand to produce an economic equilibrium in our present social system, and the first and foremost is the great increase in population to be provided with food, clothing and all the other necessities of life. The second is that what was considered luxury yesterday is considered necessity today, and also that this last phase of the subject has grown to such a state that necessity and extravagance are quite commonly confused. So both the increased population and the greater individual requirements of each unit demand the production of the necessities and luxuries of life to an extent before unthought of. That these can be and are being provided shows a march of progress in our manufacturing facilities; but at the same time our natural resources are being used at a tremendous pace. That our natural resources are not limitless but must be intelligently conserved is being more fully realized day by day and is leading to a study of economics, not only by individuals but by governments. The scientist and engineer in this, as in each great epoch of development, must lead the way, and it is being recognized more clearly now than in the past that they must be the great students of economics, and that their labors must be more and more in the direction of teaching the world at large how to do for one dollar what could not be done before for two.

As an example of what the scientist is doing in this direction, we may cite the example of the incandescent lamp, where the efficiency has been successively increased from 3.1 to 2.5 and from 2.5 to 1.25 watts per candle; and the announcement so recently made in the technical press that, in certain sizes, the nitrogen filled lamp will increase this efficiency to one-half watt per candle is cheerful evidence that we are still advancing along the paths of progress.

THE ECONOMIC STATUS OF THE ELECTRIC POWER HOUSE

Mr. Hobart's article on the "Cost of Manufacturing Electricity" will be read with much interest and will impress the reader by showing what complete scientific analyses are made today of every detail entering into the generation of electric energy. The economic generation and distribution of power are among the vital considerations in our present social system.

There is, perhaps, no other single factor which has led to an increase in efficiency to the same extent as has the adoption of electrical apparatus and appliances. And again, between their inception and extensive application, the strides made in increasing their efficiency has been among the greatest accomplishments of modern times.

Let us consider a comprehensive hydro-electric system as we know it today: the power house, situated in a locality which was a few years back, if not a desert waste at least a remote region; a transmission line spanning miles of country, sometimes running into hundreds of miles, operating at a potential which a few years ago was considered beyond the range of practical application, a distributing system which takes its energy to our railways, our factories, and our dwellings at potentials suitable for all purposes.

The pessimist may say "Your overall efficiency is low, you lose too much energy in converting mechanical into electrical energy, in stepping up, in transmission and in stepping down and distribution." And this appears true until we examine further. The difference between the total energy generated and the total energy given out as useful work by all the apparatus and appliances on a system is the bill we pay for transportation, or for transmitting energy from one central source to many places of consumption. This apparent loss in energy has paid the total bill that would by older methods have to be paid for hauling coal and pumping water in a thousand different places; and this efficient mode of operation has displaced the older inefficient method when hundreds of small individual steam-driven plants each with its own bad load factor and low efficiency were formerly wasting energy. And so our apparently low overall efficiency is after all a myth and our central station, whether it be hydro-electric or steam-driven, is an economic factor. In the case where water power is used we have derived a double benefit inasmuch as we have saved the coal we formerly should have used and used the energy that was formerly running waste. Indeed, our central stations are our modern warehouses where we buy our energy or our means of doing work and of doing it efficiently.

THE CONDITIONING OF AIR FOR COOLING GENERATOR

On page 627 of this issue we print an article by Mr. E. Knowlton on the subject of the conditioning of the circulating air for cooling large generators in power houses. While proposals of this sort had their inception in America, the prompt recognition of their importance has been chiefly confined to England where large power houses already have in operation complete air conditioning equipments.

Over a year ago the General Electric Company installed a system of this sort in one of their power houses and its advantages have been conclusively demonstrated by thorough tests. On the Continent of Europe it has been quite customary to filter the air through cloth screens prior to delivering it to the generators which are to be cooled. As pointed out in Mr. Knowlton's article, this requires an enormous screening area. The floor space occupied by a cloth screen installation is much greater than that required for water screening. The cloth screen becomes gradually clogged up with dust and undue heating of the generators is liable to ensue, unless the screen is frequently renovated by vacuum cleaning. These difficulties are altogether absent with water screening, which, amongst its many excellent features, possesses the important advantage of eliminating the fire risk, an inherent attribute of a cloth screen installation.

By passing the air through water sprays its temperature is materially reduced, especially during hot seasons of the year; and since the ultimate temperature of any part of the generator is a criterion of the output which can be safely delivered, obviously this initial cooling of the air increases the capacity of the generator.

At the recent Cooperstown Convention of the A.I.E.E., it was stated in the course of a discussion that a water screening plant was bulkier and more expensive than an air screening plant. This is only the case for very small installations. The installation in a large power house of a central plant for conditioning the air supplied to several large turbo-driven generators is a decidedly cheaper and more compact proposition and is in every way more effective than the equivalent air screening plant.

Mr. Knowlton's paper not only gives valuable detailed data regarding the quantities of air required under various conditions, but also deals with the general subject of air conditioning as affecting wholesome conditions in the engine room.

THE COST OF MANUFACTURING ELECTRICITY

By H. M. Hobart, M. Inst. C. E.

Consulting Engineer, General Electric Company

This article presents this most interesting subject of the cost of procuring electrical energy, by first taking up in sequence the physical and chemical changes whereby the production is secured. Then it goes on to illustrate how great is the simplicity secured by the substitution of electrical units, in the early calculations, for those of the thermal unit type. A direct comparison is made, item for item, of the costs of manufacturing electricity as generated by a steam-turbine-driven plant and by an internal-combustion-engine-driven plant. The costs are segregated according to the most approved methods of accounting, viz., Production, Investment, and Administration Costs. A dissertation follows on the cost as influenced by load-factor, power-factor, and character of the electricity demanded. The article is based upon a lecture delivered to the Engineering Students of the General Electric Company at the Schenectady Works, June, 1913. Concluding is a bibliography of other articles on the subject dating from 1894.—Editor.

Electricity is a form of energy. Gas is a form of matter. Electricity and gas are widely-used commodities. Each requires elaborate machinery for its manufacture in the large quantities in which it is applied to the varied uses of a community. It is as reasonable to speak of the manufacture of electricity, a form of energy, as it is to speak of the manufacture of some material substance, such as gas. A widely-employed method of manufacturing the commodity which we term electricity consists in suitably transforming a portion of the stored-up energy of coal into heat by burning the coal in the presence of suitable supplies of air,* transforming a small portion of this heat into work and finally transforming most of the work into electricity. This is a very roundabout process. The energy appears successively in the form of:

I. Chemical energy (of coal and air).
II. Heat energy (or briefly heat).
III. Mechanical energy (or work).
IV. Electrical energy (or electricity).

If we represent by 100 the quantity of energy originally present in the coal, then at the end of this chain of transformations the quantity of electricity obtained will rarely amount to more than 11. That is to say, the overall efficiency in manufacturing electricity from coal is rarely more than 11 per cent. The remaining 89 per cent is wasted in the course of the process.

Few engineers, even among those engaged in the business of manufacturing electricity, are closely acquainted with the overall-efficiency values obtained in practice. This is partly owing to the troublesome and old-fashioned system of units which are still employed and which render difficult an otherwise simple calculation. It is customary to express the quality of coal in terms of its calorific value, viz., British thermal units per pound. Good coal has a calorific value of, say, 14,500 British thermal units per pound. The British thermal unit is a unit of energy, and represents the amount of energy required to raise the temperature of one pound of water by 1 deg. Fahr.† Electricity is sold in kilowatt-hours. Our bill comes in with the statement that we have consumed during the last month 40 kw-hr. of electricity. At 8c. per kw-hr. the amount of the bill is $3.20. We have *really* consumed 40 kw-hr. of *energy*.

1 kw-hr. = 3411 B.t.u.

The bill might quite properly have stated that the consumption for the month had been 136,000 British thermal units of electricity (since $3411 \times 40 = 136{,}000$), and the charge could just as well have been on the basis of

$$\left(\frac{8.0}{3.411}\right) = 2.36\text{c. per } 1000 \text{ B.t.u.}$$

The amount of the bill would, as before, have been

$(0.0236 \times 136 =)\$3.20$.

But it will be agreed that any such extension in the use of the British thermal unit would be a retrograde step.

Conversely, it would mean progress if engineers would express the calorific value of coal in kw-hr. per lb. instead of in British thermal units per lb. I have already stated the relation

1 kw-hr. = 3411 B.t.u.

Consequently instead of expressing the calorific value of a certain sample of good coal as 14,500 B.t.u. per lb., we can state that it contains

$$\frac{14{,}500}{3411} = 4.25 \text{ kw-hr. per lb.}$$

If 100 per cent efficiency could be realized in the process of manufacturing electricity from coal, we could obtain 4.25 kw-hr. of electricity from every pound of coal burned. But if in a certain case of a large central station the efficiency is 11 per cent, then

* For coal of good quality, the consumption of every ton of coal requires the consumption of some 20 tons of air.

† It is very unfortunate that the mechanical engineers of English-speaking countries cling so tenaciously to the Fahrenheit scale of temperature as the confusion involved in the transformation of units is very great.

we know that we shall only obtain

$$0.11 \times 4.25 = 0.467 \text{ kw-hr.}$$

for every pound of coal burned; or, conversely, for every kw-hr. of electricity sent out from the central station,

$$\frac{1.00}{0.467} = 2.14 \text{ lb}$$

of coal are burned under the boilers. If the coal costs, in some particular instance, $3.00 per 2000 lb. ton, then the fuel cost amounts to

$$\frac{2.14}{2000} \times 300 = 0.32\text{c. per kw-hr. of output}$$

from the central station.

From the analysis of the results obtained with modern central stations employing steam-turbine-driven generating sets, the following are found to be representative values for the annual overall efficiency:

Capacity in Millions of Kw-Hr. per Annum	Annual Overall Efficiency in Per Cent
5	8
20	10
100 and larger	11

Overall efficiencies of from 10 to 11 per cent were obtained as early as 1905 at generating stations in Stockholm, Berlin, Vienna (see pages 29, 34 and 47 of the author's "Heavy Electrical Engineering," Van Nostrand), and at the Interborough's 59th St. station in New York (see page 3 of Vol. XXV, of Trans. A.I.E.E.). Annual overall efficiencies of 11 per cent now are obtained in the more important Edison stations. At the Interborough's 59th St. station, the annual overall efficiency is now over 12 per cent.

Let us consider the case of a station designed to deliver to the outgoing cables 200 million kw-hr. of electricity per annum. If its overall efficiency is 11 per cent, the calorific value of the coal burned will be

$$\frac{200 \text{ million}}{0.11} = 1820 \text{ million kw-hr.}$$

We have seen that good coal has a calorific value of 4.25 kw-hr. per lb. This is

$$4.25 \times 2000 = 8500 \text{ kw-hr. per ton.}$$

Thus in the course of the year we must burn

$$\frac{1{,}820{,}000{,}000}{8500} = 214{,}000 \text{ tons of coal.}$$

If the coal costs $3.00 per ton, then the annual outlay for fuel is

$$3.00 \times 214{,}000 = \$642{,}000.$$

The cost of fuel is a large item in the total cost of the electricity as delivered to the outgoing cables from the central station. The fuel sometimes represents as great an outlay as all the remaining outlays taken together. It is tempting therefore to give careful consideration to alternatives permitting of improved efficiency.

It is here necessary to digress in order to point out the distinction between the various uses of the word "efficiency." The value of 11 per cent which I have employed for the overall efficiency from the coal to the outgoing cables is an "energy" efficiency. That is to say, it represents the ratio of the central station's total output of electricity in a given time (in this case, 1 year) to the input in the form of the chemical energy of the coal burned during that same period of time. It is the ratio of two *quantities of energy.* But when we state that the full-load efficiency of a machine is 93 per cent, we are alluding to a "power" efficiency. Power is the rate of expenditure of energy and when we state that our machine has an efficiency of 93 per cent, we mean that for a particular instant, when it is carrying full load, the watts output amounts to 93 per cent of the watts input; at another instant when it is only carrying quarter load the efficiency of this machine may be only 83 per cent. The "power" efficiency becomes identical with the "energy" efficiency during a given period when the load is maintained constant throughout that period.

The "energy" efficiency of 11 per cent takes into account all the varying conditions of output during the 8766 hours of a year. During the short periods of maximum load, the efficiency of the station may be 15 per cent or more, but high values of this sort are offset by the very low values of 3 or 4 per cent occurring during times of very light load.

A large, high-speed electric generator may have a full-load efficiency of 97 per cent. The steam turbine by which it is driven may have an efficiency of 20 per cent. The boilers supplying the steam may have an efficiency of 80 per cent. This gives a combined efficiency of

$$0.97 \times 0.20 \times 0.80 = 0.155 \text{ or } 15.5 \text{ per cent.}$$

Owing, however, to the vicissitudes of the varying loads and conditions of actual practice, this "power" efficiency of 15.5 per cent corresponds to an "annual overall efficiency" of only some 11 per cent.

As against the power efficiency of some 15 per cent, which can be obtained with large steam-turbine installations, it is practicable to obtain a power efficiency of 30 per cent with some types of internal-combustion engine, such as the Diesel engine using crude petroleum, and some types of gas engine.

But just as the 15 per cent power efficiency of the steam plant comes down to 11 per cent "annual overall efficiency," the 30 per cent power efficiency of the internal-combustion engine will correspond to some 22 per cent "annual overall efficiency." There are not enough large central stations employing exclusively internal-combustion engines to provide practical data as to the annual overall efficiency which can be obtained with them; and I have taken 22 per cent since it is a reasonable value when considered with reference to the attainable power efficiency, and since, as with the ratios of power efficiencies of the two kinds of station at full load, it is just twice the 11 per cent which I have employed for the annual overall efficiency of the steam-turbine station. These efficiency values are tabulated as follows:

	Power Efficiency of Station at Full Load	Annual Overall Efficiency of Station
Steam turbine station	15 per cent	11 per cent
Int.-comb. engine station	30 per cent	22 per cent

Let us consider a 200-million-kw-hr.-per-annum station equipped with internal-combustion engines and with an annual overall efficiency of 22 per cent. Let us assume that the fuel is crude petroleum costing 4c. per gallon. One U. S. gallon is the volume of 8.35 lb. of water. The specific gravity of crude petroleum is about 0.86. Consequently one gallon of fuel weighs:

$$8.35 \times 0.86 = 7.17 \text{ lb.}$$

The calorific value of petroleum is 18,000 B.t.u. per lb., which works out at

$$\frac{18{,}000}{3411} = 5.30 \text{ kw-hr per lb.}$$

or

$$7.17 \times 5.30 = 38.0 \text{ kw-hr. per gallon.}$$

For an output of 200,000,000 kw-hr. per annum the input must be

$$\frac{200{,}000{,}000}{0.22} = 910{,}000{,}000 \text{ kw-hr.}$$

Consequently the annual consumption of oil will be

$$\frac{910{,}000{,}000}{38.0} = 24{,}000{,}000 \text{ gallons.}$$

If the price is 4c. per gallon, then the outlay for fuel will be

$$24{,}000{,}000 \times 0.04 = \$960{,}000.$$

Thus we have:

	Central Station Equipped with Steam Engs.	Central Station Equipped with Int.-Comb. Engs.
Annual overall efficiency	11%	22%
Cost of coal at $3.00 per ton	$640,000	. . .
Cost of oil at 4c. per gallon		$960,000
Cost of coal per ton for equal fuel costs	$4.50	

The results may be thrown into another instructive form:

Fuel and Price	Overall Effic.	Total Annual Outlay for Fuel	Fuel Outlay per Kw-Hr. of Output
I. Coal at $3.00 per ton	11%	$640,000	0.32c.
II. Coal at $4.50 per ton	11%	960,000	0.48c.
III. Oil at 4c. per gallon	22%	960,000	0.48c

Here, then, we have an excellent example of the futility of mere efficiency to reduce cost. With coal at $4.50 per ton the fuel outlay per kw-hr. of output is the same (notwithstanding the 11 per cent efficiency of the steam proposition) as with oil at 4c. per gallon, with the 22 per cent efficiency of the oil-engine proposition.

The reason is brought out clearly if we compare the cost of the energy in the fuel in the two cases.

We have seen that one ton of good coal contains 8500 kw-hr. Thus the cost of the fuel per kw-hr. of calorific value is

$$\frac{450}{8500} = 0.053\text{c.}$$

The oil costs 4c. per gallon and, since, as we have seen, there are 38.0 kw-hr. in a gallon, the cost per kw-hr. of calorific value is

$$\frac{4.00}{38.0} = 0.106\text{c.}$$

The cost of each kw-hr. in the oil fuel is twice as great as the cost of each kw-hr. in the coal fuel.

This cost ratio of 2:1 just offsets the 2:1 efficiency ratio.

The fuel cost is, however, only one of several components of the total cost of manufacturing electricity. There is the outlay for lubricants, an outlay which (expressed as a percentage of the total cost) is nearly negligible in large steam turbines but is very serious in internal combustion engines. The outlay for circulating water may be considerable in a steam-turbine station. Then there is the outlay for repairs. With respect to repairs, the outlay is larger per kw-hr. of electricity generated when internal combustion engines are used, than when steam turbines are used, since the latter are far smaller, simpler, and more immune from wear and from need for adjustment. As to wages, this item may be larger in the steam station owing to the boiler room component, which is eliminated in the station with oil engines.*

The items so far considered, namely fuel, lubricants, water, supplies, repairs, and wages, are termed the Production Costs; and constitute one of the three components into which Messrs. Stott and Gorsuch, in a paper entitled "Standardization of Method for Determining and Comparing Power Costs in Steam Plants," have recently suggested† that the total cost of manufacturing electricity should be sub-divided. Stott and Gorsuch's proposal is that the method of keeping costs shall be standardized and that the components of the total cost of manufacturing electricity shall be termed:

I. Production Costs
II. Investment Costs
III. Administration Costs

In a steam-turbine station, as we shall see later, the Production Costs constitute much the largest component.

I.—The Production Costs

In the following table, I have supplemented our estimates of the fuel costs by reasonable values of the other items going to make up the Production Costs for a 200-million kw-hr. central station supplying light and power to a large community.

* If, however, the internal combustion engines are of some type employing producer gas, then the producers are comparable, as far as relates to wages, to the boilers in a steam station; indeed the outlay for wages in such a station would usually be in excess of the corresponding outlay in a steam station as would also the outlay for repairs and for amortization. On the other hand, in a producer-gas station there is sometimes a credit item to be taken into account which relates to the revenue from the sale of by-products recovered from the coal.

† See page 1099 of Proceedings of American Institute of Electrical Engineers for May, 1913.

	Production Costs per kw-hr. of Output for 200-Million kw-hr. Station	
	Equipped with Steam Turbines with Coal at $4.50 per Ton	Equipped with Int.-Comb. Engines with Oil at 4c. per Gallon
Fuel	0.48c.	0.48c.
Lubricants, water and supplies	0.02	0.05
Repairs	0.07	0.12
Wages	0.10	0.08
Total Production Costs	0.67c.	0.73c.

II.—The Investment Costs

As already stated, the second component relates to the Investment Costs. The Investment Costs are made up of the interest on the investment, taxes, insurance, and amortization.

Owing to its high speed and general construction, a large steam-turbine generator represents an exceedingly small investment per kw. of capacity. As a representative figure we may take $12‡ per kw., whereas, a set driven by a large internal-combustion engine with auxiliaries will represent an investment of some $60 per kw. This handicap is not offset by the elimination of boilers and condensers. The investment for boilers and condensers and coal handling apparatus only runs to some $30 per kw. The total cost of the complete station may usually be kept down to $60 per kw. for a 200-million kw-hr. station when steam turbines are employed, but would run above $80 per kw. for a station of the same capacity employing internal-combustion engines.

We must now estimate the amount of machinery which we shall require in a central station capable of delivering 200 million kw-hr. per annum. If the load were uniform during the entire 8766 hours in a year, it would amount to

$$\frac{200,000,000}{8766} = 22,800 \text{ kw.}$$

But in the case of a plant for supplying the miscellaneous needs of a large community the load will vary a great deal from hour to hour on any particular day, and it will also be much smaller in summer than in winter, and on Sundays than on week days. This

‡ The precise price depends upon periodicity, speed, voltage, steam consumption and other factors, and may be lower or higher than the above figure.

is taken into account by stating the load-factor, which is the ratio of the average load to the maximum load. We may speak of the daily load-factor or of the yearly load-factor. In our case we are concerned with the yearly load-factor and from experience with many such central stations we know that a yearly load-factor of some 0.40 to 0.50 is attainable in a large city such as New York, or Chicago.* If we take the load-factor at the rather high value of 0.5 then the ratio of the average load to the maximum load is 0.5. In other words, the maximum load is equal to twice the average load. We have already ascertained that the average load during the entire year is 22,800 kw. Consequently the maximum load occurring at any time during the year is 45,600 kw.† But it is not safe to rely on all our machinery being continuously in working condition. We must have a reasonable proportion of spare machinery. Consequently, in the present case, we must install about 60,000 kw. of machinery although our maximum load is only 45,600 kw. We shall probably equip our steam turbine station with four 15,000 kw. generating sets. For the station employing internal-combustion engines, there will be a much larger number of much smaller machines. On the basis of $60 and $80 per kw. respectively, the total investment for the central station will be

$$60{,}000 \times 60 = \$3{,}600{,}000$$

for the steam turbine proposition, and

$$60{,}000 \times 80 = \$4{,}800{,}000$$

for the oil engine proposition.

We may take interest at 5 per cent, taxes at 1.5 per cent, insurance at 1.5 per cent, making 8 per cent for these three items. It remains to provide a sinking fund which consists of amounts set aside each year in order that, as the machinery becomes worn out or obsolete, there may be funds available for replacing it with new and up-to-date machinery. The various components of a central station will have different lives. Thus, while buildings will not require to be renewed for many years, boilers have a relatively short life. If we take 20 years as the "equivalent" life for the entire investment, then we find from "amortization" tables that we must set aside each year, *not* $\left(\frac{100}{20}=\right)$ 5 per cent of the investment, but only 3.0 per cent. In other words, if we want to have a fund of $100 at our disposal at the end of 20 years, we may set aside $3 every year and so invest this fund as to obtain 5 per cent interest; then, although in 20 years we shall only have set aside $(20 \times 3 =)$\$60, the interest will have increased the sum standing to our credit at the end of 20 years to $100. Thus the annual charges on the investment for our central station will amount to

5.0 per cent for interest
1.5 per cent for taxes
1.5 per cent for insurance
3.0 per cent for amortization

11.0 per cent.

The total annual Investment Cost is 11.0 per cent of the capital value of our station, or

$0.11 \times \$3{,}600{,}000 = \$396{,}000$ for the steam station

$0.11 \times \$4{,}800{,}000 = \$528{,}000$ for the int.-comb. station

In terms of the output, these investment costs amount to:

$\frac{39{,}600{,}000}{200{,}000{,}000} = 0.195$c. per kw-hr. for the steam station and

$\frac{52{,}800{,}000}{200{,}000{,}000} = 0.264$c. per kw-hr. for the internal-combustion station.

III.—The Administration Costs

Allusion has already been made to a third and final component contained in the cost of manufacturing electricity. This third component covers the Administration Costs. It is made up of salaries of officials, and of office expenses in general. In the present instance it may be taken as amounting to 0.05c. per kw-hr.

We can now obtain the total cost of manufacturing the electricity in the two cases, by tabulating and adding the three components as given in the following table.

It is interesting to see that, in the case of the plant with 22 per cent efficiency, the total cost is 13 per cent greater $\left(\frac{1.04}{0.92} = 1.13\right)$

* On page 403 of ELECTRICAL ENGINEERING for July 10, 1913, the following figures are given for several stations for December, 1912: The Commonwealth Edison Co. of Chicago had a peak load of 233,000 kw., an annual output of 799 million units, and a load-factor of between 43 and 44 per cent. The New York Edison Co. had a peak load of 210,800 kw., an annual output of 619 million units, and a load-factor of 33.4 per cent. The Brooklyn Edison, Boston Edison, and Philadelphia Electric Companies, with peak loads of from 40,000 to 66,000 kw., had load-factors of 33.7, 30.6, and 32 per cent respectively. The article further states that the Victoria Falls and Transvaal Power Co. expect the load-factors of most of their stations will shortly be in the neighborhood of 70 per cent, on account of the almost continuous work at the mines.

† The above statement serves the purposes of the present occasion. In actual estimates for power supply undertakings, careful investigations are made to predetermine the maximum load and its duration, by a statistical investigation of each particular case, and the load-factor will then be obtained afterwards as the ratio of the estimated average load to the estimated maximum load.

than in the case of the plant with only 11 per cent efficiency. There are two causes for this. In the first place we have seen that

TOTAL COST (PER KW-HR.) OF MANUFACTURING ELECTRICITY FOR A 200-MILLION KW-HR.-PER-ANNUM STATION WITH A LOAD FACTOR OF 0.5

	Station Equipped with Steam Turbines and Burning Coal Costing $4.50 per Ton	Station Equipped with Internal Combustion Engines Consuming Oil Costing 4c. per Gallon
I. Production Costs	0.67c.	0.73c.
II. Investment Costs	0.20c.	0.26c.
III. Administration Costs	0.05c.	0.05c.
Total Costs	0.92c.	1.04c.

the oil fuel costs twice as much as the coal per kw-hr. of calorific value. Incidentally, it may be of interest to point out that, had the coal only cost $2.25 per ton (and in many central stations good coal is obtained at this price), then the oil would have cost *four times* as much as the coal per kw-hr. of calorific value, and even could the oil engine station have had 44 per cent overall efficiency, the fuel cost per kw-hr. of output would have been as great as in the 11 per cent efficiency steam-turbine station.

On the other hand, if the fuel consists of the waste gas from blast furnaces then the internal-combustion engine proposition is relieved of any charge for fuel and stands a better chance of being the economically-correct plan.*

The second reason for the greater cost with the 22 per cent efficiency station relates to the greater Investment Cost per kw-hr. of output. Projects are continually being put forward for reducing the cost of manufacturing electricity but they are in many instances chimerical, owing to the high investment cost accompanying the reduced fuel cost. I have examined cases where the Investment Cost has risen to such values that, even were there *no charge whatsoever for fuel*, the total cost of manufacturing electricity would have been greater than in steam-turbine stations.

It is, of course, also conceivable that the fuel prices involved in a proposition could be so high that even were the *Investment Cost* reduced to a negligible amount, the total cost of manufacturing electricity would be greater than with a steam turbine station.

The conditions attending the acquirement of certain water powers have been such that it might be said that the fuel cost had been eliminated. In such cases the Production Cost has no fuel component but (unlike the waste-gas proposition), the Investment Costs involved in water storage and other civil engineering work may be and sometimes are so much greater than for a steam station as to bring the Total Cost of electricity up to a higher value than for a steam station.

Influence of Load-Factor on Cost

In our example the load-factor was taken at 0.50. While not an absolutely precise statement we may, nevertheless, consider it approximately true that for a station turning out 200 million kw-hr. per annum, but with a load-factor of 0.25, the Investment Costs will be doubled. Similarly, could we attain to unity load-factor, the Investment Costs would be halved. The Production Costs would also be slightly affected by the load-factor. Stott takes the Production Costs as inversely proportional to the fourth root of the load-factor. Taking this rule and confining our attention to the steam turbine station, we arrive at the following values for the Total Costs of manufacturing electricity for load-factors of 0.25, 0.50 and 1.00. We have:

$$\sqrt[4]{25}=2.24 \qquad \sqrt[4]{50}=2.65 \qquad \sqrt[4]{100}=3.16$$

$$\frac{1}{2.24}=0.445 \qquad \frac{1}{2.65}=0.376 \qquad \frac{1}{3.16}=0.316$$

$$44.5 : 37.6 : 31.6 = 0.80 : \mathbf{0.67}\dagger : 0.56$$

Table of component and total costs for 200-million-kw-hr.-per-annum steam stations for different load-factors and burning coal costing $4.50 per ton.

	Load Factor =0.25	Load Factor =0.50	Load Factor =1.00
I. Production Costs	0.80c.	**0.67c.**	0.56c.
II. Investment Costs	0.40	0.20	0.10
III. Administration Costs	0.05	0.05	0.05
Total Costs per kw-hr.	1.25c.	0.92c.	0.71c.

The values for the Total Cost are plotted in Fig. 1 as a function of the load-factor. From the curve in Fig. 1 we see that for the conditions in question, the Total Cost is 2.05c.

* See recent paper by H. J. Freyn, of the Allis-Chalmers Manufacturing Company of Milwaukee, entitled "The Gas Engine in Modern Blast Furnace and Steel Plants."

† 0.67 is the value already arrived at for the Production Costs for the 0.50 load-factor steam station burning coal costing $4.50 per ton.

per kw-hr. for a station designed for a load-factor of 0.10 as against a Total Cost of only 0.71c. per kw-hr. for a station for the same total output of 200-million-kw-hr.-per-annum, but designed for a load-factor of 1.00.

It is, of course, obvious that with a load-factor of 1.00 the machinery could run steadily at its most economical load. The overall efficiency would be thereby increased and would approach the power efficiency corresponding to that load. Not only would the fuel cost be decreased but also the outlay for lubrication, repairs, and wages, owing to the uniform load and also because of the circumstance that the size of the installation would be reduced to approximately half of that required for a load-factor of 0.50.

Influence of Power-factor on Cost

Attention will now be called to the influence of the power-factor of the load on the Total Cost. We all know that a polyphase generator to deliver a given load—say, 20,000 kw.—must be larger and more expensive and less efficient, the lower the power-factor corresponding to the 20,000 kw. Prof. Arno in Italy has made an exhaustive investigation of this question and has found that the cost for various power-factors is proportional to two-thirds of the output expressed in kilowatt-hours plus one-third of the output expressed in kv-a.-hours. Thus confining our attention to our steam turbine station for a load-factor of 0.5, we have arrived at a Total Cost of 0.92c. per kw-hr.

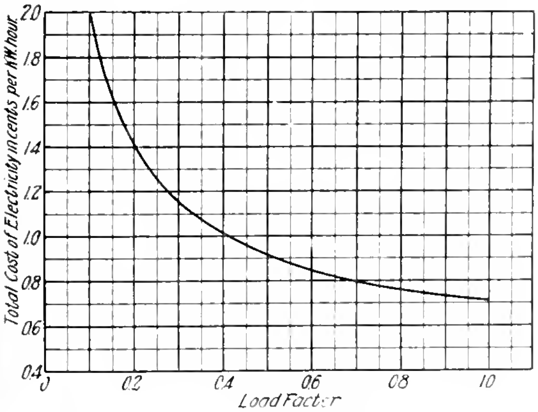


Fig. 1. Curve Showing the Relation Between Cost of Electricity and Load-Factor

This cost has been implicitly taken as corresponding to a load of unity power-factor; for example, we may consider that the entire output was sent to synchronous substations which were so operated as to maintain the power-factor at unity. Let us investigate the increase in price corresponding to loads of 0.9 and 0.8 power-factor respectively. For one kw-hr. of output, the kv-a-hr. output would be

1.00 kv-a.-hr. for 1.00 power-factor
1.11 kv-a.-hr. for 0.90 power-factor
1.25 kv-a.-hr. for 0.80 power-factor

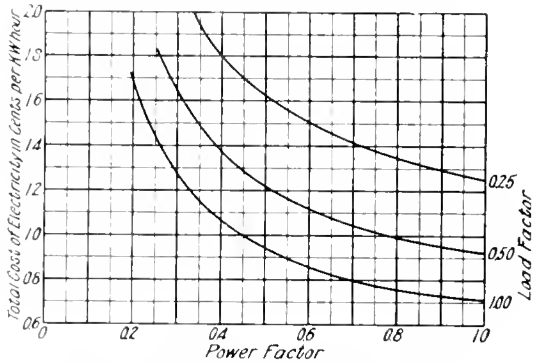


Fig. 2. Curve Showing the Relation Between Cost of Electricity and Power-Factor, at Three Different Load-Factors

The costs in the three cases would be proportional to

$\frac{2}{3}\times 1.00+\frac{1}{3}\times 1.00=1.000$
$\frac{2}{3}\times 1.00+\frac{1}{3}\times 1.11=1.037$
$\frac{2}{3}\times 1.00+\frac{1}{3}\times 1.25=1.083$

Consequently, our Total Costs would have been:

For p-f. = 1.00...... 1.000×0.92 = 0.920c. per kw-hr.

For p-f. = 0.90...... 1.037×0.92 = 0.952c. per kw-hr.

For p-f. = 0.80 ...... 1.083×0.92 = 0.997c. per kw-hr.

In Fig. 2 are given three curves plotted with total cost as ordinates and power-factors as abscissæ. The three curves relate respectively to load-factors of 0.25, 0.50, and 1.00.

As far as the generating station is concerned the cost of electricity will be a minimum for a load of unity power-factor, for the reason that the generator and cables then carry the minimum current for a given output. But with power-factors of less than unity and leading current, there will be for slight departures from unity power-factor but little increase in the cost of manufacturing electricity, since the extra capacity required for the greater current will be partly offset by the decreased excitation required. The generators become to a certain extent self-exciting, part of the excitation emanating from their armatures. An estimate of the costs would be of some such relative values as those indicated in the following table:

Lagging current and p-f. = 0.80. Cost = 1.00c. per kw-hr.

Lagging current and p-f. = 0.90. Cost = 0.95c. per kw-hr.

Current in phase. Cost = 0.92c. per kw-hr.

Leading current and p-f. = 0.90. Cost = 0.93c. per kw-hr.

Leading current and p-f. = 0.80. Cost = 0.97c. per kw-hr.

These values are plotted as the curve in Fig. 3.

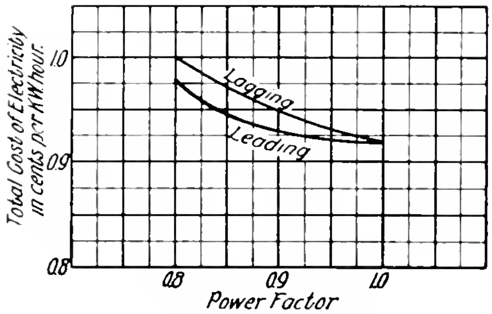


Fig. 3. Curve Showing the Relation Between Cost of Electricity and Power-Factor, Leading and Lagging

Dependence of Cost of Manufacturing Electricity on the Kind of Electricity and its Pressure

The figures so far given have referred to three-phase electricity at the pressure at which it is generated. If it is stepped up to a very high pressure, in order to be transmitted to a distance, the cost will be greater by the amount of the Investment Costs for the step-up transformers and of the losses in these transformers.

Thus if the outlay for step-up transformers is $150,000 and if we estimate on a life of 20 years, then the annual outlay on the investment is

$$\frac{0.11 \times 15,000,000}{200,000,000} = 0.0083\text{c. per kw-hr. of output.}$$

If the loss in these transformers is 2.5 per cent, then the total cost of the stepped-up electricity (for p-f. = 1.00) is equal to:

$$1.025 \times 0.92 + 0.0083 = 0.944 + 0.008 = 0.952\text{c. per kw-hr.}$$

Further increases are incurred in the cost by the time the electricity has been transmitted to a distance, owing to the cost of, and the losses in the transmission line. At the end of the transmission line the current will be stepped down. For many purposes it is required to be transformed into continuous electricity in substations equipped with rotary converters or motor-generators.

Then there are cases where the electricity is delivered from the generating station as single-phase electricity. In such cases the cost is greater by virtue of the increased cost and lower efficiency of single-phase generators as compared with three-phase generators.

Not long ago I worked through with considerable care* a comparison of this sort where, in the one case, the station provided three-phase electricity which was transformed in distant substations into continuous electricity. In the other case, the station provided single-phase electricity which was transmitted the same distance and stepped down in stationary transformers in the substations and delivered as single-phase electricity. In the first case, the generation and transmission were at unity power-factor. In the second case, the power-factor was 0.75. The cost of coal was $2.00 per ton and the load-factor on the generating station was 0.50. The generating station in each case delivered to its outgoing cables 160 million kw-hr. per annum. The results of the comparison were as follows:

	COST OF ELECTRICITY PER KW-HR. AT EACH STAGE OF THE PROCESS	
	Three-Phase Proposition with Synchronous Machinery in the Substations	Single-Phase Proposition with Stationary Transformers in the Substations
Cost of the electricity when delivered to the step-up transformers	0.783c.	0.817c.
Cost associated with the step-up transformers	0.027	0.037
Cost after stepping up	0.810	0.854
Cost associated with the transmission line	0.094	0.130
Cost at distribution end of transmission line	0.904	0.984
Cost associated with the substations	0.339	0.973
Cost as delivered from the substations	1.244	1.057
Total Cost	1.25c.	1.06c.

In this case, the continuous electricity delivered from the substations cost 18 per cent more than the single-phase electricity of 0.75 power-factor.

As delivered *to* the substations, however, the single-phase 0.75 p-f. electricity cost 9 per cent more than the three-phase unity-power-factor electricity.

* This was in a paper entitled "The Relative Costs and Operating Efficiencies of Polyphase and Single-Phase Generating and Transmitting Systems," published at page 159 of the Proceedings of American Institute of Electrical Engineers for February, 1912.

Attention should also be drawn to the ratios of the costs of the electricity as actually delivered from the substations, to the costs of the electricity when delivered from the generating station. These results are

$$\frac{1.244}{0.783} = 1.59 \text{ for the three-phase proposition}$$

and

$$\frac{1.057}{0.817} = 1.29 \text{ for the single-phase proposition.}$$

By the time the electricity is delivered on the premises of the small consumer, the actual cost to the supply company per kw-hr. delivered will often be many times the cost per kw-hr. delivered from the central station.

Many considerations enter into the determination of the equitable rate for each consumer. The result depends largely upon the nature and amount of the consumer's requirements, but it will in any case be decidedly in excess of the cost as delivered from the substations, for the low-pressure distributing network involves considerable outlay and is the seat of further losses.

In the following list are enumerated some of the circumstances which affect the equitable price to any consumer:

Circumstance 1. The distance from the generating station to the consumer's premises.

Circumstance 2. The circumstance as to whether there are other consumers in the same neighborhood, or whether a transmission line must be provided for the express purpose of reaching a single consumer. The cost also depends upon whether the transmission line may be overhead, or whether it must be underground. In the case of a large consumer, say a railway, it may be necessary, in order to ensure continuity of service, that the transmission line be in duplicate, which, of course, materially increases the cost. On the other hand, it may be practicable to save the expense of wayleaves by arranging with the railway to locate the transmission line along the railway's right-of-way.

Circumstance 3. The amount of electricity annually delivered to the consumer. This is the most potent factor in reducing the cost per kw-hr. delivered.

Circumstance 4. The consumer's load-factor. Usually this should be high to ensure low cost, but a bad load-factor, provided the consumer's peak load occurs at the time of the station's "valley" load, permits of supplying power at a lower price than even to a customer whose consumption is at unity load-factor.

Circumstance 5. The extent to which the consumer's heavy loads and peak load do, or do not, overlap with the heavy loads and peak load of other consumers, especially of those consumers, if any, who are supplied over the same transmission line. This is in elaboration of the latter part of Circumstance 4.

Circumstance 6. The form in which the consumer requires his electricity. If he requires it in the form in which it is originally generated at the central station as regards pressure and periodicity, the appropriate price is lower than it is when he requires it transformed to a lower pressure, or at another periodicity, or as continuous electricity.

Circumstance 7. If the consumer requires alternating electricity, the cost to him will be less if he requires it in the polyphase form than if he requires it in the single-phase form.

Circumstance 8. The lower the power-factor of the consumer's load, the higher will be the cost per kw-hr. delivered to him provided the low power-factor is associated with lagging electricity. With leading electricity a low power-factor will usually justify an especially low price, provided there is a considerable load of lagging electricity on the system.

Drawing conclusions from the above review of the influences occasioning variations in the cost to different consumers, it will no longer occasion surprise when I state that the electricity manufacturing undertaking may be making an equal percentage of profit from all consumers, although the prices charged range from only 1c. per kw-hr. to some consumers, up to over 10c. per kw-hr. to other consumers. This range of fully 10 to 1 in the equitable price is inevitable in the business of the bulk manufacture of electricity and its sale in varying quantities to many consumers.

Indeed, it is often the case that a large undertaking supplies a considerable number of small consumers with electricity at a price of 10c. or less per kw-hr. under conditions which occasion a cost to the undertaking of at least 20c. per kw-hr. for the electricity supplied to these small consumers.

In our comparison of two large generating stations, the one equipped with steam-turbine-driven generating sets, and the other with generating sets driven by internal-combustion engines, it has been indicated that the latter plan is inferior. If, however, we were to consider the case of a *small* generating plant, the advantage would often be found with the oil-engine proposition. Oil-engines have as good efficiency in sizes of small capacity as in those of large capacity, whereas steam turbines are less efficient in sets of small capacity. In a small station greater advantages are associated with eliminating the boiler plant and the condensing plant than in large stations. Moreover, in a small, local station it will be usual to generate continuous electricity directly, as the load will usually be in the immediate neighborhood of the station.

The speeds of oil engines are suitable for direct connection to continuous-electricity generators, whereas the speeds of steam turbines are far too high to permit of satisfactory results when employed for direct connection to continuous-electricity generators. We have already seen that the cost of the continuous-electricity delivered from the substations will usually be of the order of 50 per cent greater than the cost of the three-phase electricity delivered from the central station.

For these and related reasons there should be quite a field for the internal-combustion engine for small stations. Indeed it has in certain instances been found economical to re-arrange substations which had been supplied from distant generating stations, and operate them with oil engines.

There are specific detailed improvements which are being made and there are many others which should be made in connection with processes of manufacturing electricity, and which are of a nature to further decrease the cost.

The following bibliography will be of value to those interested in undertaking the detailed study of this subject.

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VENTILATION OF STEAM TURBINE ENGINE ROOMS

By Edgar Knowlton

Turbo-Generator Department, General Electric Company

The gradual growth of the output capacity of those power stations which have replaced some or all of their reciprocating engines by high speed turbines without increasing the size of their engine rooms has, in some cases, reached such a degree that the original ventilating systems have been found to be inadequate, resulting in discomfort to the attendants and abnormal operating temperatures of the electrical apparatus. This article cites the growth of several typical plants and shows how imperative it is that special attention be given to the ventilation of the engine room. It describes the most approved methods of supplying air to, and conducting it from, both vertical and horizontal turbines; discusses and furnishes formulæ to apply in the design of the air ducts to accomplish this purpose; and states the quantity of air required. The operation of a humidifier is described, and its cost per kilowatt of station capacity is given. Its effects on the specific heat of the ventilating air, on its cleanliness, and on its temperature are explained. The article concludes with recommendations for the improvement of ventilation of present existing stations and the design of future ones.—Editor.

The main objects to be accomplished by the ventilation of power station engine rooms are the comfort of the attendants, and the maintenance of a safe operating temperature for the electrical apparatus. Under some conditions these requirements conflict, and one of the purposes of this article is to show how both results may be attained with a minimum sacrifice in either direction.

TABLE I

Comparison of reciprocating engine stations of about twelve years ago and present steam turbine stations.

1	2	3	4	5	6	7
Station No.	Original Plans		Present Conditions		Future Conditions	
	Kw./Cu. Ft.	Kw./Sq. Ft.	Kw./Cu. Ft.	Kw./Sq. Ft.	Kw./Cu. Ft.	Kw./Sq. Ft.
1	R		R-ST		R-ST	
	0.030	1.07	0.052	1.86	0.052	1.86
2	R		R-ST		R-ST	
	0.0103	0.48	0.0103	0.48	0.0206	0.96
3	R or ST		ST		ST	
	0.056	2.97	0.063	3.30	0.080	4.20
4	ST		ST-ST		ST	
	0.038	1.00	0.060	1.55	0.070	1.97
5	ST		ST		ST	
	0.082	2.15	0.082	1.72	0.123	3.22

The power houses of twelve years ago containing reciprocating engines were large compared to the losses which appeared as heat in the engine rooms, and there was ample opportunity for the admission and egress of air. In recent years the use of the steam turbine has greatly increased the kilowatt capacity of engine rooms, and, where reciprocating engine units have been replaced by steam turbines, the kilowatt capacity of the stations has been doubled or even quadrupled.

Table I gives a comparison of several stations, illustrating the marked increase in capacity. An explanation of this table follows:

Station No. 1. This station was designed and built as a reciprocating engine station of 84,000 kw. capacity. Later steam turbines partly superseded the reciprocating engines and the capacity at present is 145,000 kw. Further increase is not contemplated on account of the limitations of boiler and switchboard space.

Station No. 2. This station was designed for large vertical reciprocating engine units which required a very high engine room. The factor $\frac{\text{kw.}}{\text{cu. ft.}}$ is small compared with steam turbine stations. At the present time this station has several steam turbine units in addition to the reciprocating sets, and although the floor space is not all occupied the capacity is about that originally planned. The addition of other steam turbine sets will allow the capacity to be at least doubled, without reaching the limits of the other equipment. These are the values given in the sixth and seventh columns. It is probable that these values can be considerably exceeded.

Station No. 3. At the time this station was designed the steam turbine had given promise of commercial success, and the station was planned to accommodate 90,000 kw. in reciprocating engine units or 120,000 kw. in steam turbine units. The latter plan was finally adopted and at the present time the capacity is approximately the latter value.

Station No. 4. This was one of the first large stations to be designed strictly as a steam turbine station. The designed capacity was 105,000 kw., which has later been increased to 165,000 kw. The present indications are that the capacity will eventually be about 210,000 kw.

Station No. 5.* This is one of the modern steam turbine stations using vertical shaft units of large capacity. If this station had been designed for large horizontal shaft steam turbine sets the output per unit of floor area would probably have been less, but the output per unit of cubical contents and exposed wall area would have been considerably greater, due to less height of engine room.

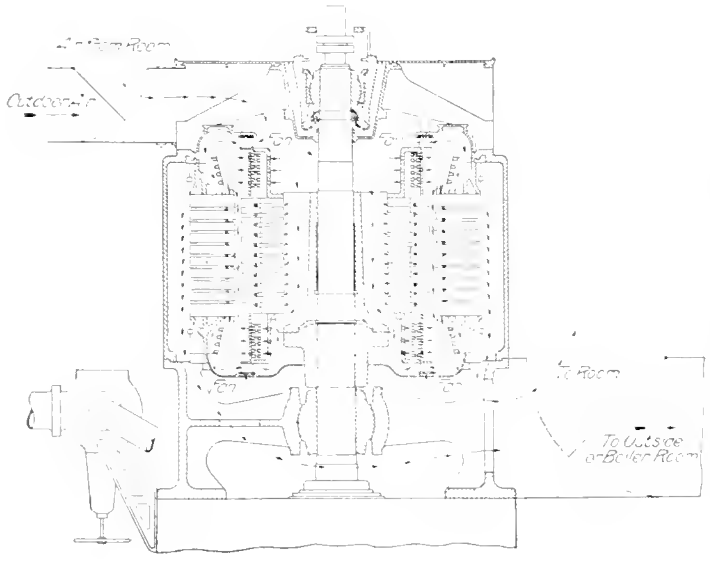


Fig. 1. Diagram of External and Internal Air Passages of a Vertical Shaft Steam Turbine Alternator

Column 1. The stations are numbered for convenience and are arranged chronologically.

Columns 2, 4, and 6. These give the ratio of the total capacity in kilowatts of all the main generating units to the cubical contents of the engine room in cubic feet.

Columns 3, 5, and 7. These give the ratio of the total capacity of all the main generating units to the sq. ft. of wall surface. In estimating the area only the walls exposed to the outer air are considered. These are usually one side, two ends, and the roof. This gives the cooling surface, and is also an approximate indication of the window area, through which air may be circulated.

The columns 2 to 7 (inclusive) refer to several different periods in the station's development. For instance, Station No. 1 was originally a reciprocating engine station, but the units are gradually being superseded by steam turbine equipment with a correspondingly greater output. If this change is being carried to its logical end the capacity will be several times that originally planned.

The letters R and ST in this table are used to indicate the type of generating sets.

R refers to reciprocating units.

ST refers to steam turbine units.

In some cases both types of apparatus are used in the same station.

The data given in Table I is on stations of large capacity, but smaller ones have undergone similar changes.

In industrial plants the conditions are apt to be worse, due partly to the lack of knowledge as to the proper care and surroundings of electrical machinery.

Steam turbine units are very much smaller in proportion to their output than reciprocating units, and the ventilation of the generators is much more difficult. During the period when reciprocating engines were in use the capacity of alternating current generators was limited more by the requirements of voltage regulation than of dangerous temperatures. At the present time it is recognized that a high speed alternator having inherently close voltage regulation is undesirable in other respects, so, generally, if close regulation is necessary, it is obtained by the use of automatic regulators. This leaves the capacity of the unit dependent on the heating, which in turn is a function of the ventilation. Since the output of stations has been approximately tripled, by the substitution of steam turbines for reciprocating engines, the quantity of air passed through the station should be increased in the same ratio.

At first steam turbine units were installed in stations operating reciprocating engines. The turbo-generators received their air from and discharged it into the room. This was soon found to be objectionable in several ways. (a) The discharged air re-entered the machine with its temperature considerably higher than the general temperature of the room; (b) lack of openings in the engine room

* The apparent discrepancy between the values in columns 3 and 5 is due to the station at present being one half as long and containing one half the number of units originally planned. The columns "Original Plans" and "Future Conditions" relate to the same size of station.

prevented the escape of the heated air; and (c) the presence of oil vapor in the air from the reciprocating engines was sufficient to cause the dirt to collect in the ventilating passages of the turbo-generators. The result of these several adverse conditions was high temperatures in machines and station.

The next step was to take air from a source where it would be cooler and free from oil vapor, and carry it to the generator by means of air ducts. The air was usually discharged from the generator into the engine room. This method made considerable improvement in generator and station ventilation. It had the disadvantages that, if the station itself did not have ample openings for the admission and egress of air, the station temperature was unduly high in the summer time; and in winter the air discharged from the generators was insufficiently heated in passing through the generator and the engine room was too cold. Under the latter condition reducing the quantity of air through the machine results in the air being delivered at a higher temperature but this will not raise the average temperature of the engine room as the quantity of heat delivered to the room remains unchanged. The desirability of the arrangement described depends on local conditions and the design of the station. If these factors tend to a cool station in summer and a warm station in winter the method is not objectionable.

When satisfactory results cannot be obtained by the last mentioned design, ducts may be so arranged that the air passing through the generator may be admitted and discharged wholly outside the engine room or wholly inside the engine room, or partly inside and partly outside. This allows considerable control of generator and engine room temperatures throughout the year. In hot weather the air to the generator may be admitted and discharged outside the engine room, and the room itself cooled by opening windows and door. During the coldest weather the air passed through the generator may be admitted and discharged inside the station. Between these extremes it may be desirable to take part of the air from the station and part from outside and discharge it in a similar manner.

In Fig. 1 is shown a diagram of air ducts and dampers for a vertical shaft turbo-alternator with this type of ventilating system. The air is admitted at the top and the adjustable damper allows of proper division between the amounts taken from inside and outside the room. After passing through the generator by the paths indicated with arrows, the air is discharged through a duct provided with a damper similar to that of the inlet duct.

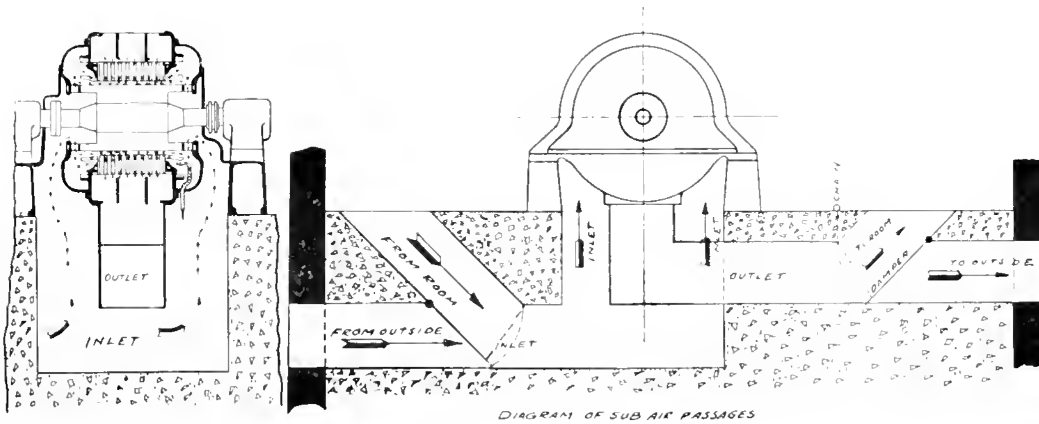


Fig. 2. Diagram of External and Internal Air Passages of a Horizontal Shaft Steam Turbine Alternator

Fig. 2 is a diagram of a similar arrangement for a horizontal shaft steam turbine set. Two views are shown, the left-hand one being a longitudinal section of the air passages in the machine, and the right-hand view a cross-section of the foundation and air passages with the adjustable dampers for controlling the air. If there is a basement under the generator which will furnish a sufficient quantity of cool, clean air the supply may be taken from this source instead of from outside the building. The ducts may be made of sheet iron and suspended from the basement ceiling.

Design of Station Air Ducts

The design of station air ducts should be carefully studied in order not to impose too great a duty on the apparatus producing the movement of air. This apparatus may consist of the rotor of the generator, fans mounted on the rotor, or independent fans. When the word fan is used in this article it refers to any of these methods of moving air.

Too great a resistance to air flow in the ducts will materially reduce the quantity of air and possibly defeat the purpose for which the ducts are installed. The resistance of air ducts is dependent on (a) the change in direction and cross section, (b) the condition of the surface of the duct, (c) the superficial area of the duct per unit of length; this takes into account the fact that for the same area of section a round or square cross-section has less friction than a rectangular or irregular cross section. Unless the deviation is great it can be neglected.

Air moving in a duct exerts a certain pressure (impact head) on a plane at right-angles to its path and a different pressure (static head) on a plane parallel to its path. The difference between the two is the pressure (velocity head) due to the velocity of the air. If the duct is uniform in section the velocity of the air and the velocity head do not change, but the impact head and the static head decrease by the same amount in the direction of the flow of air, due to the friction of the sides of the duct and to the friction of the eddy currents in the air.

The pressure of air is usually measured in inches of water. This is conveniently accomplished by having a glass **U**-tube partly filled with water and each leg connected to the two points between which it is desired to know the difference in the pressures. The difference in the water levels in the two legs gives the difference in pressure desired. Pressure is usually required between a certain point and the atmosphere, and for such a measurement one leg of the tube is left open.

Let V = Velocity of air in ft. per min.

H_v = Velocity head in inches of water.

$$H_v = \left(\frac{V}{4000}\right)$$

Therefore,

$$(1) \quad V^2 = 16{,}000{,}000\, H_v$$

Since the drop in pressure of air passing along a duct is dependent on the velocity of the air, it is convenient to consider this drop in terms of H_v (velocity head). Experiments have given the following results for sheet metal ducts.

Let H = loss of static head, in inches of water due to friction.

V = (as before) velocity of air in ft. per min.

h = greater dimension of rectangular duct cross-section, in feet.

w = lesser dimension of rectangular duct cross-section, in feet.

L = length of duct in feet.

For a sheet metal duct of rectangular cross section

$$(2) \quad H = \frac{V^2 L}{1{,}250 \times 10^6} \times \frac{h+w}{hw}$$

For a round or square sheet metal duct of diameter h

$$H = \frac{V^2 L}{625 \times 10^6\, h}$$

substituting the value of V^2 given in (1)

$$(3) \quad H = \frac{H_v L}{39\, h}$$

This means that in a round or square sheet metal duct the loss in static head due to friction in a length of 39 diameters is equal to the velocity head of the air. The friction of concrete ducts is about twice that of sheet metal and formula (3) becomes

$$(4) \quad H = \frac{H_v L}{19\, h}$$

Experiments have also shown that a right-angle turn with an outside radius equal to the diameter results in a loss of static head equal to the velocity head. The loss due to entering or leaving a large chamber is also equal to the velocity head in the duct.

To estimate the loss in static head in a round or square, sheet metal duct, find

(a) the velocity head, H_v.

(b) the number of right-angle turns.

(c) the number of sudden enlargements or reductions in area.

(d) the length of duct ÷ diameter of duct.

The loss in static head is

$$H = \left(a+b+c+\frac{d}{39}\right) H_v.$$

This is the difference in pressure (expressed in inches of water) necessary to pass the air through the duct.

For the average installation a velocity of 1500 ft. per min. does not require too large a duct nor does it impose too great a duty on the air moving apparatus. This gives a velocity head of

$$H_v = \left(\frac{1500}{4000}\right)^2 = 0.14 \text{ in.}$$

If a duct
had 3 right-angle turns,
had 1 abrupt reduction in size,
had 1 abrupt enlargement in size,
and was 42 diameters long,
the pressure necessary to pass air through the duct at this velocity would be equal to

$$\left(3+1+1+\frac{42}{39}\right) \quad 0.14 = 0.85 \text{ in.}$$

The quantity of air passed through a ventilating system varies as the square root of the difference in static pressure between the inlet and exit of the fan. At the inlet this pressure is below atmospheric pressure and therefore negative, and at the exit it is above the atmospheric pressure and therefore positive. If, in the system mentioned above, the fan produced a pressure of 8 in. from its inlet to its outlet the reduction in the quantity of air, due to the duct, would be

$$1.00 - \sqrt{\frac{8-0.85}{8}} = 1.00 - 0.945 = 0.055$$
$$= 5.5 \text{ per cent.}$$

If the fan produced a total of but 3 in. of pressure the reduction would be

$$1.00 - \sqrt{\frac{3-0.85}{3}} = 1.00 - 0.85 = 0.15$$
$$= 15 \text{ per cent.}$$

The turbo-generator manufacturer takes into account the fact that station air ducts are desirable and makes a reasonable allowance for the drop in pressure in these ducts. However, if the ducts contemplated are unusually long, small in cross section, or have a large number of turns or abrupt changes in cross section, the manufacturer should be consulted. Changes may be made in the design of the ducts to reduce the loss or the fans may be changed to produce greater pressure. The former is the most desirable since the higher pressure fans are generally less efficient than those of lower pressure.

Quantity of Air

The quantity of air for cooling a generator depends on several factors in the design, but in general it varies approximately with the total losses of the machine, excluding the friction of the bearings. Since the efficiencies of large capacity units are considerably higher than those of small capacity units, the quantity of air per kv-a. capacity is smaller in the former than the latter. The curve, Fig. 3, shows the approximate quantity of air for turbo-alternators from 1000 kv-a. to 25,000 kv-a. capacity.

Quality of Air

There are but three qualities which are of sufficient importance to mention in this article. These are heat absorption, cleanliness, and temperature.

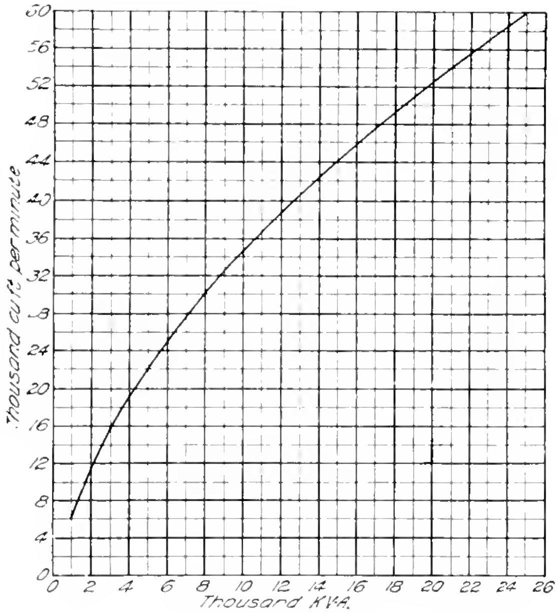


Fig. 3. Quantity of Air as a Function of the Capacity of the Generator

Heat Absorption

This subject is included in order to correct some false impressions. It is sometimes stated that damp air is more effective than dry air for cooling electrical machinery. This statement is based on the knowledge that water vapor has a higher specific heat than air, and it is assumed that the more water vapor in the mixture the greater is its specific heat. This is true, but the quantity of water vapor, even in a saturated mixture, is too small to have an appreciable effect on the specific heat.

As an example, consider three mixtures of air, and water vapor, A, B, and C, each having a volume of 100 cu. ft. and relative humidities of 100 per cent, 50 per cent and 0 per cent. Sample A is saturated with water vapor, sample B has one-half as much water vapor as sample A, and sample C is absolutely dry having no water vapor.

The calculations are on the basis of,

Original temperature	32.2 deg. C. (90 deg. F.)
Rise in temperature of the mixtures	20.0 deg. C. (36 deg. F.)
Final temperatures	52.2 deg. C. (126 deg. F.)
Specific heat of air	0.2379
Specific heat of water vapor	0.475

Sample	A	B	C
Relative humidity	100%	50%	0%
Weight of dry air in mixture, lb.	6.896	7.067	7.22
Weight of water vapor in mixture, lb.	0.212	0.106	0.00
Weight of mixture	7.108	7.173	7.22
B.t.u. to raise air 36 deg. F. (20 deg. C.)	59.06	60.52	61.83
B.t.u. to raise vapor 36 deg. F. (20 deg. C.)	3.63	1.815	0.00
B.t.u. to raise mixture 36 deg. F. (20 deg. C.)	62.69	62.335	61.83

The last item in the table shows that the energy absorbed by the saturated air is only $1\frac{1}{2}$ per cent greater than the energy absorbed by perfectly dry air.

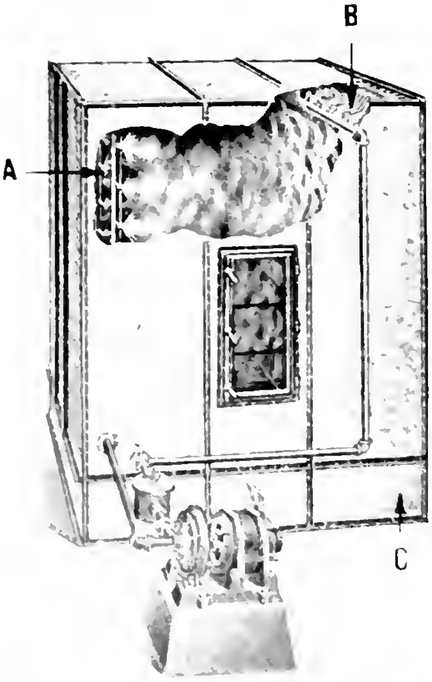


Fig. 4. External View of Circulating Pump and Humidifier With Part of Outside Covering Removed

Cleanliness

The ill effects of dirty air have been mentioned and suggestions made that the air be taken from a clean source. In some locations this is impossible, and the air must be cleaned before it is suitable for use. Cloth screens have been used to a considerable extent in Europe. The cloth is similar to Canton flannel and is mounted on a frame so as to expose a large surface of cloth with a small amount of space occupied. There is approximately 0.2 sq. ft. of cloth surface for each cubic foot of air per minute. The cloth should be fireproofed and so mounted that it is easily removed for cleaning. Screens should be frequently examined and cleaned to prevent the clogging of the pores of the cloth and the reduction of the quantity of air.

For many years an apparatus, called a humidifier, has been used in spinning and weaving mills to maintain the degree of humidity necessary for successful manufacture of the yarn and fabric. It has also been extensively used to clean the air of banks, hotels, clubs, etc. Recently, it has been adapted to the cleaning and cooling of air supplied to turbo-alternators. Fig. 4 shows a view of a humidifier with part of the outer casing removed. A centrifugal pump delivers water to spray nozzles *A* at about 30 lb. per sq. in. pressure. The water emerges in a fine spray and is thoroughly mixed with the air which enters at the left. Any particles of dirt are saturated with water, which increases their weight. The air, dirt, and spray then enter the eliminator B. This consists of vertical sheet metal plates which form zig-zag passages for the air. The particles of wet dirt and water, having greater inertia than the air, strike these plates and are carried into the settling tank C. After leaving the eliminator the air is clean and free from spray and may be carried directly to the generator. The volume of water in the settling tank is comparatively large to allow the dirt to settle in the bottom before being again taken into the pump. As a further precaution a filtering screen is placed between the tank and pump. The water is circulated in the system, hence the quantity added is that lost by evaporation.

In a properly designed humidifier the pressure necessary to pass the air through will not exceed 0.5 in. of water. This has practically no effect on the volume of air.

There is little data available on the difference in temperature between a clean and a dirty machine. The results of two tests on machines in commercial service follow—the loads were the same under both conditions:

	Dirty	Clean
Machine No. 1, rise of armature winding	54	37
Machine No. 2, rise of armature core	54	41

Temperature of the Air

With a given load the temperature of a generator is a fixed amount above the temperature of the ingoing air. In Fig. 5 is given the kv-a. load on turbo-alternators as a function of the temperature of the entering air. This curve was derived from representative twenty-five and sixty cycle machines. The load is based on a fixed maximum temperature attained by any part of the windings. Since 25 deg. C. is a standard air temperature for electrical machinery the load at this temperature is taken as 100 per cent load.

If the air is taken from out of doors in a temperate climate its temperature may vary from 0 deg. C. in winter to 40 deg. C. in summer. Reference to the curve shows that the ratio of loads at these two temperatures is 127 : 70.

The question naturally arises as to the possibility of economically cooling the air when its temperature is too high. This is done by the humidifier whose operation has been described in connection with the washing of the air. In passing through the spray chamber of the humidifier the air becomes saturated with water vapor by the process of evaporation, thereby lowering the temperature of both the air and water. The amount that the air is reduced in temperature depends on its humidity before it enters the humidifier. If the air is saturated before entering, it is obvious that there would be no evaporation and no reduction in temperature. As an example, consider the conditions which prevailed in New York at 3 P.M., July 9, 1912. These conditions are selected as they give the maximum reduction in temperature for the months of July and August of that year.

Entering air at	96 deg. F. (35.6 deg. C.)
Relative humidity	0.39

Under these conditions the air will leave the humidifier with 100 per cent humidity, i.e., saturated with water vapor, and theoretically the temperature of the air leaving the humidifier should be 76 deg. F. (24.5 deg. C.). Actually it will be slightly higher, but 2 deg. F. is ample allowance. The air is, therefore, at a temperature of 78 deg. F. (25.6 deg. C.). Since the water is circulated in the system it also maintains a temperature of 78 deg. F. (25.6 deg. C.). Reference to Fig. 5 shows that the relation of the loads under the two conditions is

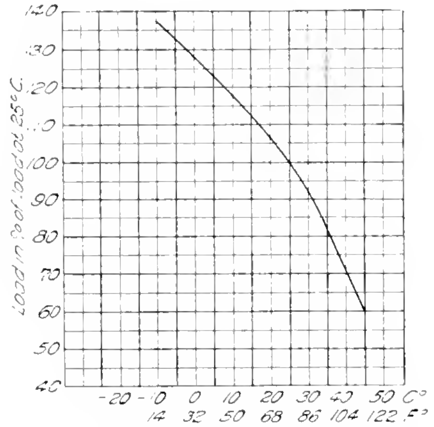


Fig. 5. Permissible Load on a Turbo-Alternator as a Function of the Temperature of the Ingoing Air

With humidifier	0.99
Without humidifier	0.81

This is a gain of 18 per cent of the load carried, with entering air at 25 deg. C. Under the most adverse conditions which have been recorded in New York City for several years, the maximum exit temperature of air from a properly designed humidifier should not exceed 82 deg. F. (27.8 deg. C.). Reference to Fig. 5 shows that the load for this temperature is 95 per cent of the load at an air temperature of 25 deg. C. This is the minimum load (based on temperature limitations) which it would have been necessary to carry in New York City at any time during the past few years with a humidifier in operation.

The air leaves the humidifier at the same temperature as the water. If there is an abundant supply of water at a temperature considerably below that which may be obtained by evaporation, it may be better to make continuous use of this supply instead of circulating the water in the humidifier, especially when conditions tend to high generator temperatures.

In other localities than New York City the conditions differ and a greater or less

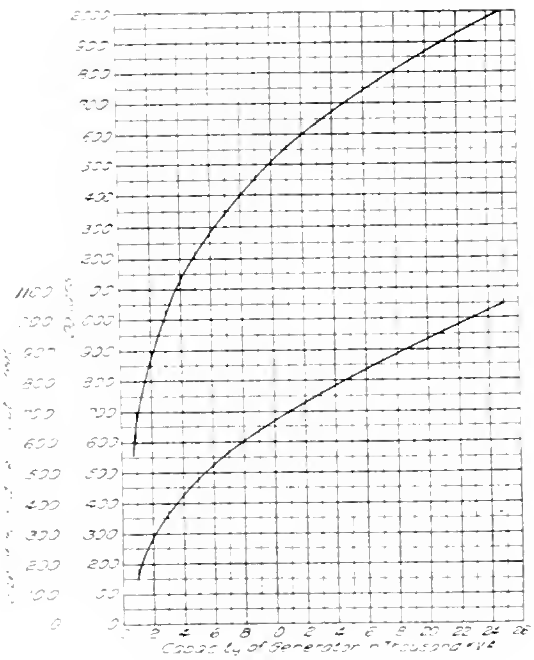


Fig. 6. Costs and Sizes of Humidifiers for Various Capacities of Generators

Upper Curve shows Costs
Lower Curve shows Sizes

benefit will result. The writer has obtained data from a number of cities in different parts of the United States. In Table II is given the *average* temperature of the air and the per cent load which may be carried with and without the use of a humidifier. This covers the months of June, July and August, and the years 1911 and 1912.

It should be noted that Table II represents [illegible] conditions. There are times when [illegible] is much larger. This is shown by [illegible] (for New York City) the average [illegible] II with the maximum values for [illegible] 9, 1912. This comparison is [illegible] III.

In Fig. 6 is given the approximate costs and sizes of [illegible] for various capacities of generators. [illegible] are f.o.b. manufactory, and include [illegible] motors. The pump motors vary [illegible] from 3 h.p. for the 1000 kv-a. to [illegible] the 15,000 kv-a generator.

In Fig. 7 is given the [illegible] sizes based on the cubic feet of air per minute. This

TABLE II

Reduction in temperature of air and increase of load obtained by the use of a humidifier; also gallons of water evaporated per thousand of cubic feet of air.

Average values for the months of June, July, and August, and the years 1911 and 1912.

	Without Humidifier: Air in Deg. C.	Without Humidifier: Load in Per Cent of Load When Air is 25 Deg. C.	With Humidifier: Air in Deg. C.	With Humidifier: Load in Per Cent of Load When Air is 25 Deg. C.	Per Cent Gain in Load	Gallons of Water Evaporated per 1000 Cu. Ft. of Air
San Francisco, Cal.	13.6	114	11.7	116	2	0.0154
Bismark, N. D.	19.1	108	15	112	4	0.0438
Jacksonville, Fla.	26.7	98	23.6	103	5	0.0430
Albany, N. Y.	20.3	106	16.6	111	5	0.0400
Boston, Mass.	21.4	105	17	110	5	0.0500
Chicago, Ill.	22.3	104	17.8	109	5	0.0510
New York, N. Y.	22.8	103	18.2	108	5	0.0525
Indianapolis, Ind.	23.4	102	18.2	108	6	0.0606
San Antonio, Texas	28.8	94	22	104	10	0.0973
Phoenix, Ariz.	30.8	90	19.2	108	18	0.1590

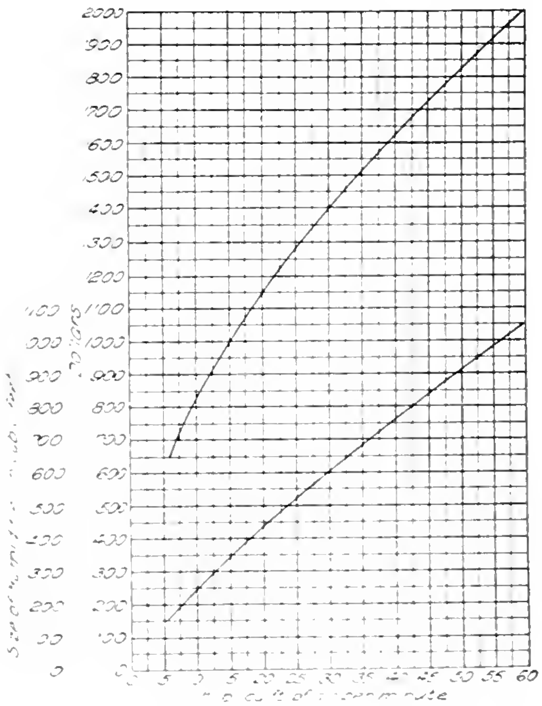


Fig. 7. Costs and Sizes of Humidifiers for Various Quantities of Air

Upper Curve shows Costs
Lower Curve shows Sizes

curve is useful in showing the cost of humidifying and cooling air for a whole station.

The velocity of air through a humidifier is about 600 ft. per min., and they are approximately 10 ft. long. This gives a basis for estimating the size of humidifier for any amount of air.

TABLE III

A comparison of the average conditions in New York City for June, July, and August, 1911 and 1912, with the maximum condition of July 9, 1912.

	Without Humidifier		With Humidifier		
	Air in Deg. C.	Load in Per Cent of Load When Air is 25 Deg. C.	Air in Deg. C.	Load in Per Cent of Load When Air is 25 Deg. C.	Per Cent Gain in Load
Average	23	102	18.5	107	5
Maximum	35.6	81	25.6	99	18

Discharge of Air to Boiler Rooms

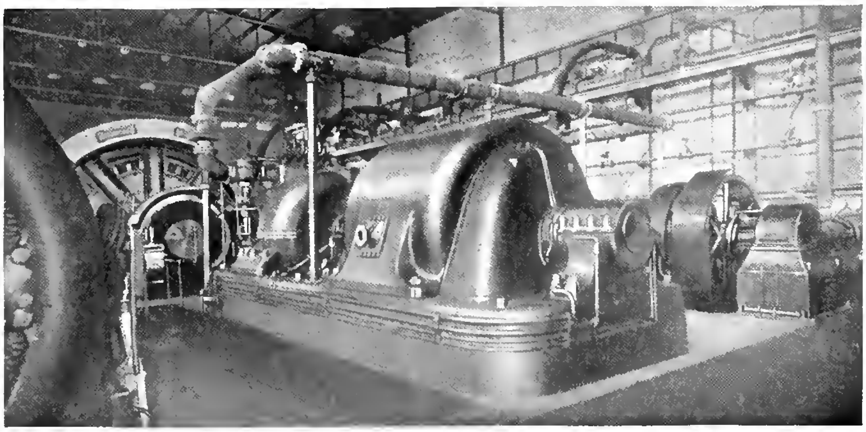
The air discharged from an electric generator contains heat energy corresponding to practically all of the generator losses. It has been suggested that these losses can be nearly all recovered by discharging this air into the fire-boxes of the boilers. The volume of air supplied by the generator is from 25 to 50 per cent of the total quantity required. The per cent varies widely, due to the difference in the types of boilers, methods of firing, kind and quality of coal, efficiencies of boilers, steam turbines, and generators. Care should be taken that the pressure in the fire-boxes does not impose too great a duty on the fans. With all of the exhaust air passed to the boiler room there would be insufficient heat in the engine room during cold weather, and it would be desirable to pass more or less air into the engine room by means of dampers such as shown in Figs. 1 and 2.

Improvement of Existing Stations

In many of the older steam turbine power stations the capacity is limited by the temperatures of the generators. This article has called attention to means for raising this limit an appreciable amount.

Design of Future Stations

In the design of future stations serious consideration should be given to the means of obtaining an effective flexible system of ventilation of both generators and station. Heretofore, the quantity of air has received the greatest amount of attention, but if equal consideration is given to the quality, the efficiency of the ventilating system will be greatly increased, and the results will be gratifying.



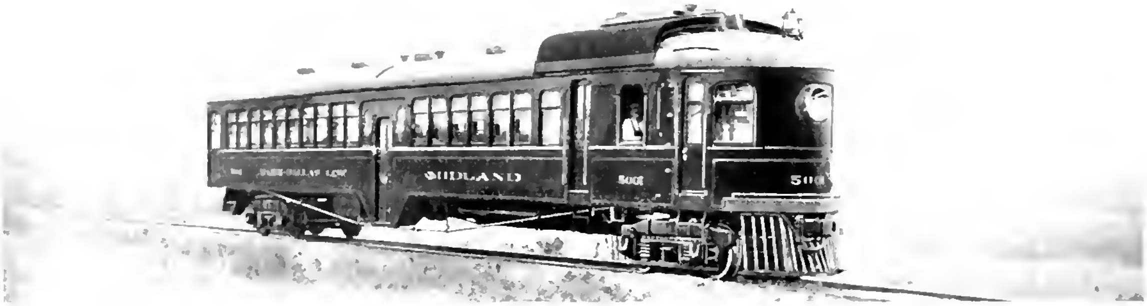


Fig. 1. Combination Passenger and Baggage Gas-Electric Motor Car on the Texas Midland Railroad. This car is 70 ft. long and is provided with both center and rear entrance

Fig. 2. Combination Passenger and Baggage Gas-Electric Motor Car Operating on the Atcheson, Topeka and Sante Fe Railway This car is 68 ft. in length and has center entrance

Fig 3. Combination Passenger, Baggage and Mail Gas-Electric Motor Car Operating on the Chicago, Milwaukee & St. Paul Railroad. This car is 70 ft. in length and is provided with rear entrance

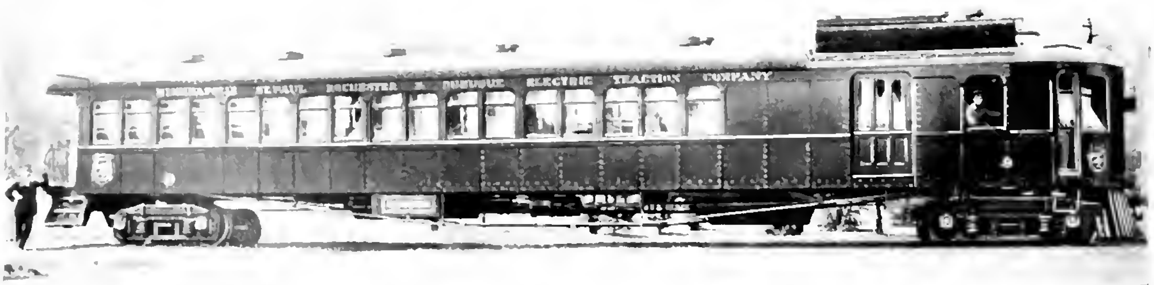


Fig. 4. Combination Passenger and Baggage Gas-Electric Motor Car Operating on the Minneapolis, St Paul, Rochester & Dubuque Railway, commonly known as the Dan Patch Line. This car is 70 ft long and has rear entrance

SOME TYPICAL EXAMPLES OF SELF PROPELLED RAILWAY PASSENGER CARS WITH ELECTRIC DRIVE

SELF-PROPELLED RAILWAY PASSENGER CARS

By S. T. Dodd

Railway Engineering and Traction Department, General Electric Company

The author deals with this important subject in an interesting and comprehensive manner. The data given in this article have been collected over a wide field of activities and represent the work of those who have been in close touch with the development of the self-propelled railway passenger car throughout the country. The comparison of the mechanical and electrical drive should prove of great value to all interested in the subject. Mr. S. T. Dodd in collaboration with Mr. B. H. Arnold read a paper on this subject before the International Fuel Association in Chicago last May, and the present article is based on that paper. In the October number of the Review we hope to publish an article by Mr. B. H. Arnold dealing with the general subject of motor car fuel and lubrication. Mr. Dodd's article, together with Mr. Arnold's, will cover the field of self-propelled cars in a very complete manner.—Editor.

The history of the self-propelled railway passenger cars extends over the last sixty or seventy-five years; indeed from the time the first steam locomotive was developed the thoughts of inventors have turned toward the development of a car in which the motive power and seating compartment would be united in one unit; and experimenters have advocated, and built, a number of different types of such cars.

Steam, compressed air, electric motors driven by storage batteries, and internal combustion engines, have all been advocated as the motive power. Without going into the details of the many different experimental cars built, and the advantages of different types of motive power, we can say that at the present time the advantages of the internal combustion engine in operation, maintenance, and radius of operation are so marked that this article will confine itself wholly to a discussion of the railway passenger car driven by internal combustion engines and a study of its characteristics, maintenance, and cost of operation.

Internal combustion engines have been built which will use fuel in any of its three forms, solid, gaseous or liquid. The use of solid fuel, however, has not as yet been successful, and gas fuels while eminently satisfactory in certain cases are practically prohibited by the conditions of motor car operation. The gas must either be carried compressed in tanks, or manufactured for immediate use in gas producers on the car. These methods, however, limit the operating radius of the car or introduce the same complications which have prevented the success of the steam car and compressed air car.

The use of liquid fuel avoids these limitations. Internal combustion engines using this form of fuel are well known and have proved satisfactory, having reached a high degree of perfection. Liquid fuel offers many advantages in methods of storage and handling, and can be obtained with a much greater heat value, weight for weight, than any other form.

As an illustration of the economy of this type of fuel, it is to be noted that gasolene cars of from 35 to 50 tons in weight, in actual operation in steam line service, are carrying an amount of fuel which is equivalent to a radius of operation of 300 miles, without recharging; and that, including the weight of water for cooling the cylinders, the total weight of fuel and cooling medium does not exceed 2750 pounds.

As the popularity of the internal combustion engine has been due to gasolene and naphtha, it is to these one naturally resorts for motor cars, and as a consequence, the car we have under consideration is popularly known as the gasolene car. From a historical standpoint the successful application of this type dates from the modern development of the gasolene engine, and is, therefore, comparatively recent. The discussion can consequently be limited to a very few successful types and these can most conveniently be discussed in two groups divided according to the method of transmission of power from the engine to the axle.

(a) Gasolene cars with mechanical transmission to the axle. These will be referred to as mechanical-drive gasolene cars.

(b) Gasolene cars with electric transmission from engine to axle, referred to as electric-drive gasolene cars.

(*a*) *Mechanical Drive*—The application of the gasolene engine to light cars for inspection and emergency service is outside of the limits of this discussion and aside from these the best known development for passenger service has been the type of car built by the McKeen Motor Car Co., or the so-called "McKeen Car." The development of this car began in the shops of the Union Pacific R. R. Co., at Omaha, under Mr. W. R. McKeen, Jr., at that time Superintendent of Motive Power of the Union Pacific. The construction of the cars was afterwards transferred to a separate organization which was formed to undertake this work and which became known as the McKeen Motor Car Co. The first of these cars was built in 1905. In its latest develop-

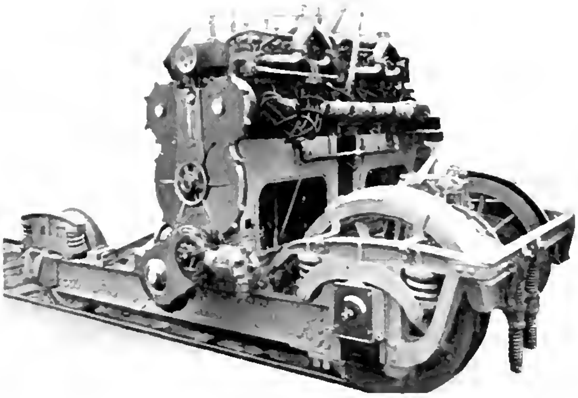


Fig. 5. Gasolene Engine Mounted on Truck of McKean Mechanical Drive Car

ment, the standard car consists of a steel body 70 ft. in length with center entrance or side doors. In this car the designer has made the side of the car assist the floor beams in strengthening and stiffening the whole structure, making of the car floor and sides a composite girder, while the shape and location of windows and doors are subordinated to the requirements of strength. The exterior of the car, having smooth sides, pointed ends, and a sloping roof, gives the general impression of being suitable for high speed service. The interior of the car is divided into an engine compartment and a seating compart-

The car is carried on double trucks, of which the rear is a four-wheel steel frame trailer truck with 33 in. wheels, and the forward truck under the engine room is a motor truck. This motor truck has one driving axle with wheels 42 in. in diameter to which the power is transmitted from the engine. The gasolene engine which stands on this truck, and swivels with it, is a six-cylinder engine with 10 in. by 12 in. cylinders driving a crank shaft at right angles to the center line of the car. A sprocket is carried on this crank shaft which drives the forward axle through a chain drive by means of an air operated friction clutch. Two gear ratios are supplied and the air clutch throws in the one or the other of these sets of gears, thus obtaining a slow speed and heavy tractive effort for starting, or a high speed for running. With either one of these gear ratios, the variation in speed from minimum to maximum is attained entirely by variation in engine speed regulated by the throttle and spark. With low speed gearing the full engine power is ordinarily attained at about 10 to 15 m.p.h., while with the high speed gearing the full engine power is attained at the maximum running speed of the car. Maximum speeds developed by these cars are reported as high as 60-70 m.p.h. The cars are fitted with fuel tanks of 100 gallons capacity and weigh complete approximately 35 tons.

The manufacturers report that in April, 1913, one hundred and thirty-eight of these cars were in service on fifty different railroads in the United States and foreign countries. The following are some of the typical railroads operating McKeen cars in various parts of the United States: Santa Fe; Buffalo,

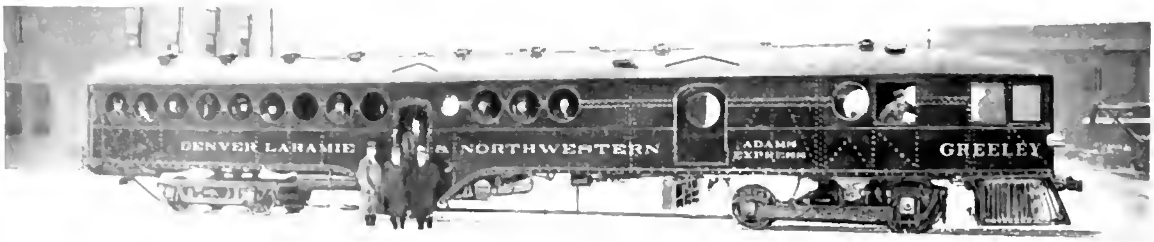


Fig. 6. Self Propelled Railway Passenger Car Operating on the Denver, Laramie and Northwestern Railway
A Car with Mechanical Drive

ment, either with or without smoker, baggage, or express compartments. The passenger compartment may seat as many as 100 passengers.

Rochester & Pittsburg R. R.; Ann Arbor; Virginia & Truckee; Union Pacific; Texas City Terminal; Woodstock & Sycamore Traction Co.; Charles City & Western Ry.; Norfolk & Southern; Chicago & North-Western; Erie Railroad; Pennsylvania Railroad; Riviera Beach & Western.

In addition to the McKeen cars, some other mechanical-drive passenger cars might be mentioned, although they are less widely in use. Among others the Fairbanks-Morse Co., of Chicago, has built a mechanical-drive gasolene car with single trucks, steel body, and seating capacity of 21 passengers. The P. H. Batten Co., of Chicago, has also built cars of this type with a seating capacity of about 30 passengers, which are in operation on three roads in the Central West. The Stover Motor Car Co., of Freeport, Ill., has supplied small single-truck gasolene cars on the Waterloo, Cedar Falls & Northern Ry. and upon the Chicago, Rock Island & Pacific R. R. The Hall-Scott Motor Co., of Oakland, Cal., has built double-truel cars with a seating capacity of 50, and a 100-h.p., four-cylinder engine driving the rear axle through longitudinal transmission and double gears.

In Europe mechanical-drive gasolene cars have been built by several companies and either are or have been in use on the Great Northern Railroad (England), the Swiss Federal Railroads, and the Wurtemburg State Railways.

(*b*) *Electric Drive*—The fundamental difference between these cars and those discussed in the preceding section is that the engine drives an electric generator, and power is transmitted electrically to motors, geared to the driving axles, instead of the engine being connected directly to the axle by mechanical gearing.

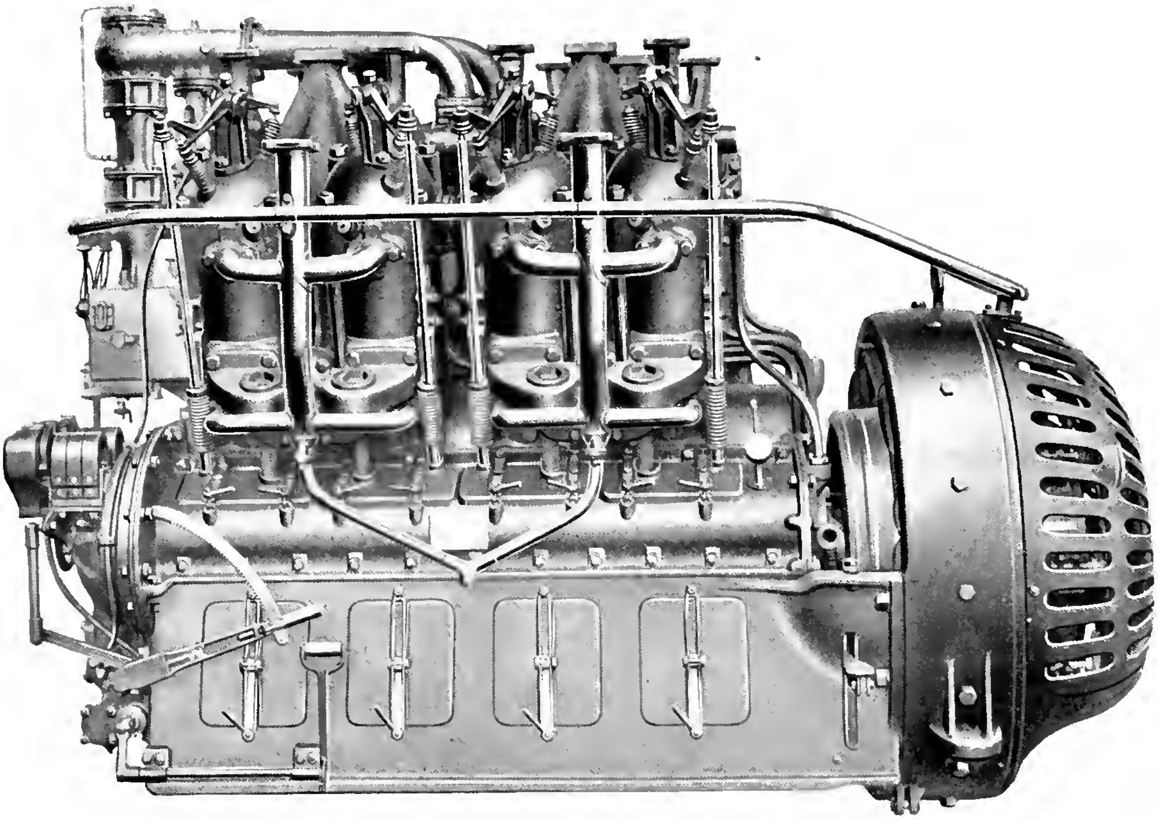


Fig. 7. Gasolene Engine Generator Set for Electrically Driven Self-Propelled Railway Passenger Cars

Of this type of car, the most extensive experience has been obtained in this country with the car manufactured by the General Electric Co., which began its design of gas-electric cars several years ago, with the construction of a car for the D. & H. R. R. This car was a standard steam railroad coach, built by the Barney & Smith Car Co., with trucks built by the American Locomotive Co.

The gasolene engine for this car was purchased in England, as at that time there were no suitable engines built in this country to meet motor car requirements. The details of electrical equipment were proportioned upon results of previous experience with heavy railway equipments. After a service of several months covering operation in commercial service of about 5000 miles, a second car was built, in which the entire equipment was furnished by the General Electric Co, and the design and characteristics were based upon their experience with the first car. The result of this experimental service has been to develop a standard type of gas-electric car which has met with very favorable reception for interurban and branch line service, and to which the following general description applies.

Fig. 8. View Showing Position of Operator and Controlling Apparatus on Self Propelled Car with Electric Drive

The car body is built of steel and is designed for the combination of the greatest lightness and strength. The front end of the car is rounded to reduce train resistance to a minimum when operating at high speeds. Either center or rear entrance are supplied to meet the requirements of traffic in various localities.

The cars are built in lengths running from 40 ft. to 70 ft. overall and weighing from 40 to 50 tons complete. The interior of the car is subdivided into passenger, smoker or second-class, baggage, and engine room. The width of the car is 10 ft. over all, full advantage having been taken of standard steam railroad clearances, and the cars have a seating capacity which may run as high as 95 or 100 passengers per car, depending upon the interior arrangement.

The power plant is located in the engine room at the front end of the car and consists of an eight-cylinder, 550 r.p.m., four-cycle gas engine of the V-type, direct connected to a 100 kw., d-c. generator. The generator is built essentially to meet motor car service and is, therefore, designed to carry a wide range of output in current or voltage, so that the output may be varied from 400 amperes at 250 volts to 125 amperes at 800 volts.

The trucks are of an equalized, swing-bolster type, suitable for the high speeds obtainable with this type of car. One of these trucks is a motor truck, designed for carrying two driving motors. The other is a standard light trailer truck. The motor truck is generally placed under the forward end of the car and carries the weight of the engine room equipment in addition to the motors. In such a case as this, about sixty per cent of the weight of the car is on the driving wheels. In some cases, however, the motor truck has been placed at the rear end of the car, under the passenger compartment, and in this case, approximately fifty per cent of the weight of the car is on the drivers.

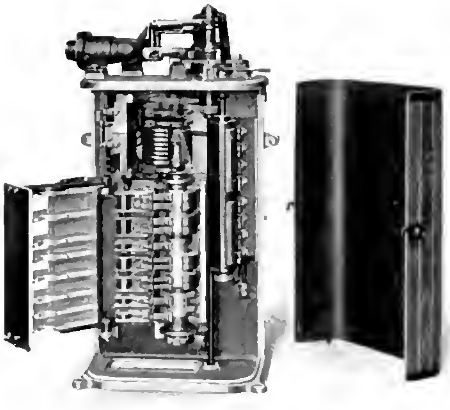


Fig. 9 View of Controller Showing Interior Arrangement of Contacts, Etc.

The car is equipped with two GE-205 100-h.p. railway motors. This is a commutating pole motor and is suited for wide variation in operating voltage. The gearing is specially selected for the service. The gear ratio is low enough that the highest maximum car speed will not develop excessive rotative speed of the armatures; at the same time the ratio is high enough to obtain the requisite starting effort without imposing excessive overloads on the motors.

The car is designed for operation from one end only. The engineer's seat is located at the right hand front window of the engine room, and controller and throttle handles are placed directly in front of him. The controller is a convenient combination of engine and generator control, with the different levers placed vertically above each other and operating about practically the same center line. The highest of these levers is the throttle lever, which controls the supply of gasolene to the engine, and as a consequence the speed and power of the engine. Directly beneath this is the electric control handle. On the first part of the range of this handle the two motors are connected in series, and the whole current of the generator passes through each of them. Successive steps raise the generator voltage from about 250 volts on the first step to about 700 volts on the seventh step. In passing to the next step of the controller, the voltage is reduced to about 250 volts, and at the same time the connection between the motors is changed, putting them in multiple with each other. On the remaining steps the two motors are running in multiple, dividing the generator current between them and each actuated by the full generator voltage. This voltage is raised in successive steps up to a maximum of about 800 volts on the thirteenth step. Two final steps, in addition to this, are suitable for particularly high speeds on level track with shunted motor fields.

The engine generator set is started by admitting compressed air to the cylinders. This is done automatically on the first opening of the throttle. As soon as the engine turns over, and the first charge of gasolene is exploded in the cylinder, the air is automatically shut off.

Air reservoirs are charged and air for the brakes, whistle, and for starting the engine is furnished from an air compressor driven from the main crank shaft of the engine. A small independent engine generator set is supplied for furnishing the lights and a separate compressor connected to this engine is used for charging the reservoirs in case they are entirely empty.

This type of car has demonstrated very marked advantages, and is in operation on a number of steam railroads in various parts of the country. At the present time 60 of these cars are in regular daily service and some of the roads on which they are in use are shown in the following table.

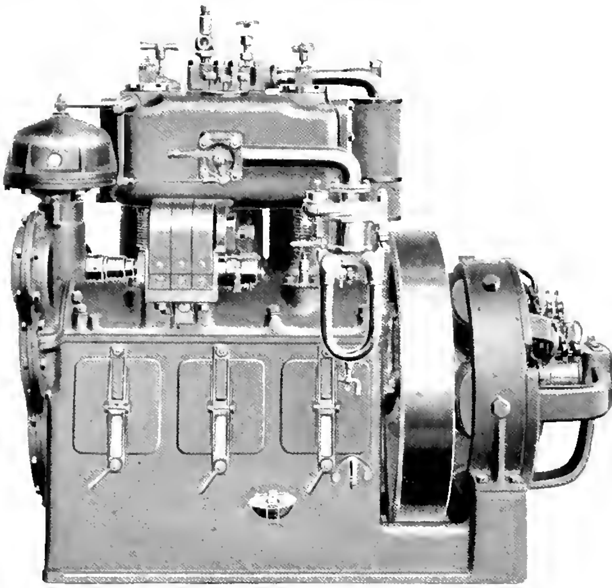


Fig. 10. Small Auxiliary Gasolene Engine and Generator for Furnishing Light, Etc.

	Number of cars in service
Southern Railway	2
Frisco Lines	16
Minn., St. Paul, Rochester & Dubuque Electric Traction Co. (Dan Patch Line)	12
Bangor & Aroostook R.R.	2
Quanah, Acme & Pacific Ry.	1
Missouri & No. Arkansas R.R.	2
Texas Midland R.R.	2
Rock Island Lines	2
Pittsburg & Lake Erie R.R.	1
Great Northern Ry.	2
Chicago, Mil. & St. Paul Ry.	7
Chicago, Peoria & St. Louis	4
Santa Fe	2

In Europe the most extensive experience with electric-drive gasolene cars has been on the Arad-Csanad Ry. in Hungary. This road has been operating gasolene cars since 1905. At the present time, they are running approximately 1,000,000 car-miles per annum and have a total record of over 5,000,000 car miles with these cars. Their records of cost of operation and maintenance on such equipments are probably more complete and extensive than any other railroad, and show an average cost of maintenance of 2.5 to 3 cents per car mile. These cars were built by the French Westinghouse Co. and recently the same type of car has been introduced into this country, in the car known as the "Dracar," built by the Drake Railway Automotrice Co., of Chicago. This company has already furnished five of these cars for the Missouri-Oklahoma & Gulf Ry. Co., and reports orders in hand for a number of other cars. The "Dracar" is 56 ft. long over bumpers and 9 ft. 6 in. in width. The car is divided into first-class, second-class, engine and baggage room compartments, and the general scheme of control and utilization of electrical energy is substantially the same as previously described in connection with the General Electric car.

A few remarks might be in place in this connection upon a type of car which has been tried to some extent and which still seems to find some advocates, that is, the combination of the gasolene-electric car with a storage battery auxiliary. The idea of storing up electricity in a storage battery appears to be so feasible, that the writer finds an insistent inquiry among some engineers for this type of car.

The fact is that the storage battery is of no real value in combination with the electric drive as it has been developed today, and as we have described it above. The real value of the electric drive lies in the possibility of working through a wide range of voltage and current, and the idea of using the storage battery in connection with it is based upon a misconception of the meaning and advantages of the electric drive and is derived from experience with constant potential control. To illustrate, with a self-propelled car having an independent gas-electric drive, if we were forced to keep constant voltage on the generator and, having constant horse-power from the engine, were forced to maintain a constant output of current, it would be absolutely necessary to furnish a storage battery auxiliary. This storage battery would provide the increased current necessary at starting and would absorb the surplus power when running under light conditions. But these are not the conditions which we have with the electric drive as developed today. We are not limited to a fixed current from the generator, as the electric generator has the same overload capacity in current as the driving motors. The only fundamental limitation is the horse-power of the engine, and by varying the generator voltage it is possible to obtain the full engine horse-power throughout the whole range of operation, from slow speed and high tractive effort at starting to high speed and low tractive effort at full speed running conditions. Keeping this in mind, it is evident that with the variable voltage control it is possible to obtain the same results from the electric drive alone that would be obtained from constant potential control with the addition of a storage battery. In addition to this, a storage battery has an efficiency of only 40 to 60 per cent and this loss is entirely eliminated by leaving the battery out. As far as weight is concerned, the same weight of material which would give a kilowatt of continuous capacity in the form of gas engine and generator would only give a kilowatt for one hour if installed in the form of a storage battery. It appears from these facts that with variable voltage control the gas-electric drive gives the same results as the storage battery auxiliary and with greater economy in weight and power.

Comparative Characteristics

Now to compare the characteristics of the mechanical-drive gasolene car with the electric-drive gasolene car, the fundamental difference between them lies in the method of transmission of the power between engine and axle. The comparison of the characteristics is well illustrated in the curves of Fig. 11. These curves show the speed, tractive effort, and gasolene consumption of a car equipped with a 100 h.p. 550 r.p.m. gasolene engine, driving in the one case, through electrical transmission, the motors geared to 33 in. driving wheels, and in the other case, through mechanical transmission, a single pair of driving wheels 42 in. in diameter. The slow speed gear reduction has been assumed at 7.5 to 1 and the high speed gearing at 1.6 to 1. These conditions correspond approximately to those ordinarily obtained on mechanical-drive gasolene cars of this weight and capacity. The following characteristics can be noted by reference to the curves:

(1) *Engine Speed*—In the electric-drive car the engine speed is independent of the car

speed and is maintained at the normal value 550 r.p.m. throughout the whole range of car speed. In the mechanical drive car the engine speed is proportional to the car speed. It starts at a low value with the starting of the car, and increases with the car speed up to 600 revolutions at a car speed of 10 m.p.h. At this point the change gear clutch is thrown in, the engine speed is cut down to 100 r.p.m., with the higher gearing, and is again raised with the car speed to 650 r.p.m. at a car speed of 50 m.p.h.

(2) *Engine Horse Power*—This is approximately proportional to the engine speed. With the electric drive the horse power is maintained at 100 h.p. throughout the range of car speed, but with the mechanical drive the horse power varies, reaching its maximum value at the maximum speed corresponding to the two gear ratios.

(3) *Tractive Effort at Wheel Rim*—The electric drive, on account of its constant horse power output, develops a tractive effort which varies inversely with the speed. It reaches a maximum of 8500 pounds at slow speeds, and falls off with increasing speeds at such a rate that at any point the product of speed and tractive effort are constant. The mechanical drive develops a maximum tractive effort of 3400 pounds up to a car speed of 10 m.p.h. At this point, where the high speed gearing is thrown in, the tractive effort drops to 900 pounds, which is maintained approximately constant through the further range of car speed.

The speed-torque characteristic of the electric drive is very similar to that of the steam locomotive. The maximum tractive effort is limited by the slipping point of the wheels, or by the maximum current which the generator can drive through the motors with the full engine output. That is to say, the current at which the total horse power of the engine is used up in heating of the motor and wiring will be the limiting current, and the corresponding tractive effort will be the maximum obtainable. General Electric gas-electric cars will in practice develop a maximum tractive effort of 10,000 to 14,000 pounds, depending on the gearing.

(4) *Fuel Consumption*—In the electric drive the fuel consumption is constant, on account of the constant horse power output. In the mechanical drive the fuel consumption varies with the output of the engine, and, therefore, with the speed of the car, except for the varying efficiency of the engine at different speeds.

Advantages of Electric Drive

The electrical transmission from engine to axle is apparently an added complication, but a number of advantages are claimed for it which largely offset the apparent complication.

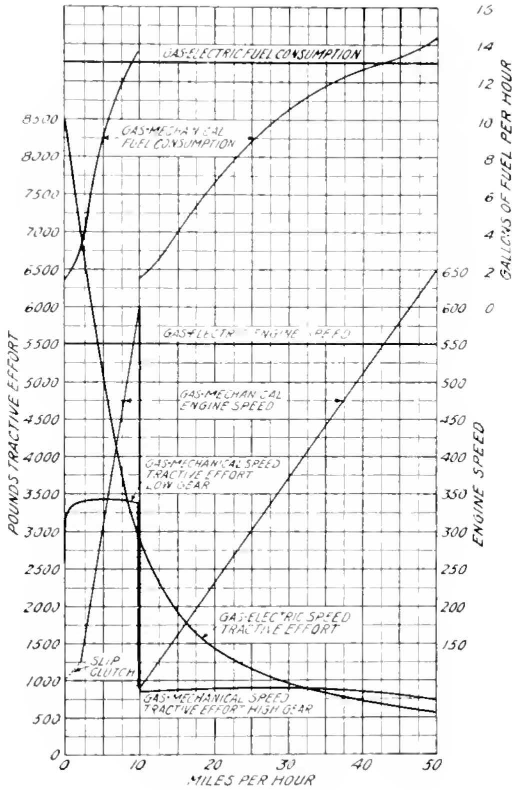


Fig. 11. Curve Showing Comparative Characteristics of Mechanical and Electrical Transmission

These advantages may be briefly stated as follows.

1. Superior control.
2. Greater reliability.
3. Lower cost of maintenance.

(1) The control is superior to clutches and change gears for the following reasons:

Electric drive is equivalent to an infinite number of speed relations between the engine and car wheels without any change of clutches or gears.

The full engine output may be had at all car speeds.

It permits driving through two or more axles which is a considerable advantage for grade work or slippery rails.

The rigid wheel base of the driving truck may be made short, permitting the use of shorter curves at Y's and turn outs.

Starting and acceleration is made with absolute smoothness.

Accidental conditions can be met, such as the hauling of an occasional trailer or the negotiating of a heavy grade, which could not be met if the maximum tractive effort of the car were rigidly fixed by the gear ratio.

The car can be reversed without stopping the engine, an advantage quickly apparent in yard work, switching, coupling, etc.

In case of failure of the brakes, the motors may be used to stop the car.

(2) It possesses greater reliability for the following reasons:

Speed changes are made without shocks to the apparatus.

The engine is mounted on springs on the car body and is not subject to hammer blows when passing over crossing frogs or switches.

It is free from dust and foreign material in the bearings and piping.

Minor defects are easily detected and adjusted before they become serious, due to the accessibility of the engine.

(3) The cost of maintenance is less because:

The apparatus is less subject to shocks, and, therefore, requires fewer renewals.

All parts of the engine are easily accessible.

The location of the apparatus permits making reliable water and gasolene connections and the placing of the radiator on the roof where it is protected from flying stones, etc.

Electric equipment has demonstrated its low cost of maintenance in railway service and the electric railway motor in particular is generally acknowledged to be the most rugged piece of apparatus in railway service.

Fuel and Lubrication

At the present time some of the light distillates of petroleum are the only fuels commercially available for such cars as we are describing. While this fuel has been referred to under the general term "gasolene" the fact is that the quality required is not as high as the product usually demanded and furnished under that name. At the present time, the manufacturer of these cars is co-operating with the refiners of petroleum in making an extensive study of the characteristics and specifications of petroleum distillates which are suitable for engines of the type used on the gas-electric car.

Besides petroleum distillates, there is to be considered the future possibility of the use of other liquid fuels, such as fuel oil or alcohol, but in the present state of development of the art none of these are commercially available.

The whole question of fuel and lubrication of internal combustion engines for motor cars is so extensive and far reaching that it must be dealt with in a separate article.

Inspection and Maintenance

A managing officer contemplating the purchase of motor cars usually asks a number of questions somewhat as follows, each of which we have answered briefly:

What kind of men are required to successfully operate motor cars?

A large percentage of the gas-electric motor cars are being operated by the locomotive engineers who formerly ran the steam locomotives which have been replaced by motor cars. No particular attainments are necessary to run motor cars other than that required for handling any other motive-power equipment.

What kind of training and examinations should the men go through to properly qualify for operating motor cars?

It is desirable for railroads, when getting their first cars, to secure the service of an expert operator from the manufacturing company for a limited period, depending upon the circumstances and number of men to be qualified. The operators can best be broken in by starting them in to handle the cars as soon as possible, under the direction of such an instructor. The men, of course, should be provided with an instruction book, and the instructions should follow somewhat the following lines: The men should be made familiar with the names, functions, and location of all the apparatus on the car. They should be given a brief general idea of the principles of a gas engine, electric generator, and electric motors. After this they should be given lessons in the proper manipulation of the car, how to run the car with the best fuel and oil economy, and how far the power plant can be pushed without overworking it. They should be taught to notice the forewarnings of trouble, how to locate such trouble, and how to make necessary running repairs and adjustments. Special instructions should be given to the matter of carburetor adjustments and the timing of the engine.

What daily inspection is necessary?

This, as a rule, should be assigned to the operators and the men who look after the cars at their lay-overs. This daily inspection should be such as is usually made to all classes of equipment, viz., to see that no parts have become deranged and see that all adjustments are correct.

What periodic inspections are necessary?

In order to get the best results out of any motor car, it is essential that a definite scheme of inspection and maintenance be laid out. The practice of interurban electric roads is probably the best scheme to follow. According to their practice, the motor cars should have a regular inspection at stated periods. This should be a combination of mileage and time. For any car, regardless of mileage, a thorough inspection should be made at least every ten days, and where long mileage is made at least every 2000 miles. Where practical, it is desirable to have such inspections once a week. This inspection should be rigorous and requires the services of a fairly skilled man. The importance of thorough inspection of motor cars cannot be overestimated, as in all probability a large percentage of incipient trouble can be prevented by a thorough system of daily and periodic inspection, and the making of running repairs and adjustments when first needed. The man who will successfully take care of axle car-lighting equipment is also well fitted to take care of the equipment on motor cars. One of the most effective ways of making inspections is to provide a list of questions for the inspector to answer. In order to answer all the questions correctly, the inspector will have to make an examination of everything of importance on the car.

What facilities are necessary at lay-up points?

The critical feature in caring for gasolene motor cars is the preventing of the radiators from freezing and the heating of the car. Where cold weather is encountered, a heated shelter is highly desirable. Where cars have to remain outside, a supply of hot water is very convenient for refilling the radiator, as this will allow the radiators to be completely drained at night. An arrangement of a tank in the baggage car can be resorted to, which will allow the water from the radiators to be drained into this tank and thus be kept from freezing during the lay-over, and then forced back into the radiators by compressed air. This last arrangement also enables a car to lay up at any outlying point in an emergency.

What repair parts should be kept on hand?

It is very desirable to carry a selected list of repair parts. For an amount of between $200 and $300 per car a considerable number of small parts can be secured which will give a large return in insurance against failure. For overhaul parts it will be found that experience in the course of time will tell what it is desirable for each particular company to carry, but, as a rule, it is thought that such parts can be anticipated previous to the car being laid up for classified repairs.

Operating Costs

As an illustration of some of the actual operating results obtained with gas-electric motor cars, the following statements are submitted. These figures are selected on account of the number of cars involved and the amount of mileage made.

TABLE I—FRISCO LINES

COST OF OPERATING GAS-ELECTRIC PASSENGER MOTOR CARS

Following is a consolidated statement for six months from July 1, 1912, to December 31, 1912, covering the direct cost of operation, including classified repairs made during the interval. This includes the performance of fourteen cars operating under varying grade and climatic conditions. Some of these cars were on several different runs.

Revenue motor car-miles	251,627
Revenue trailer car-miles	114,164
Total passenger car-miles	365,791
Per cent of time trailers hauled	40.3
Gals. fuel (naphtha) used per m.c.m.	.721
Gals. fuel (naphtha) used per p.c.m.	.496

	Total cost for 6 months	Average cost per motor train-mile
Wages of crews	$19,840.96	$0.0788
Fuel (naphtha)	11,857.68	.0471
Lubrication (gas engine)	1,553.28	.0062
Cleaning, supplies and misc. expenses	2,545.91	.0101
Running and shop repairs	7,769.73	.0309
	$43,567.65	$0.1731

The above includes extensive classified repairs given two cars, and all the running and shop repairs on the other cars.

Table II shows more detailed information on the performance of six of the above cars. They were all on representative assigned runs averaging 166 revenue miles daily; four hauled trailers regularly and each carried a full, motor car, train crew. The actual revenue mileage only is shown, as no allowance is made for turning or other non-revenue mileage. The runs cover varying speeds and grades. The maximum grade, 2.3 per cent, occurs on the Bolivar-Chadwick run, where a trailer is hauled regularly. On this run there is one stretch of 2 per cent grade for a distance of four miles.

TABLE II FRISCO LINES

COST OF OPERATING GAS-ELECTRIC PASSENGER MOTOR CARS

Following is a consolidated statement for eight months from July 1, 1912, to February 28, 1913, covering the direct cost (no classified repairs made during interval) of cars 2104, 2105, 2106, 2107, 2108, 2109 operating between Muskogee and Westville, Okla.; Dawton, Okla., and Quanah, Tex.; Sherman and Dallas, Tex.; Chadwick and Bolivar, Mo.; Kansas City and Clinton, Mo.; and Clinton and Enid, Okla.

Revenue motor car-miles	181,438
Revenue trailer car-miles	127,605
Total passenger car-miles	308,043
Per cent of time trailers hauled	70.3%
Average working weight of motor cars	51.5 tons
Average load of motor cars (estimated)	3.5 tons
Average working weight of trailer cars	23.5 tons
Average load of trailer cars (estimated)	2.5 tons
Gross weight motor trains (average)	73. tons
Total gross ton-miles	13,296,28
Gallons fuel used per motor train-mile	.751
Gross ton-miles per gal. fuel	97.6

	Total cost for 8 months	Average cost per motor train-mile
Wages of crew	$14,417.09	$0.0794
Fuel (naphtha)	8,666.42	.0477
Lubrication (gas engine)	1,356.49	.0075
Cleaning, supplies and misc. expense	1,586.89	.0088
Running repairs labor	2,908.46	.0160
Running repairs material	1,242.28	.0067
	$30,187.63	$0.1661

As an example of the performance on an interurban line with a very fast schedule, Table III is submitted. The trailers hauled consist of a mixture of passenger, freight and work cars. The cost of heating supplies and maintenance of equipment includes also the cost of these trailers. The longest maximum grade of 1.5 per cent is about two miles, and one stretch where the grade averages 1.37 per cent for a distance in excess of four miles. In addition to the station stops, there are two railroad crossings at grade where all trains must stop for the conductor to go ahead and turn crossing gates. The motor cars then pull over the crossing and wait until conductor resets gates. There is also a draw bridge which is not interlocked, where all trains must stop.

TABLE III—DAN PATCH LINE

Minneapolis, St. Paul, Rochester & Dubuque Electric Traction Co.

COST OF OPERATING GAS-ELECTRIC MOTOR CARS FROM JAN. 1 TO AUG. 31, 1912

Total motor car-miles	216,498
Total trailer car-miles	75,948
Total car-miles	292,446
Per cent of time trailers hauled	35.5%
Number of motor cars in service	8
Length of line	37.34 miles
Maximum grade	1.5%
Schedule time for express trains	1 hr. 17 min.
Average distance between stops for express trains	3.734 miles
Schedule speed m.p.h. of express trains	29.1 miles
Schedule time for local trains	1 hr. 35 min.
Average distance between flag stops for local trains	1.067 miles
Schedule speed m.p.h. of local trains	23.6
Gals. fuel used per motor train-miles	.758
Gals. fuel used per car-mile	.527

	Total cost for 1 year	Average cost per motor train-mile	Average cost per car-mile
Wages of crew	$12,056.95	$0.0557	$0.0412
Fuel (naphtha)	17,622.26	.0814	.0603
Lubrication (gas engine)	1,141.56	.0052	.0039
Journal oil	77.77	.0004	.0003
Supplies and car heating	1,389.03	.0064	.0047
Maintenance of electric equipment	1,949.81	.0090	.0067
Maintenance of cars and trucks	1,394.56	.0065	.0047
Shop expense and heating	3,507.77	.0162	.0120
	$39,139.71	$0.1808	$0.1338

CITY STREET LIGHTING WITH SERIES TUNGSTEN LAMPS

By G. H. Stickney

Edison Lamp Works, Harrison, N. J.

The author shows that the art of illumination as applied to city and suburban lighting has made rapid strides in development. He enumerates the six principal considerations necessary to good lighting effects, and then proceeds to expand these considerations in an interesting and instructive way. In the latter part of the article, he gives much valuable detailed information that will be of considerable interest to those following the subject, and concludes by a few brief paragraphs on the calculation of illumination.—Editor.

Until recently the success of a street lighting system was too often judged only by the brightness of the individual units, but now, thanks to the better general knowledge of the subject, the merits of a lighting system are determined by the amount of light rather than by the brightness, and also by the proper distribution. Indeed, the art of illumination has made such rapid progress that to-day, in up-to-date communities, a good lighting system is considered as essential as is a good police system and an efficient fire fighting force.

Principal Considerations

The economic and scientific aspects of the problem are daily receiving more attention. These may be summarized as follows:

(1) A sufficient amount of light must be supplied and so distributed as to give an approximately uniform illumination.

(2) Street lamps should have as low an intrinsic brilliancy as is compatible with economy, and be so located that any glare will not interfere with ordinary vision.

(3) With the usual height and spacing, the greatest intensity of light should leave the lamp at an angle of about 20 degrees below the horizontal.

(4) The light should be steady, for flickering obviously reduces the illuminating efficiency of the lamps.

(5) There should be good diffusion of the light rays so as to avoid deep shadows.

(6) The lamp should be placed fairly high, thus giving more light at distant points and avoiding long distorted shadows from objects on the roadway.

Taking up these important considerations more in detail:

(1) The actual intensity of light required for safe traveling varies with the amount of traffic on the street. If the traffic is heavy and liable to become congested, a large amount of light should be supplied so that all obstructions can be perceived at a glance. To escape being run over or to avoid collisions, quick decision is often necessary, and accordingly there should be sufficient light on the street so that the easiest and safest path can be instantly detected. In other places, where travel is not as dense, the danger of collision is reduced and less light will be found satisfactory.

Uniform illumination, however, is a quality which every street lighting installation should possess, and to which too much importance cannot be attached. This does not mean that there should be absolutely no variation in intensity over the entire street surface, but rather that there should not be a great variation between the maximum intensity near the lamps and the minimum intensity midway between. The allowable variation has been given as 10 to 1, and although this value cannot always be attained in practice yet it can often be closely approximated. If the variation in intensity is allowed to become much greater, the danger of accidents occurring in the shaded places is unnecessarily great. In fact, the gloom in these dark portions of the street is apparently very much deepened by contrast with the adjacent light portions, and consequently greater caution should be exercised. We are all familiar with the effect upon the eyes experienced when one goes from daylight into a darkened room and again when returning to daylight conditions. In the former case a considerable period intervenes before one can distinguish objects, even though they may be easily visible after the eyes become adjusted; in the latter case, one is confronted with a blinding effect which also interferes with sight, even though there may be no objectionable glare when one becomes accustomed to the intensity. Similar effects, although usually to a lesser degree, interfere with the vision of the traveler in streets where excessive contrast exists through the use of high power light units placed too far apart. Some writers have recommended a non-uniform illumination as assisting in so-called silhouette vision. It is probable that this does present some advantages to the automobilist, whose headlight eliminates the dark spaces, thus decreasing the contrast effect. The automobilist, being interested in seeing a considerable distance ahead, would see large objects silhouetted against the background. On the other hand, the ordinary driver and particularly the pedestrian, who really deserve the first consideration in designing street lighting, are considerably handicapped by the uneven illumination, since they cannot readily see inequalities or obstructions in the pavement, if such happen to come in a dark part. Moreover, this sort of lighting is more favorable to "hold-ups." Better effect can be obtained, even with a lower total flux of light, by spacing smaller units closer together. In other words, the actual intensity of light used need not be high if the distribution is uniform. Therefore, in designing a street lighting installation a great deal of attention should be paid, first, to the size of the units so as to secure a sufficient amount of light, and second, to the characteristics of the illuminant, its height, spacing, equipment, etc., so as to secure a reasonably uniform distribution.

(2) In a well designed system for street lighting, units should not be so brilliant as to dazzle the eye and so produce a blinding effect. Glare is always objectionable and to minimize it the light rays must be prevented from entering the eye directly, or an illuminant of a relatively low intrinsic brilliancy must be chosen. In either case it is often advantageous to locate the lamps along the side of the streets as high as practicable, so as to keep them out of the range of vision when looking up or down the street.

(3) If the maximum candle-power were nearer the horizontal, too much of the light would be wasted on the sides of the buildings or trees, while if the maximum candle-power were nearer the vertical, too great an intensity of light would be concentrated under the lamp. In order to secure the desired illumination at the points midway between the lamps, the maximum candle-power should be given off at an angle varying from 10 to 30 degrees below the horizontal.

(4) With a flickering light, at one moment the object is illuminated while at the next moment it is in shadow. That is, the light shines on the object for a part of the time only, and part of that time is required for the eye to accommodate itself to the change in intensity.

Not only is an unsteady light a source of discomfort to the eyes, but it interferes with vision to a degree depending upon the amount and character of the variation. A steady light is more valuable for seeing purposes than one of varying intensity, even when there is considerable disparity in the average intensity.

(5) By good diffusion is meant that the light rays radiated from the lamp should be so reflected and broken up that the apparent source of light is much enlarged. This does not allow a large amount of light to be concentrated in any one ray as it leaves the lamp, but instead increases the number of rays and decreases the quantity of light per ray, thus avoiding the possibility of deep shadows and at the same time reducing the glare. Light shadows upon the roadway are by no means objectionable, but a deep shadow places that portion of the street surface in almost the same condition that would result from no lamps at all along the street. In fact, a few deep shadows at close intervals will oftentimes make that part of the street more dangerous than if there were absolutely no lights, for with these few shadows travelers do not exercise the same degree of caution as on an unlighted street. The deep shadows, resulting from poorly diffused artificial light, have the same effect as a flickering light source upon the eye of the observer who is rapidly passing through alternate light and dark spots.

(6) One of the most prevalent faults in present street lighting practice is the placing of lamps too near the ground. This low suspension of the lighting units has several disadvantages for it causes a large portion of the street surface to be covered by shadows, and it tends toward uneven spot lighting. When the lamp is placed low, any little projection above the street surface casts a long shadow, and the shadows from larger objects are narrow and distorted. Consequently, the amount of street surface darkened by the shadows is much more than it would be if the lighting units were suspended higher. The trouble cannot be remedied by replacing the lamps with more powerful units, as they only intensify the shadows and exaggerate the trouble. Reasonably high suspension of the lighting unit aids in furnishing the proper amount of light to the points midway between the lamps, and reduces the glare from contrast between the light and dark spots. When light rays, having the same angle of elevation, leave two lamps placed at

unequal heights, the rays from the lower lamp will strike the ground nearer the post. In other words, the higher the lamp is placed, the further from the post will the light rays extend. There is, however, the other extreme, which should also be avoided, that is the excessively high suspension of the lamps. This phase of the question will be considered more in detail in the latter part of this article, as sometimes the foliage interferes with the distribution of the light so as to prevent the proper theoretical suspension of the lamp. But the general rule holds that we should suspend the lamps fairly well above the ground in order to illuminate distant points properly and make the shadows as short as possible.

Other Considerations

The chief purpose in street lighting is the illumination of the roadway, and all rules and scientific principles for making installations are but guides in attaining this result. If there is an installation giving a certain minimum normal intensity at the midway points, and it is desirable to double the distance between the lamps without altering the minimum intensity, then, if the height of the lamps is also doubled, the light flux per unit must be four times as great as before, because the intensity from a given light source varies inversely as the square of the distance. Conversely, for the same illumination and twice as frequent spacing, the light flux per unit will be only one-fourth as great, with a corresponding decrease in the amount of energy consumed. It will therefore be seen that on the basis of light flux and energy alone, smaller lamps and closer spacing would be best. But with every lamp unit there is a certain fixed charge independent of the energy consumed. If the lamps are spaced too close together this fixed charge per unit becomes larger than the energy charge per unit. There is accordingly a midway point which gives the best lighting effect and is at the same time most economical. The series tungsten system with its low maintenance charge per unit and the great range of sizes in which it is made, allowing the selection of that size of unit which will give the exact amount of light desired at any point, closely approaches ideal conditions.

Tungsten filament lamps will operate equally well on either direct or alternating current of any commercial frequency, thus allowing the selection of that kind of energy which can be most economically generated and transmitted under local conditions, or the connection of the lamps to some circuit already installed. Furthermore, when a constant current transformer is employed it allows the use of different sized units, either temporarily or permanently, without the cost of a new circuit. The new lamps are selected for the required candle-power, but of the same ampere rating as the circuit already in use, and installed at the desired points upon the existing circuit.

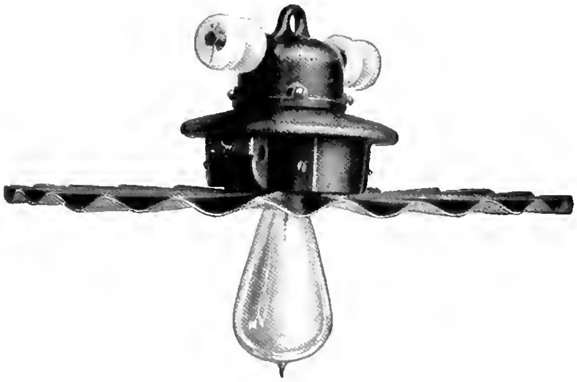


Fig. 1. Radial Wave Reflector for use with Series Tungsten Filament Lamps

Tungsten lamps can be operated with complete satisfaction in series with magnetite arcs, provided precautions are taken to avoid an excessive starting current. Care should be exercised, however, to select lamps whose normal ampere rating is equal to that of the average current flow of the circuit. When a large number of tungsten lamps are located in reasonably compact groups, it may be advantageous to operate them on circuits separate from the arc lamps.

The tungsten lamp maintains its candle-power and brilliancy practically constant throughout life. As shown by the curves (Fig. 2), the candle-power of the carbon lamp drops to 80 per cent of its original value in 700 hours, while the tungsten lamp drops only to 95 per cent of its candle-power in the same length of time. The drop of 5 per cent is so slight that it is hardly noticeable, and can be measured only by accurate instruments.

The series tungsten lamps for street lighting, unlike the multiple lamps which are rated in watts and volts, are rated in candle-power and amperes, and designed for a constant-current circuit. With series lamps the same amount of current flows through all the lamps upon that circuit, and accordingly the current strength for which the lamps are designed must be given. Also, by knowing the ampere rating, lamps of different candle-power values but of the same current strength, can be operated upon the same circuit. The candle-power rating is given because most street lighting contracts are made upon a candle-power basis. Such a contract basis gives the central station the benefit of any improvement or increase in efficiency whereby the same amount of light is secured for a smaller energy consumption.

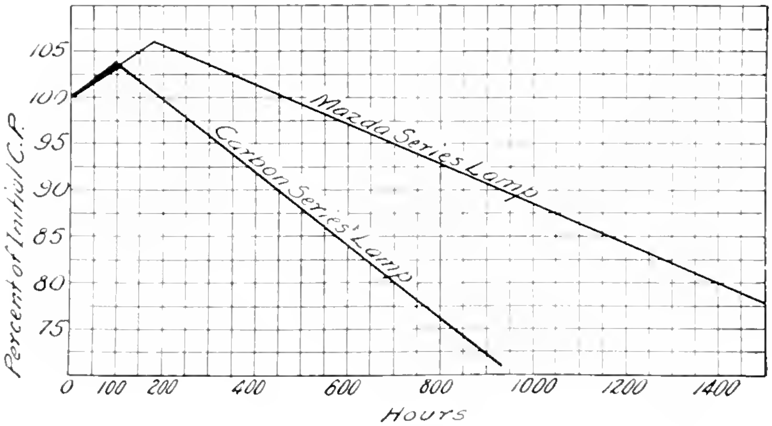


Fig. 2. Variation in Candle-power During Life of Tungsten Series and Carbon Series Lamps

The series lamps are now made in both large and small sizes, and enable the lighting of entire cities being accomplished by means of tungsten filament lamps.

In downtown districts the use of the multiple lamp may be advantageous, since it can be tapped directly from the commercial circuits, thus simplifying the arrangement of wires either overhead or in conduit. In such cases, provision must be made locally for switching the lamps on and off, either automatically or by patrolmen. Where a considerable number of lamps are to be controlled, it is the common practice to make the connection from a single switch for an entire block or square, thus minimizing the labor of switching.

For long stretches of country roads or interurban thoroughfares, where the lighting need only serve the purpose of outlining the road, and where uniform illumination cannot be afforded, the series tungsten lamp is the best illuminant. It operates successfully on a high voltage alternating current circuit, thus securing the greatest efficiency of transformation and distribution of energy with the least cost in apparatus and equipment.

In the design of a street lighting installation no hard and fast rules can be laid down, as local conditions will play an important part in determining the amount and distribution of light. However, care should be exercised to place the lamps fairly well up above the ground, when there is no foliage or other obstruction to the distribution of the light, thus securing the maximum amount of light at the distant points and causing the shadows to be shorter and less extensive. If, however, the lamps are suspended too high what is gained in uniformity is lost in intensity. A lamp hung 20 ft. above the ground gives but one-quarter as great an intensity directly under the lamp as the same lamp placed 10 ft. above the ground. In determining the height, spacing, etc., of the illuminants for any installation where uniform intensity is desired, the amount of light at the midway points is the determining factor. In some places where the foliage of the shade trees is allowed to come within 12 ft. of the ground, the theoretically correct suspension of the unit would not be advantageous. Instead, the lamp should be placed so low as to be under the foliage, thus preventing any of the light from being cut off by the trees. In this way the maximum amount of light is given upon the roadway, and the best possible illumination secured, even though it may not be ideally distributed. For every illuminant there is a certain spacing and height at which it will give the best results, depending upon the characteristics of the illuminant, the intensity desired, the distance between lamps, and the environment. Tungsten filament lamps of from 32 to 100 candle-power, equipped with radial wave reflectors, should ordinarily be placed at a height of from 12 to 18 ft., and larger candle-power tungsten lamps with the same equipment at a height of about 20 ft., while the distance between lamps should vary between five and ten times the mounting height.

For instance, upon a business street, where the traffic is heavy and liable to become congested, an installation of 200 candle-power lamps, 18 ft. high and 100 ft. apart, on each side of the street; or, 350 candle-power lamps, 29 ft. high and similarly spaced, would be good practice. The actual size of the lamps used would depend upon the intensity desired. Upon a residential street where the traffic is not very heavy sufficient illumination of a fairly even intensity would be supplied by 100 candle-power lamps placed 15 ft. high and 100 ft. apart. If the foliage were dense and close to the ground 60 candle-power lamps could be used, spaced every 60 ft. and placed at a height of about 12 ft., does not necessarily mean placing the lamps at the extreme corner of the curb, since this might introduce glare which would interfere with the vision of a driver about to turn the corner, especially if the lamps are placed low.

The lamps should be equipped with a radial wave reflector, Fig. 1. This reflector changes the distribution curve of the tungsten lamp so that the maximum amount of light is given off at an angle of 20 degrees below the horizontal instead of exactly at the hori-

Fig. 3. Night View Taken on Water Street, Elmira, N. Y., Showing Well Distributed and Even Illumination. The Uniformity of Illumination and the Absence of Any Deep Shadows on Either the Road or Side Walk is Very Noticeable. The Lighting in this Instance is Effected by Series Tungsten Filament (Mazda) Lamps. There are Three 80 Candle-Power Series Lamps on Each Standard Taking 6.6 Amperes. The Lamps are Spaced 60 Ft. Apart

which will ordinarily clear the foliage. Upon streets where the traffic is not sufficient to warrant even an approximately uniform intensity, and where the spacing of the lamps depends upon the money available for the lighting, the best results are obtained by using 32 or 40 candle-power lamps placed 15 ft. above the ground.

Since the danger of collision is always greater at street intersections where lines of travel intercept, it is important that the lights be so arranged as to provide relatively high intensity at these points. This, however, zontal. As a result, the actual illuminating efficiency of the lamp is increased 35 per cent and uniform illumination is more easily obtained.

In many installations the lamp is placed at the side of the street, thus making the installation less expensive, keeping the light rays from shining directly into the eyes, and reducing the glare.

The staggered placing of the units, that is, consecutive lamps on opposite sides of the street, is an aid in giving uniform illumination where the street is broad, although it does not make so good an appearance as when lamps are placed opposite. Where the street is narrow staggering may not be as desirable as placing the lamps in a single row on one side of the street. In fact it is more expensive to install, and is actually disadvantageous, as it confuses the outline of the road especially where there are curves.

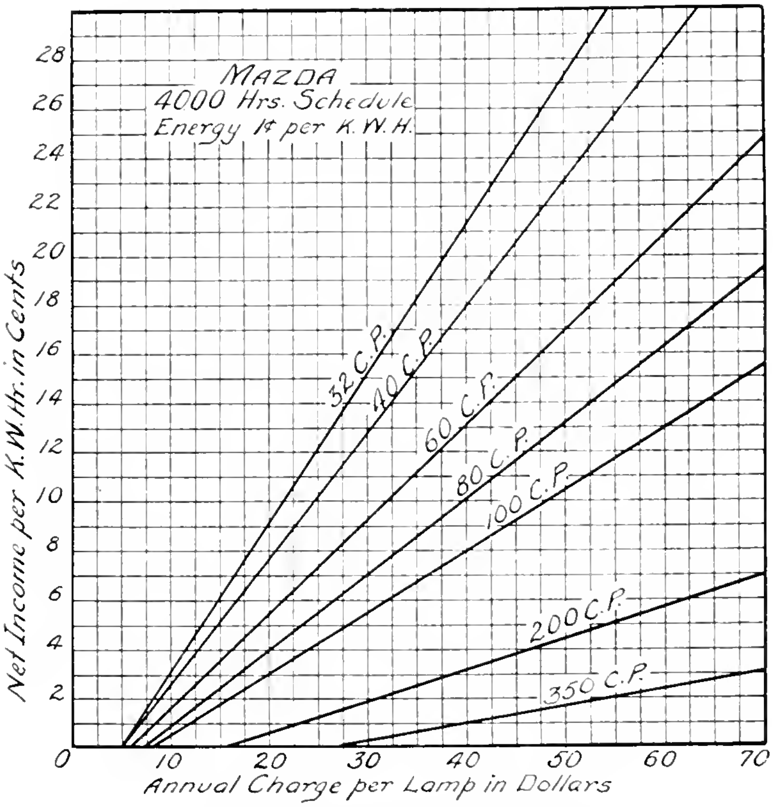


Fig. 4. Curves Showing Net Yearly Income to Central Stations for Operating Tungsten Street Series Lamps

NOTE.—Net income does not include overhead charges but is calculated as follows:

$$\text{Net income per Kw-h.} = \frac{\text{Annual Charge} - (\text{Cost of Energy} + \text{Renewals})}{\text{Annual Kw-hours}}$$

In any street lighting installation it is desirable to place the lamps in straight lines and hang them at equal heights above the street. If this is done the perspective appearance of the street especially after dark will be greatly improved. No expense beyond a small amount of thought and care is required, but the neglect results in an untidy appearing installation, no matter how ornamental the lighting units.

When a new series street lighting installation is being made, the current strengths that are most generally adopted are 4, 5.5 or 6.6 amperes. For any given candle-power the higher the amperage of the lamps, the lower their voltage. Therefore, for an installation of a definite number of lamps, of a definite candle-power, any decrease in the line current means a large increase in the line voltage, equal to the product of the increased voltage per lamp, multiplied by the number of lamps in the circuit. This increase in line voltage necessitates a corresponding and extensive increase in insulation. If we go to the other extreme and select an unusually large current value, the amount of energy dissipated along the line will be excessive. This energy lost in transmission increases very rapidly with a slight increase in the current value, as it is approximately equal to the product of the square of the current and the resistance of the line. Consequently the most economical current value for a street lighting system is that value which balances up the interest and depreciation upon the cost of insulation against the line loss, so as to make the total maintenance cost as low as possible. The current values that most nearly satisfy these conditions are 4, 5.5 and 6.6 amperes, particularly the latter value. These are also the current strengths for which many arc lamps are made.

where F equals foot-candles, C equals candle-power in the direction of the point, and E is the distance in a direct line from the lamp to the point.

In figuring the illumination for any such points it will be seen that there are two factors in the formula to be determined, namely, E^2 and C.

Candle-power varies for different angles of

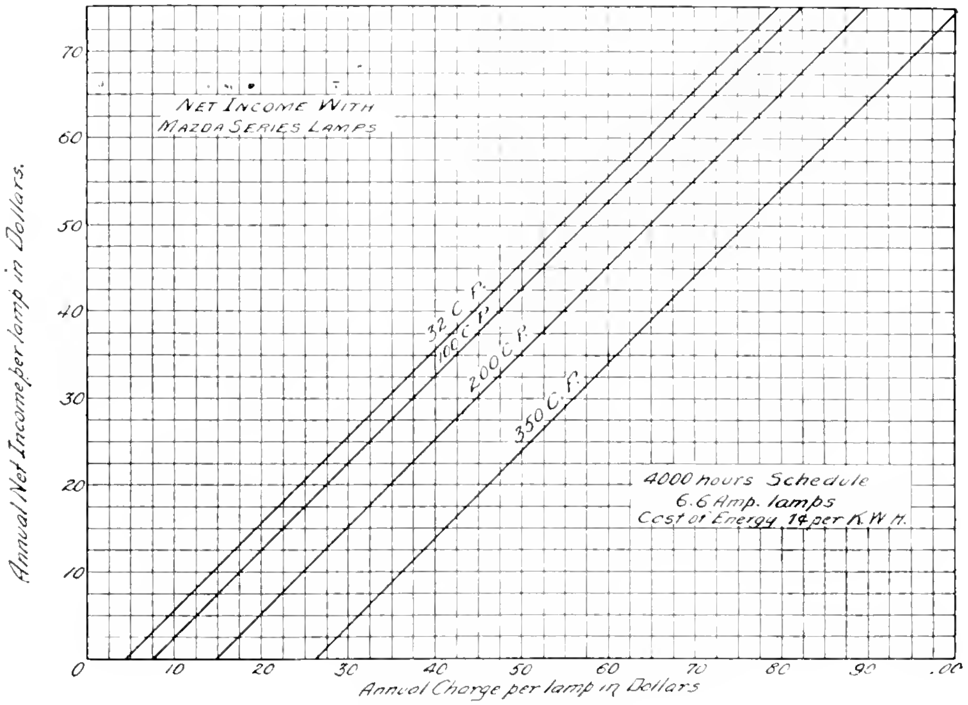


Fig. 5. Curves Showing Net Yearly Income to Central Stations for Operating Tungsten Street Series Lamps

NOTE.—Net income does not include overhead charges, but is calculated as follows: Annual net income per Lamp in Dollars = Annual Charge − (Cost of Energy + Renewals)

CALCULATION OF ILLUMINATION

The intensity of illumination furnished by a lamp to any point in the street is usually expressed in foot-candles on a surface normal to the rays of light at that point. Otherwise expressed, assuming that there is a stone or other object at the point in question, the illumination is expressed in terms of foot-candles, measuring the intensity received on the face of the object which is turned directly toward the light. If the candle-power of the lamp is known the illumination at any particular point can be calculated by the law of inverse squares, which is expressed in the following formula: $F=\frac{C}{E^2}$

elevation, but can easily be read on the curves, if the angle of the ray directed toward the test point is known. This angle as well as the distance E can be determined either by calculation or by a graphical method.

The graphical method of determining the angle of elevation and direct distance from the lamp to the point in the street is illustrated in Fig. 7. The photometric curve is superposed on a sketch drawn to the scale of one-eighth inch to the foot and shows the lamp twelve feet from the pavement.

To determine the illumination at any point such as A, 48 feet from the point B directly beneath the lamp, the line E is drawn from L to A.

Assuming that H is the equivalent of 12 feet and D the equivalent of 48 feet, E is found to be $49\frac{1}{2}$ feet.

We further find that the line E cuts through the photometric curves at 14 degrees below the horizontal and at this point the candle-power, as read from the curve, is 39 for the 40 candle-power lamp without reflector, 43 with conical reflector, and 51 with radial reflector.

The illumination at A can then be calculated as follows:

No reflector, $F = \frac{39}{19.5^2} = \frac{39}{2450}$

$= 0.016$ foot-candles.

Conical reflector, $F = \frac{43}{19.5^2} = \frac{43}{2450}$

$= 0.0176$ foot-candles.

Radial reflector, $F = \frac{51}{19.5^2} = \frac{51}{2450}$

$= 0.0208$ foot-candles.

In a similar manner, illumination can be calculated for points nearer to or farther from the lamp by simply indicating the point at its proportional distance along the ground line and measuring the line drawn from the lamp to the point. It can also be applied for different heights of lamps by drawing ground lines parallel to the one in the sketch and located above or below it so as to give H its proportional value. For the 60 and 80 candle-power lamps the illumination is practically proportional, and can be figured from the same curve.

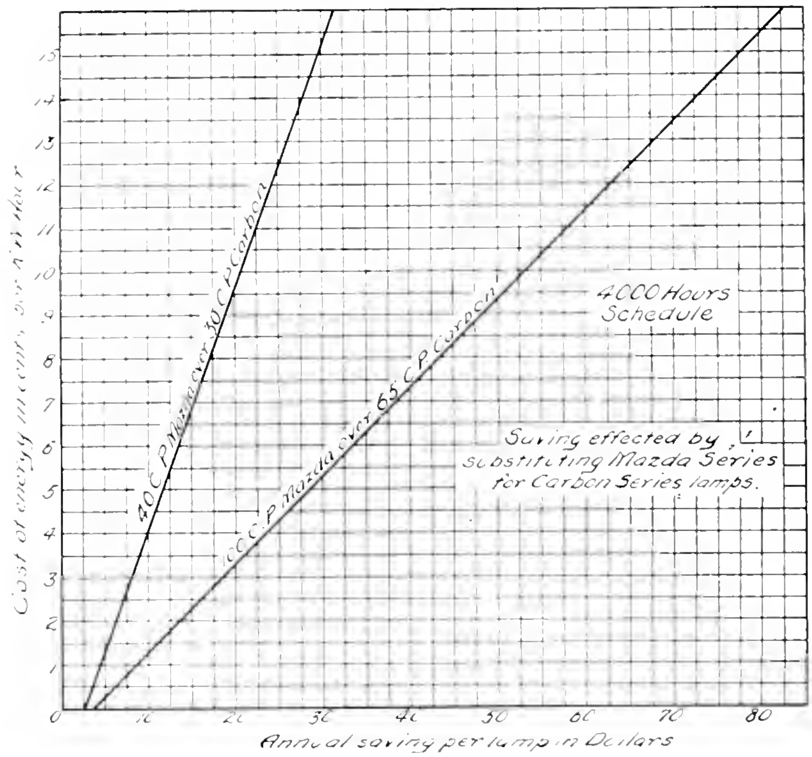


Fig. 6. Saving Effected by Substituting Tungsten Series for Carbon Series Lamps

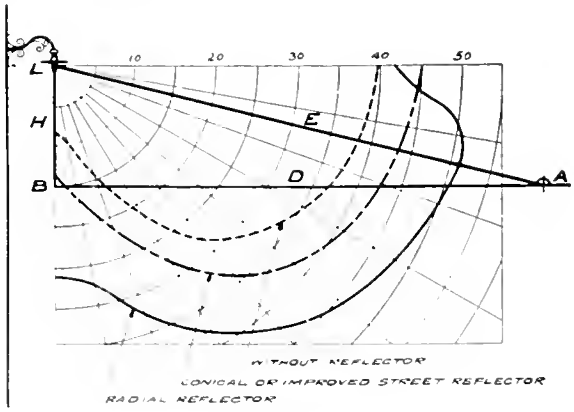


Fig. 7

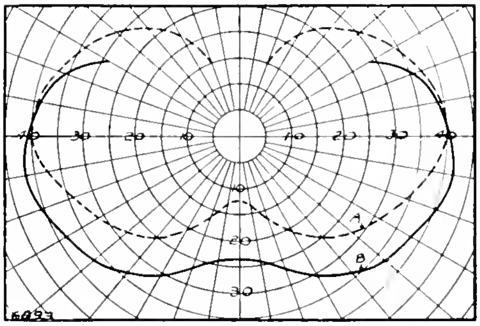


Fig. 8

40 c-p. series Mazda lamp (clear)	
15 in. radial wave reflector	
Mean hemispherical c-p.	36.8
Mean spherical c-p.	28.6
Downward lumens	231
Total lumens	360

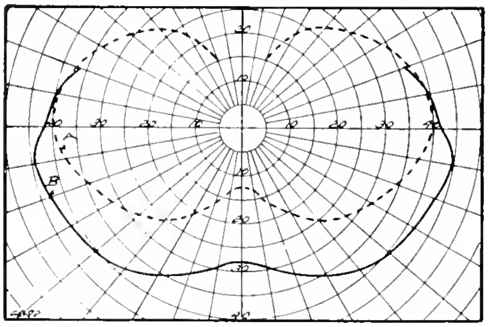


Fig. 9

40 c-p. series Mazda lamp (clear)	
20 in. radial wave reflector	
Mean hemispherical c-p.	40.5
Mean spherical c-p.	28.4
Downward lumens	254
Total lumens	357

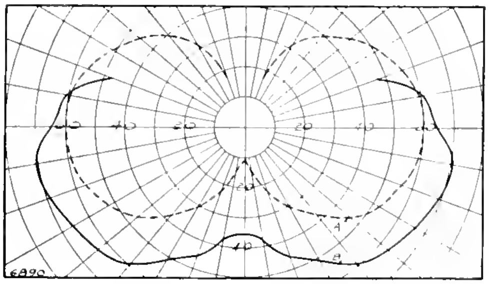


Fig. 10

60 c-p. series Mazda lamp (clear)	
20 in. radial wave reflector	
Mean hemispherical c-p.	62.5
Mean spherical c-p.	43.2
Downward lumens	393
Total lumens	543

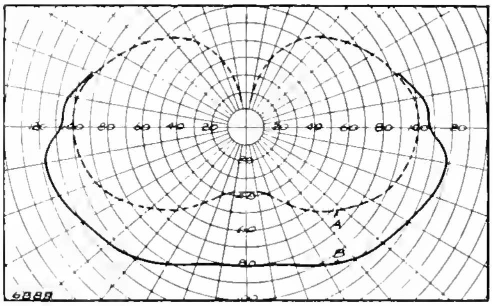


Fig. 11

100 c-p. series Mazda lamp (clear)	
20 in. radial wave reflector	
Mean hemispherical c-p.	105.8
Mean spherical c-p.	73.9
Downward lumens	664
Total lumens	930

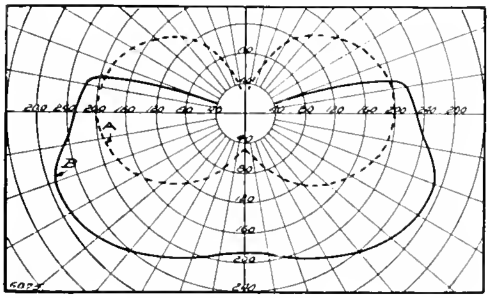


Fig. 12

200 c-p. series Mazda lamps (clear)	
24 in. radial wave reflector	
Mean hemispherical c-p.	247
Mean spherical c-p.	152
Downward lumens	1549
Total lumens	1910

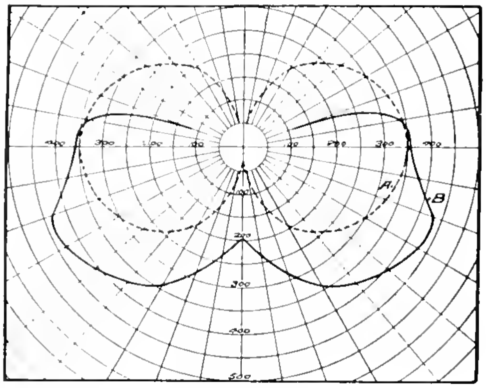


Fig. 13

350 c-p. series Mazda lamps (clear)	
24 in. radial wave reflector	
Mean hemispherical c-p.	382
Mean spherical c-p.	246
Downward lumens	2400
Total lumens	3090

Some Typical Photometric Curves of Tungsten Lamps

THE APPLICATION OF SWITCHBOARD RELAYS TO THE PROTECTION OF POWER SYSTEMS

PART III

By D. Basch

Switchboard Engineering Department, General Electric Company

The first part of this paper appeared in our April number and dealt with the physical construction of the various types of relays and the operating conditions governing their selection, from the standpoint of the time characteristic. The second portion, in the June issue, was devoted to a third classification, based on the nature of the disturbances with which relays have to deal. Six classes of disturbances were specified, of which one, ***overload and underload***, was fully discussed. The second, ***short circuit***, was followed through generator and transformer short circuits, well into the discussion of the requirements of line short circuit protection. The whole of the present installment also has to do with line short circuits; and in fact, there are so many sides to the problem that it is necessary to again carry part of the section over to our next installment. The series will probably be completed in two further installments.—Editor.

A_6. Direction of energy flow normally always the same. Two or more transmission lines used, paralleled at both ends.

With two or more transmission lines running in parallel between two stations, each line must be equipped with relays which will protect it against trouble within its own circuits, and at the same time be unaffected by trouble of any nature occurring in any other line in series or in parallel with it.

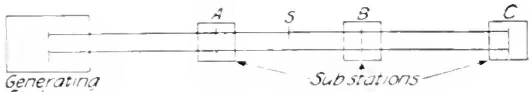


Fig. 14

The simplest form of such a transmission scheme is shown in Fig. 14. Assuming a short circuit in the upper line between substations *B* and *A* at the point *S*, energy would be fed into the short circuit from two directions; (1) from *A* through the upper line *AS* in the normal direction and also from *A* through the lower line *AB* in the normal direction, and (2) through the section *SB* of the upper line in a direction opposite to the normal. It is therefore evident that an overload relay at the source end and a reverse-power relay at the load end would properly take care of the trouble. The reverse-power relay should be instantaneous, and the overload relay selective time, to give the best results, as is shown in Fig. 10.*

It is of the utmost importance that the reverse power relays operate only under conditions of reversal. A reverse-power relay of the solenoid type commonly used at one time contained a current and potential coil wound on a common core with a plunger moving vertically inside the core. The coils were wound in such a manner that under normal conditions the instantaneous magnetic effects of the coils were opposed to each other, giving zero effect as a resultant. With the reversal of direction of energy, the instantaneous direction of current in the potential coils would remain the same, whereas the direction in the current coil would reverse, so that both coils would then act in the same direction, creating a magnetic field of sufficient strength to cause the plunger to move into contact.

However, reverting again to Fig. 14, it will be seen that if the short circuit is sufficiently close to station *B*, the potential on the busses in *B* will be lowered to such an extent that the increase of current in both lines, and in both relays due to the short circuit, is sufficient to make the influence of the potential coils on both relays negligible. If we call C the normal magnetomotive effect due to the current coil, P the normal magnetomotive effect due to the potential coil, and if we assume that the short circuit causes the current to rise to three times normal and the potential to drop to 50 per cent normal, then under ordinary conditions the resulting magnetomotive effect is $C-P=0$, or $C=P$. $C+P$, or $2\ C$, would then be required to operate the relay.

Under short circuit conditions the magnetomotive effect on the relay in the upper line would be $3\ C+\frac{1}{2}\ P=3\ C+\frac{1}{2}\ C=3.5\ C$, and in the lower line $3\ C-\frac{1}{2}\ P=3\ C-\frac{1}{2}\ C=2.5\ C$, each sufficient to operate the relay. Therefore both relays would go out, causing a shut down on both lines, instead of segregating the line in case of trouble and leaving the healthy line intact. Similar trouble may be caused by a short occurring in one of the lines between *B* and *C*, close to station B. This would also be liable to put out the two

*For Figs. 5 to 13 inclusive see Part II of this article, General Electric Review, June 1913.

reverse power relays at *B*, in the two lines between *A* and *B*. The relay shown in Fig. 5 should be used, as it is not affected by any rise in current, no matter how low the potential, so long as the direction of feeding does not change.

There are conditions, however, under which the solenoid type of relay, slightly modified, will render efficient and inexpensive protection. With two lines or more running in parallel, two sets of these reverse-power relays may be installed as shown in Fig. 15. The diagram refers to a three-phase, three-wire system, and the potential transformers on the busses are arranged with middle taps on the secondaries, so as to permit the potentials to be in phase with the currents. Two double-pole relays are employed, the two poles of each relay being connected to corresponding phases in the two lines I and II. A rigid connection in the form of a crossbar or walking beam, pivoted in the middle, is arranged between the two poles of each relay, so that with equal pull on each pole, neither of the two plungers can go up, and with a heavy but unequal pull only the one with the heaviest pull.

Referring again to Fig. 14: with the same conditions that brought about simultaneous operation of the two individual reverse-power relays—a short circuit at *S* close to *B*—the pull on each plunger is more than required to operate each one individually; but on one it is 2.5 C and on the other 3.5 C. The one with 3.5 C will, therefore, overpower the one with 2.5 C and pull up. As one plunger goes up and the other one is pulled down, the difference between the force of the pulls on the plungers will grow more pronounced, since the one going up enters a magnetic field of increasing strength and the other a field of decreasing strength.

In the other case referred to in the discussion of the plain solenoid-type reverse-power relay, viz., a short circuit occurring in one of the lines between *B* and *C* close to station *B*, there will, of course, be a tendency on both plungers of the interlocked relay to go up, due to the heavy current and low voltage; but as both lines carry the same proportion of load, the pull on both plungers will be equal, and because of the mechanical interlock no action can result. The interlock reverse-power relay may still be used, although when more than two lines are run in parallel it becomes necessary to interconnect all lines in sets of two, as indicated in Fig. 16. That is, relay *a* connects phase 3 of line III and II; relay *c* connects phase 3 of II and I; relay *b* connects phase 1 of III and II; relay *d* connects phase 1 of II and I; relay *e* connects phase 3 of III and I; and relay *f* connects phase 1 of III and I.

It should be remembered that one or more of the lines installed may temporarily be cut out for inspection or repairs, or on account of very light loads.

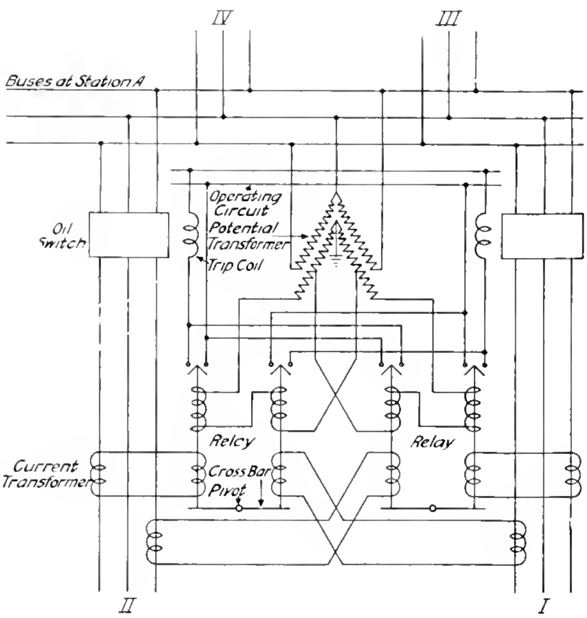


Fig. 15

Considering the case shown in Fig. 15: if one line, say II, is cut out, the left-pole of the relay would be energized by its potential coil, while the right pole would ordinarily not be energized at all, on account of current and potential coils opposing each other. The left plunger would therefore go into contact and hold the right plunger down, so that no further action would result in the remaining line I.

However, with a short circuit on another line in series with II, say III, considerable current would pass through line I and lower the voltage at the busses to which the potential coils of the interlocked relays are connected, and it is quite possible that the pull on the right pole would increase above the pull on the left pole, so that the right plungers would go into contact and open up the line I. Thus, instead of letting the relays in line III isolate the trouble so that power may be transmitted without interruption through

I and IV, the whole system would be shut down.

To take care of this possibility, all line oil switches operated by interlocked reverse-power relays should be equipped with auxiliary switches, which, when a line switch is open, will kill both poles of the interlocked relay. For instance, if in Fig. 15 the line oil switch II is opened, its auxiliary switch should make inoperative both relays, rendering the line switches in I non-automatic. With only one line connecting two stations, no automatic protection is required on the incoming end anyway, as a short circuit on this particular line would operate the overload relay on the outgoing end and shut down the whole system beyond the point of the trouble. With more than two lines, as shown in Fig. 16, the opening of the line oil switch in III should render inoperative relays *a*, *b*, *c*, and *f*, leaving in circuit only *e* and *d*.

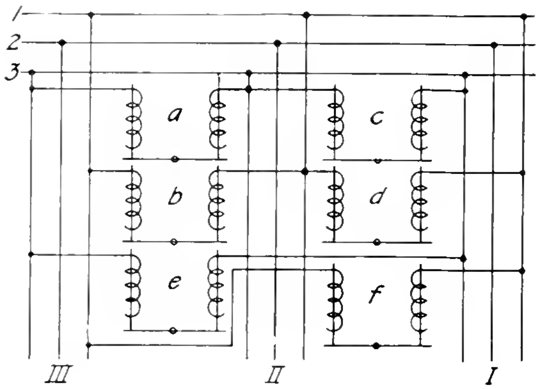


Fig. 16

Particular mention should be made of the fact that this interlocked reverse-power relay should not be used where the direction of energy is usually always the same, but may reverse at times due to trouble in other circuits (see Fig. 17). A short circuit in line 3 at S would cause reversal of the direction of energy in line 1, and also in 6 and 5, due to energy being fed into the short from the generating station through line 7.

It is, of course, very difficult to adjust both plungers of one interlocked relay absolutely alike. There will generally be some slight inequality in the setting of the two plungers, resulting in an unequal initial pull on the two plungers in spite of equal load.

In the case shown in Fig. 17, an exceptionally heavy magnetic field will be produced on the relay, owing to the fact that the current and potential coils will work in the same direction. The current is high and the potential not much reduced, since at least one whole line is between the point of short circuit and the potential source for the relay. The effect of unequal setting in such a field will be greatly magnified, and may easily exceed the limits within which the inherent difference of adjustment may be compensated. The result would then be the action of the relays in lines 6 and 5, instead of in 3.

Under the conditions outlined above, it is recommended that reverse-power relays as shown in Fig. 5 be used with time elements so graded that their highest setting is below the lowest setting of the selective time-limit overload relays at the outgoing ends of the line, and that lines 6 and 5 have a longer setting than 4 and 3, etc. It is easily seen that the interlocked relay cannot be used where bus section switches are installed in the busses to which the lines containing these relays are connected. If these bus-section switches should be open, the division of load through the two lines would not be constant any longer, and according to different load conditions in the two bus sections to which the lines are connected, unequal pull may be

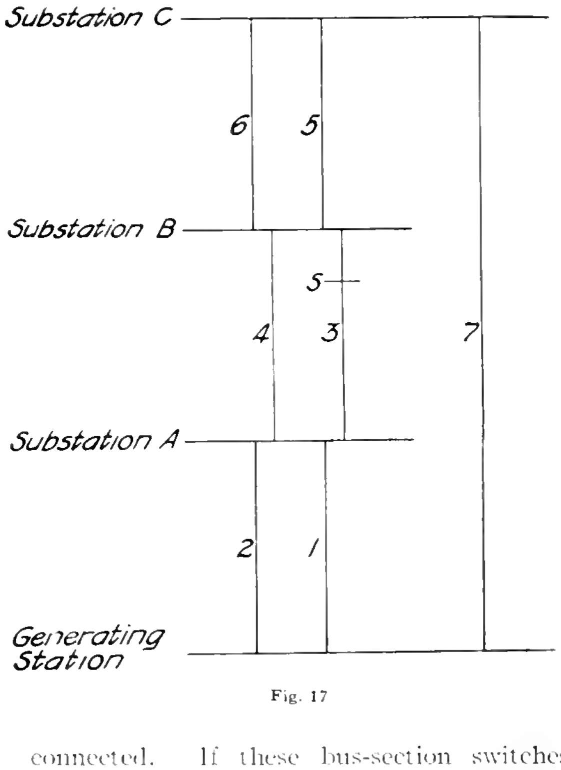


Fig. 17

exerted on the two plungers, causing the relay to make contact under otherwise normal conditions. The reverse power relay of Fig. 5 should be used in such cases.

Where never less than three transmission lines are run in parallel, inverse time-limit relays are sometimes installed on the incoming end, with selective time-limit relays at the outgoing end. See Fig. 18.

Assuming a short circuit at *S* in line II, with all three lines I, II, III in service, energy will be fed into the short circuit from II to S, and in a parallel circuit from I and III to the bus, and from there through II to *S*. It is evident that a relay in line II must receive the sum of the currents fed through I and III and, with all three relays of the inverse time-limit type set for the same time and current, the time required to operate relay in II must be shorter than for relays in I and III. The greater the number of lines, the more positive will be the differentiation in time between the relays. When considering the use of such inverse time-limit relays for this purpose, it should be remembered that the relay will cause a general shut-down on the incoming end of all lines, if at any time less than three lines are in service and trouble should occur just then on one of the lines. Both relays would then receive exactly the same current and, if this current were high enough, both relays would go out simultaneously.

Furthermore, the effectiveness of the relays must be questioned where exceptionally heavy short-circuit currents may be expected. This does not mean that the ratio of short-circuit current and generator current must be high, but that the ratio between current carried normally in the transmission line and that developed through short circuit may be high, as for instance, where only part of the generated capacity is distributed through this particular set of transmission lines.

Inverse time-limit curves have a high gradient in their first part, but for currents from about five times normal and up the gradient is very low. To revert again to Fig. 18: if the short circuit current in the relay in line II is, say 10 times normal, and in line I and III five times normal, the difference in time for the three relays is apt to be so small that slight differences in the mechanical characteristics of the oil switches controlled by the relays or variations in the shape of the time curves of the individual relays may be sufficient to offset the calculated difference in time, and cause either all relays or the wrong ones to go out.

8a. Direction of flow of energy may reverse under normal conditions. Single transmission line.

On page 383* reference was made to line *BC* (Fig. 13) as having special characteristics. According to load conditions along the whole transmission system between the two generating stations, the neutral point

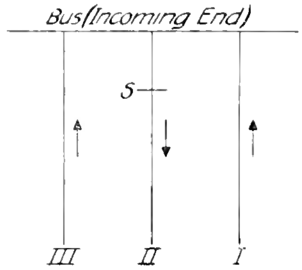


Fig. 19

of distribution, i.e., the point of equal potential drop to both generating stations, will shift between *B* and *C*. At times energy will flow from *B* to *C*, when *C* is the neutral point; at other times from *C* to *B*, when *B* is the neutral point. This variation in the direction of the flow of energy may be very sudden and frequent, and is entirely beyond the control of any switchboard operator or power dispatcher.

Similar conditions prevail in line *BC* in Fig. 11. Proper relays for such lines must be unaffected by reversal of the direction of flow of energy; they must not be affected by any distributed overload carried over the line, and must operate only in case of single-phase or polyphase short circuit in their own line.

Fig. 19 shows a relay which has given good results under these conditions. This relay is based on the principle that as long as there is no trouble in the line to which it is connected, the direction of flow of energy must be the same at both ends of the line. Only in case of trouble will the direction not be the same, for then energy will be fed into the trouble from both ends of the line.

A relay of a construction similar to the one shown in Fig. 5, but with double contact, is installed at each end of the line. Current and potential coils are fed from instrument transformers in the line. The two pivotal points of the relays at both ends are connected each to a low voltage relay, and then joined together through a pilot wire connecting

* See Part II of this article, GENERAL ELECTRIC REVIEW, June, 1913.

the two stations and running parallel to the transmission line to be protected.

The contacts of the relay proper are connected to a low voltage pilot bus, which must be common to both stations. In the case of an interconnected three-wire system

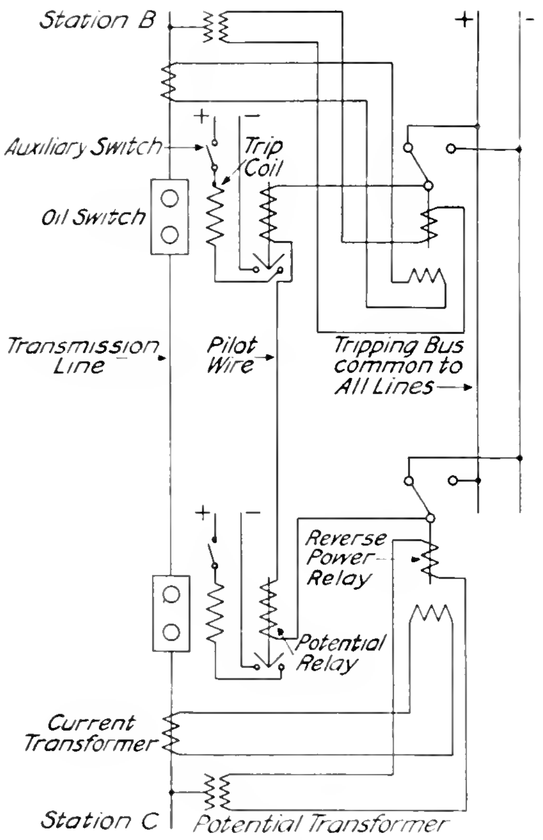


Fig. 19

touching both stations, one outside and the neutral may be used. For railway lines the ground rail and for underground cables the lead sheath may be used as one bus, a separate wire transmitting the other polarity of a low-voltage circuit from one station to the other. If no such common carriers are available, two separate wires must be run from the station containing the low voltage circuit to the other station.

The two relays proper are wound in such a manner that, according to the direction of flow of energy, the contact levers on both relays tend to make contact, the one in *B* to the positive pilot bus and the one in *C* to the negative bus, or the one in *B* to the negative and the one in *C* to the positive bus. Under these conditions the full potential of the pilot bus is impressed on the low voltage relays, so that their plungers are held out of contact.

Assume now that at a certain time energy is fed from *B* to *C*, with both contact levers of the relay lying against the left-hand contact. A short-circuit occurs on the line. Immediately the direction of flow of energy reverses in *C*, energy being fed back into the short circuit. The dynamometer movement of the relay in *C* swings the contact lever over against the right contact and the two low voltage relays are short circuited (positive to positive) so that their plungers drop into contact and energize the trip coils of the oil switches at both ends of the line.

In order to take care of single-phase short circuits as well as polyphase, the pilot wire relays are built up in single-pole units with

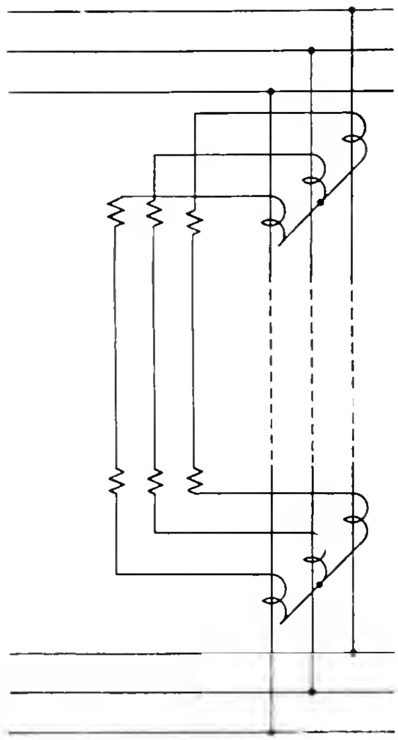


Fig. 20

their contacts suitably interconnected. For any load up to a predetermined amount in any direction, a spring of proper strength holds the contact levers in a certain direction, as shown in Fig. 19. Only when currents exceeding this amount flow through the current coils in the direction opposite to that corresponding to the normal position of the contact levers, will the contact levers swing over against the other contact.

In this manner the relay will hold in, even at no load, and it will also be possible to close the oil switches after they have opened. A slight time element is attached to the pilot wire relay to prevent the oil switches from tripping out when, due to a heavy overload current through the line in the direction opposite to the one corresponding to the normal position of the contact levers as may be caused by trouble in another line in the transmission system, both contact levers swing over against the other contact. Without this time element the low voltage relays might trip out when the contact levers are between the two contacts.

This relay scheme requires, as mentioned above, one pilot wire between the relay pivots and a maximum of two pilot busses. These wires may be very small, as the current taken by the low voltage relays is only in the neighborhood of 1/2 amp. It should be noted that this relay carries its own danger signal; if the pilot wire breaks or any trouble develops on the pilot busses, the relay will immediately indicate it.

Another pilot wire scheme used extensively on the continent will now be described. Current transformers are installed at both ends of the line with their secondaries connected bucking. Trip coils for the line oil switches are placed in the secondaries, as shown in Fig. 20. Under normal conditions the trip coils are not energized. However, when trouble occurs anywhere along the line, the direction of current reverses at one end and the current-transformer secondaries are then boosting, i.e., in series, and the oil switch trip coils are actuated.

The current transformers used for this relay must have special design features, as they usually run with secondaries practically open-circuited and, of course, no instruments can be used with them in addition to the relays. In order to prevent charging currents (when closing oil switches on a line) and surges from tripping the oil switches, resistances must be connected in parallel with the high-tension side of the current transformers. Careful adjustment of the transformers is necessary in order to obtain zero current in the secondaries under all possible conditions of normal operation. If a pilot wire in this relay system should accidentally open, no warning would be given that the protective system was inoperative. Their conspicuous advantage lies in the fact that they are absolutely independent of potential.

The objection to the use of time-limit relays instead of pilot-wire relays can best be understood by reference to Fig. 11. If time-limit relays are installed at both ends of lines *BC* and *CD*, a short circuit, for instance in *BC*, would necessitate a shorter time element in *BC* at *C* than for the relays in *CD*. On the other hand, a short circuit in *CD* would require a longer time setting in *BC* at *C* than for the relays in *CD*. However, cases like that shown in Fig. 13 may be taken care of with selective time-limit relays in line *BC* at both ends, with time setting less than for selective time-limit relays at *A* and *D*.

AUTOMATIC SUBSTATIONS

By H. R. Summerhayes

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The principal installation described in this article (which was read before the recent Cooperstown convention of the A.I.E.E., and has since been amplified for the Review) is the automatically operated converter substation of the Detroit Edison Illuminating Company, which represents the first case where a synchronous converter has been installed to operate without the constant attention of an attendant. Practice has always required operators at converter substations, and in earlier days they were necessary; but the converter is now such a reliable piece of apparatus that operators can sometimes be dispensed with. To show to what degree this installation is of an unusual nature, the author mentions some of the more familiar examples of the automatic operation of electrical apparatus, such as axle-driven generators for train lighting, transformer substations, regulators, motors for pumps and blowers, etc., and describes in detail an induction-generator installation and a motor-generator installation embodying some new and interesting features of automatic operation. The induction generator is arranged to operate, after having been started by an operator, without attention and at full gate opening at all times, no governor having been provided. The motor-generator set is provided with devices for automatically bringing it into synchronism or re-starting it, when, because of failure of the supply, it falls out of step or comes to rest. The converter substation is remarkable in that all operations of starting, paralleling, and load adjustment are effected without the employment of any control wires other than the three-phase conductor carrying the main current, and the set is fully protected against short circuit on both the a-c. and d-c. sides and against runaway. The successful operation of this substation over a long period of time has proved it to be a valuable engineering achievement.—Editor.

The prime purpose of this paper is to present a description of the automatic substation at Detroit, in which there is installed a synchronous converter which is controlled entirely from a distant station. Some further observations are also made on automatic substations in general.

AUTOMATIC OPERATION

Automatic operation, strictly defined, is that where a machine performs its functions without any human control. In the Detroit station the control is from a distance, but the apparatus may be said to be automatic inasmuch as the various functions of its starting, stopping and regulation are performed without the supervision of an attendant in the station where the machine is located.

The operation of a commutating machine of fairly large size in a substation without an attendant, supplying current to a commercial lighting system, is so different from the general practice that in leading up to it some consideration will be given to the more familiar examples of automatic substations.

Remotely controlled electrical apparatus is now widely used for a variety of different purposes. It is generally employed for reasons of convenience, to save labor, or because the machine to be controlled is inaccessible, or to concentrate at one point the control of a number of machines whose functions are related. When the machine is inaccessible by reason of its location or because of its being enclosed, or when it is out of sight and hearing of the operator, it does not matter whether it is in the next room or a mile away. It is only a question of degree.

The following are some of the more familiar examples of remote control. In some of these the machine which is operated by the electric control is visible to the operator, and in other cases he receives signals that the machine has operated, but in nearly all cases the electric motor is out of sight and receives only occasional attention and inspection.

TRAIN LIGHTING

In systems of train lighting with an axle-driven generator, the generator itself is inaccessible and out of sight and receives only occasional attention. Its operation as to commutation, temperature rise, etc., is taken for granted, and the control is usually by four automatic devices, i.e.:

(1) A pole changer, which reverses the polarity of the generator when the direction of motion of the car is reversed.

(2) An automatic switch, which keeps the generator disconnected from the system at low train speeds and connects it when a certain speed is reached.

(3) A current regulator, which varies the generator field so as to supply a constant current to the storage battery.

(4) A lamp voltage regulator, which operates usually by working on a variable resistance in the lamp circuit.

In the case of train lighting the generator is inaccessible to the extent that it might as well be a mile away.

TRANSFORMER SUBSTATIONS

The transformer substation, whether out-of-doors or indoors, is one of the most familiar examples of the operation of electrical apparatus without an attendant. Of course, the transformer is a stationary piece of apparatus, but even a transformer shares with moving machinery the possibility of injury by lightning or overload.

REGULATORS

It is not unusual practice for lighting companies supplying alternating current to install automatic feeder regulators in a transformer substation which has no attendant and only occasional inspection. Here we

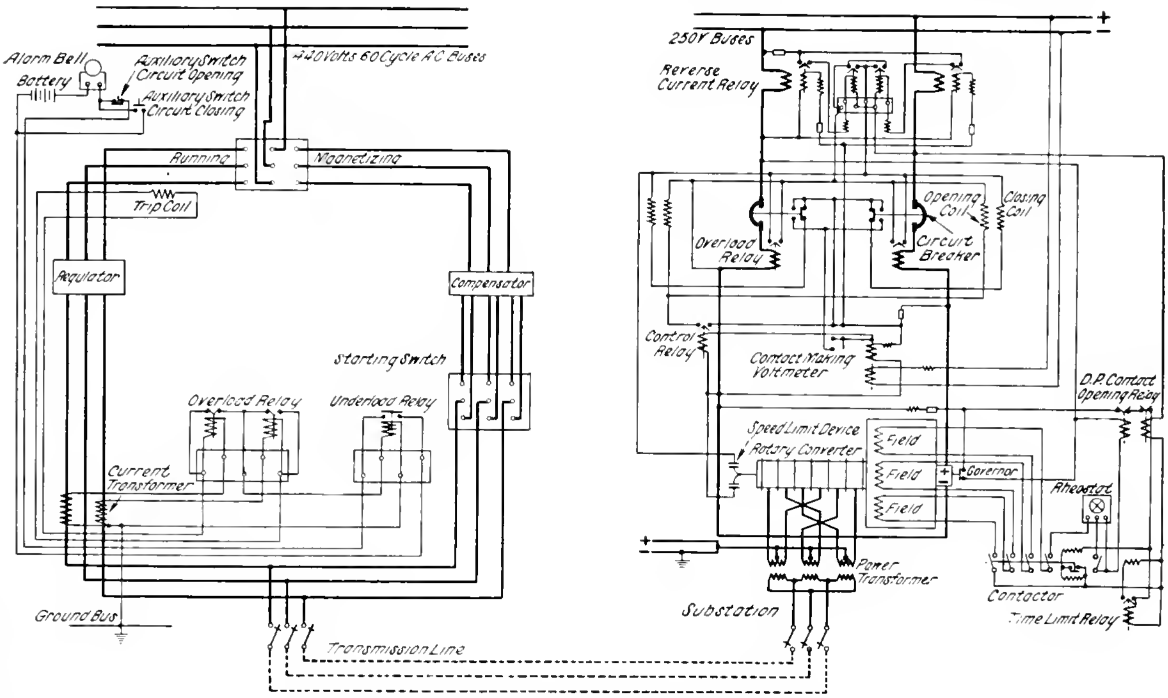

Fig. 1. Wiring Diagram of the Controlling Substation and the Automatic Substation

have a transformer with the addition of an intermittently moving machine. Small regulators of the pole line type are now built, designed to be mounted on a pole out-of-doors and to operate continuously and automatically with very infrequent inspection. These regulators contain a continuously rotating motor.

BLOWER MOTORS AND PUMP MOTORS

These motors are frequently located in inaccessible places and receive scant attention as to operation. They are started from a distance and are depended on to give good commutation and to operate without undue heating or bearing trouble.

They are frequently controlled by automatic pressure regulators or float switches, and may be located at a distance so that the only indication the operator has of their having started is the current in his ammeter.

TRANSPORTATION

A very large class of remotely controlled apparatus is used for various kinds of transportation, such as electric street railways, electric trains, elevators, cranes, ore loading machinery, mine hoists, electric ship propulsion, etc. In all of these the electric motor is remote from the operator and receives only periodic inspection. Its operation is taken for granted, but in most cases the operator sees the movement of the machinery to which it is connected and regulates the control accordingly. In case of large mine hoists, the hoist may be out of sight of the operator, who has merely an indicator to show its movements.

LIGHTING OF ISOLATED BUILDINGS

There are a good many installations for the lighting of large residences, hotels, etc., in the country, consisting of a storage battery and generator and an internal combustion engine, which may be said to be examples of automatic substations; since in some of these installations arrangements are made so that the voltage of the storage battery is allowed to vary between narrow limits, the engine and generator being automatically started up at the lower limit and stopped when the storage battery is charged to the higher limit. These installations do not require any attention so far as the generator is concerned, excepting an inspection from time to time.

Fig. 2 Induction Regulator Located at Controlling Substation for Adjusting Load on Automatic Substation

FURTHER APPLICATIONS

From these cases of automatic remote control, in which electric motors, many of them of the commutating pole type, are used in sizes from a fraction of a horse power up to thousands of horse-power, and in others where small commutating, direct current generators are used, it is only a step further to a generating station or a substation in which the same principles are applied.

INDUCTION GENERATOR

There will shortly be installed on a hydro-electric system in the West an induction generator of about 1400 kw. capacity, which will be located in a station, without an attendant, several miles from the main hydro-electric generating station of the company. This machine, after being started up by an operator sent over for the purpose, will operate without any hydraulic governor, the water-wheel working at full gate opening all the time. While connected to the line it will receive its magnetizing current from the synchronous generators in the other station, and will deliver its full load into the system at all times when the load exceeds the rating of this induction generator. The frequency and speed will be controlled by the waterwheel governors at the main station, where most of the generators are of larger capacity.

At times when the total load becomes less than the capacity of the induction generator, it will be disconnected by the operator at the main station by opening the switch on the line leading to it. The generator will then run at nearly double speed and will be allowed to do so until again required, at which time an operator will be sent over to slow down the induction generator to a point approximating synchronism, when it may be thrown on the circuit again. It will, of course, be designed to run safely at double speed for any length of time, but in case the machine will not be required for a long period an operator will be sent to shut it down.

It would be possible, by the use of three or four control wires and a motor-operated hydraulic governor, to start up and shut down this machine from the main station, in which case the only attention required would be daily inspection and oiling of the hydraulic governor and such parts of the waterwheel as require oil. This installation is, of course, much simplified by not having any exciter. As at present planned, it is also much simplified by not having any hydraulic governor, the only moving parts in the station being the rotors of the waterwheel and generator, which are on the same shaft. The only bearings are the thrust and steady bearings, which are lubricated by a simple oil pumping system that is in operation whenever the induction machine is running.

This induction generator, being of rather slow speed and operating at 60 cycles, has a power-factor of about 80 per cent. If the head permitted a high speed generator, the power-factor could be made much better.

It is worthy of note that this installation is situated on the same power canal as the main plant, but above it, and will use the same water. The only governor will be an emergency over-speed trip, which will not shut down the waterwheel, but will simply disconnect the induction generator from the line in the event of a sudden interruption of load on the main line, as otherwise the induction generator would speed up and drag the other machines along with it.

MOTOR-GENERATOR

There are a number of cases in which town lighting is supplied from a 2300 volt, 60-cycle generator driven by a 25-cycle synchronous motor, which draws its power from a transmission line. In one of these cases, that of a comparatively small installation where the motor-generator is about 250 kw. capacity, the duties of the operator make it necessary for him to be absent from the station a considerable part of the time, and during his absence the apparatus in the station,

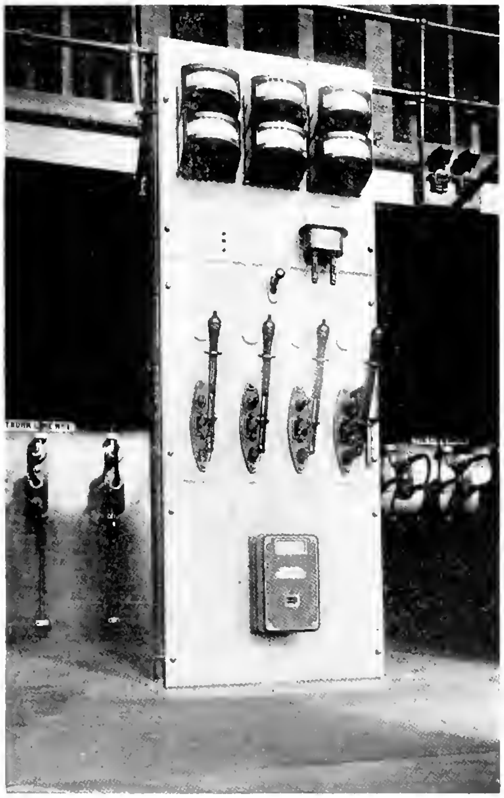

Fig. 3. Front View of the Switchboard Located in the Controlling Substation Showing the Starting and Running Switches for the Converter of the Distant Automatic Substation

consisting of the motor-generator mentioned, constant-current transformers nd induction regulators, operates without trouble.

Whenever an interruption occurs on the 25 cycle transmission line, however, the loaded motor-generator set is likely to fall out of step, and, if the interruption is of sufficient length, the motor may not come into step again when the power comes back, but will take such a large current as to open the

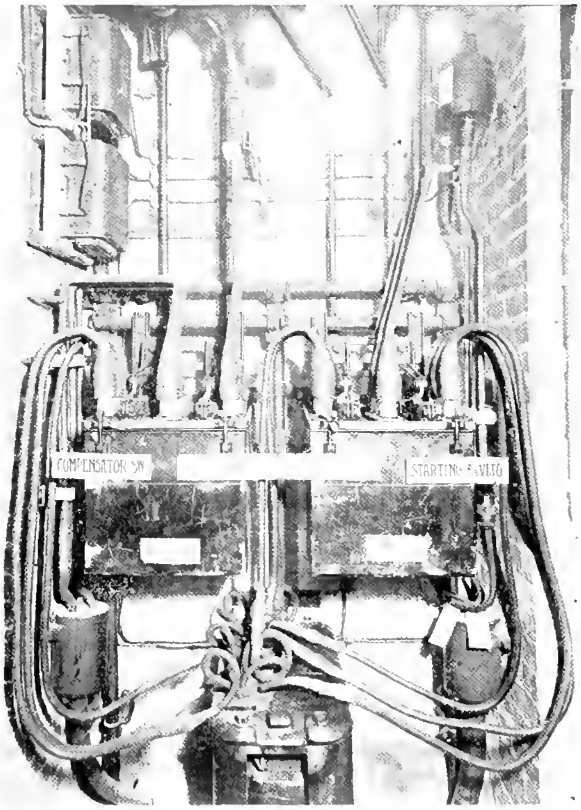

Fig. 4. Back View of the Switchboard Illustrated in Fig. 3

automatic switches and shut down the local plant.

It is planned to install in the station an arrangement for automatically re-starting the motor-generator set in case of such interruptions on the transmission line, so that service may be resumed in the least possible time, whether or not the operator is present.

The arrangement will consist of a centrifugal governor on the shaft of the motor-generator, set so as to close its contacts at about 15 per cent below synchronism and to open the circuit at a slightly lower speed. The opening of this centrifugal switch will cause various contactors to open, performing the following functions:

(a) The synchronous motor will be thrown on the half-voltage taps of a starting compensator.

(b) The field of the synchronous motor will be opened.

(c) A resistance will be thrown into the field of the 60 cycle generator, thus cutting down its load materially.

In case of an interruption on the transmission line sufficiently long to cause the machine to fall out of step, the centrifugal switch will open, and by performing the above functions will leave the motor-generator

Fig. 5. Exterior View of the Automatic Substation (Rowena Street)

running with reduced load at a gradually decreasing speed; the synchronous motor being connected to the starting tap with field open ready for a start when the current comes back on the transmission line.

When the service on the transmission line is restored the synchronous motor will speed up and at 90 per cent of synchronism the centrifugal switch will close, thereby closing the circuits of three time-limit relays, which operate as follows:

(1) To throw on the field of the synchronous motor, and cause it to fall into synchronism.

(2) To throw the motor over from one-half line voltage to full line voltage.

(3) To restore the generator field to its full original strength.

The induction regulators connected to the lighting feeders and the constant current transformers supplying the series lighting will then resume service automatically. The set will then be running under the same conditions as before the shut-down.

All of the contactors will be operated by alternating current supplied from a small step-down transformer connected to the transmission line. They will not be capable of operating until the current comes back on the transmission line. No storage battery or other extra source of power is required. The outfit is so arranged that a short circuit or burnout of any of the devices will cause no harm beyond the destruction of the device itself, with the exception of course of its failure to co-operate.

The same principle of automatic restarting may be employed for a synchronous motor installation where the motor drives a pump or air compressor, in which the load may be reduced temporarily through a by-pass or other valve, or mechanical apparatus operated by a solenoid.

It may also be employed for synchronous motors driving a mechanical load, when the design of the motor is such that it will start the load and bring it up to nearly synchronism without the necessity of relieving the load during starting. There will also be certain advantages in using such an arrangement in a station where operators are employed, on account of the saving in time.

SYNCHRONOUS CONVERTER

The Edison Illuminating Company of Detroit has installed a synchronous converter with special automatic switchboard equipment so arranged that the converter can be started, controlled, and stopped from a distant point without any control wires.

Location

The synchronous converter, transformers, and part of the switching appliances are located at the Rowena Street substation, about one mile from the center of the Edison three-wire network and the same distance from Station I, where the equipment is controlled. Station I is one of the largest substations on the Edison system at Detroit.

Purpose of Installation

The load on that part of the Edison three-wire network near Rowena Street station, which is located in one of the residence sections of Detroit, has been increasing so rapidly that the illuminating company was faced by the alternative of installing more feeder copper or a new substation, in order to keep the service in this section up to standard. Either of these alternatives involved considerable expense, compared to the revenue from the section in question; but it was, however, decided to install a 500 kw. rotary converter in a substation having no attendant. Arrangements were to be made so that the rotary could be started, stopped, and its voltage and load controlled from Station I a mile away, and, in addition, the machine was to be automatically protected in case of disturbances on the system or accidents to the machine itself.

regulator is connected in series with the running switch and is not in circuit when starting. (Fig. 2)

1 switchboard containing four hand-operated oil switches, of which No. 1 is a magnetizing switch, No. 2 and No. 3 tap switches for use with a compensator, and No. 4 a running switch. Fig. 3 illustrates the front and Fig. 4 the back of this switchboard.

3 a-c. ammeters.
1 power-factor indicator.
1 polyphase indicating wattmeter.
1 watthour meter.
1 compensating voltmeter to read the voltage at

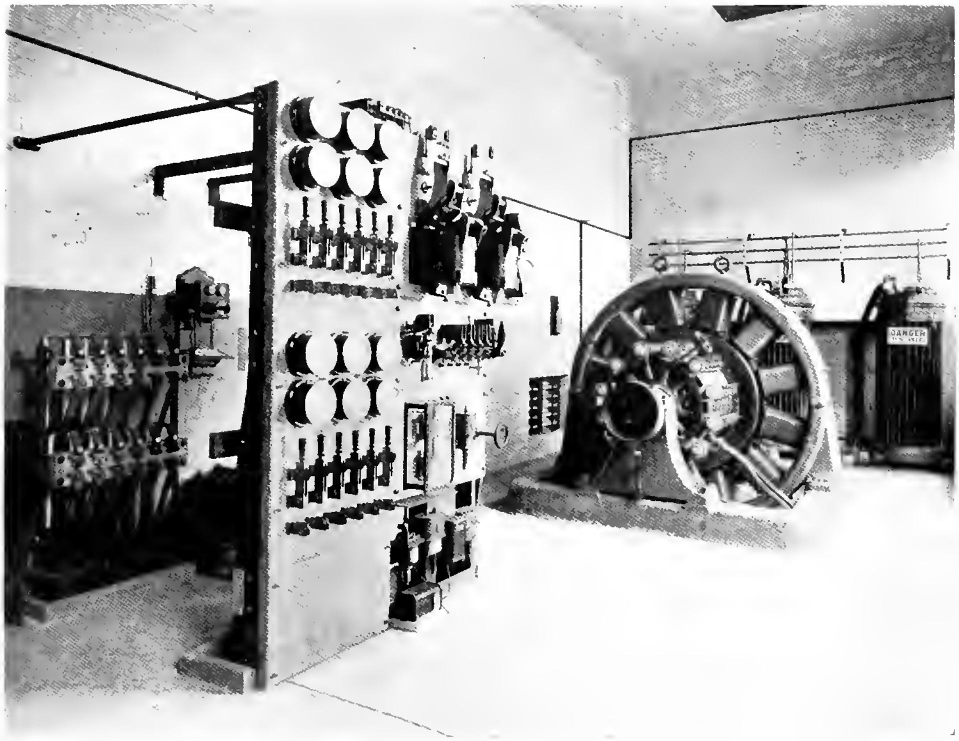

Fig. 6. A General View of the Interior of the Automatic Substation (Rowena Street)

This problem was put up to the engineers of the manufacturing company, the illuminating company stipulating that there should be no control wires, the only conductors extending between Substation I and Rowena Street station being those of the triple conductor cable carrying the 4400 volt, three-phase, 60-cycle primary current.

The connections are shown in Fig. 1.

List of Apparatus at Substation I

The apparatus located at Substation I consists of the following:

1 4400-volt, three-phase starting compensator with 1/3, 2/3 and full voltage taps.

1 4400-volt, three-phase induction regulator with a total range of 20 per cent in voltage. The

Rowena Street. Necessary current and potential transformers.

1 underload relay and bell alarm.

1 inverse time limit overload relay. The overload relay operates the running switch.

Rowena Street Substation

At this station are located the rotary converter, which is a six-phase, 12 pole, 500 kw., 600 r.p.m., 250/300 volt machine; three oil-cooled transformers, each rated 175 kv-a., 4400/205 volts; and the automatic control apparatus consisting of the following:

2 3000-amp. solenoid-operated main circuit breakers with overload trip.

2 reverse current relays for above.

1 solenoid control relay used in connection with the circuit breakers.

1 differential contact-making voltmeter.

1 four-pole field contactor. (The field is broken at several points, on account of the high induced voltage at starting.)

1 single-pole field contactor, with time limit relay.

1 field rheostat.

1 double-pole relay for protection of field circuit.

1 centrifugal switch or governor mounted on shaft of rotary converter.

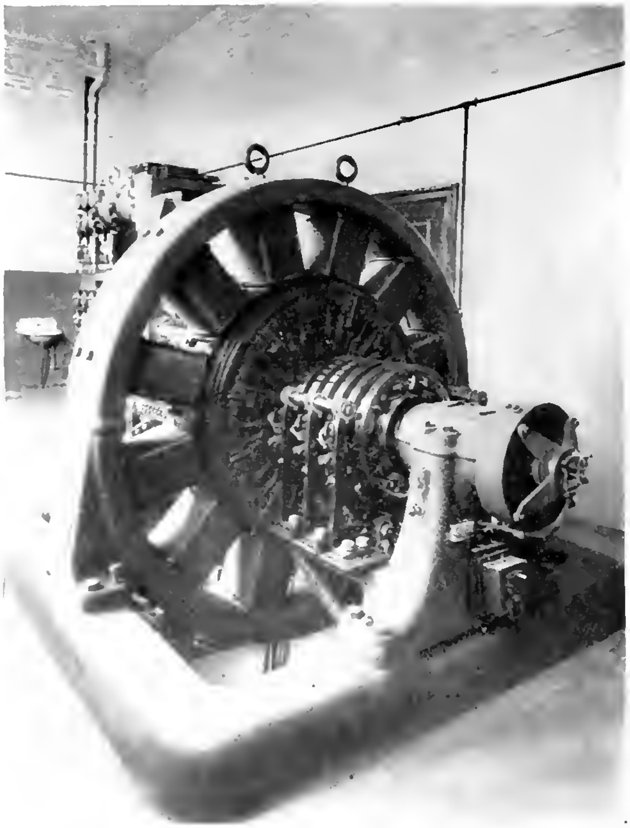

Fig. 7. Alternating Current End of the Automatic Converter Showing Its Electromagnetic End Play Device

Fig. 5 is a view showing the exterior of Rowena Street substation, which is built without windows to prevent the noise from being heard outside of the station. Ventilation is obtained by means of baffled openings in the side wall and the roof. Fig. 6 gives a general view of the interior.

The alternating current end of the converter, with the electro-magnetic end-play device, is shown in Fig. 7.

Fig. 8 is a front view of the switchboard showing the automatic control device at the right and feeder panel at the left. A back view of this board is given in Fig. 9, in the upper right-hand corner of which is shown the main reverse current relays.

All the devices of the control equipment, excepting the field rheostat and governor, are mounted on two marble panels. The circuit breakers are supplied with sockets and auxiliary handle so that they may be worked by hand.

A number of feeders connected to different points on the 125/250 volt Edison three-wire system in this vicinity are brought into the Rowena Street substation. The feeder switches being normally left closed, there is 250 volts on the bus in this station available to operate the contactors which close the field when the control circuit of these contactors is closed by the governor.

Starting

In order to start up the rotary, the operator at Substation I proceeds as follows:

1st. The induction regulator is set at maximum lowering position.

2nd. The magnetizing switch is closed.

3rd. The 1/3 tap switch is closed, throwing 1/3 voltage on the line leading to the Rowena Street substation. The rotary starts on this tap and reaches synchronism in 20 or 30 seconds. Just before the converter reaches synchronism (that is, within 5 per cent of synchronism), the governor on its shaft closes the control circuit of the field contactors and the four-pole contactor operates immediately, exciting the rotary converter field from the bus so as to give it the correct polarity, but with a considerable resistance in series with the field. As soon as this weak field is thrown on, the rotary converter pulls into synchronism with the proper polarity but at 1/3 voltage. This operation is made evident to the operator at Station I by his ammeter, on which the current decreases from the initial starting current to about one-half this value, and suddenly increases as the field is automatically applied, then settles to a low and steady value as the converter falls into synchronism.

4th. Just after the automatic application of the field, the operator opens the 1/3 tap switch and closes the 2/3 tap switch.

5th. The operator then opens the 2 3 tap switch and closes the running switch. After closing this switch the rotary is in synchronism but operating at a low d-c. voltage on account of the position of the induction regulator and the very weak field. Also, on account of the weak field, the power-factor at this time will be lagging.

6th. Within a few seconds the second field contactor automatically operates, cutting out sufficient field rheostat resistance to give the rotary full normal field current. The control circuit of this contactor was closed by the governor at the same time as that of the other contactor, but its operation was delayed by a time limit relay. The operation of this contactor is immediately perceived by the increase in current on the a-c. ammeter and the changing of the power-factor from lagging to leading.

7th. At this point the rotary is running in synchronism with full field and correct polarity and is all ready to be connected to the direct current busses, excepting that its voltage is low, owing to the position of the induction regulator. The operator now brings up the voltage with the induction regulator, and at the moment the voltage across the brushes of the rotary converter exceeds by a very small percentage the voltage on the busses the contact-making voltmeter operates. This device is differentially wound, one coil being connected to the busses and the other to the brushes of the rotary converter. The bus voltage may vary at different times of day from 250 to 300, but whatever is the voltage across the busses, this differential device acts only when the rotary converter voltage exceeds the bus voltage by a small percentage. This device makes a circuit through the control relay, which operates the closing coils of the two main circuit breakers and connects the rotary converter to the busbars. This action is so accurate that the rotary may be made to take any percentage of load that is required. Ordinarily it is so adjusted that when the circuit breakers close, the rotary takes about one-tenth load.

Load Control, Etc.

The voltage at points on the Edison three-wire system in the neighborhood of the Rowena Street station is observed at Station I by means of the pressure wires ordinarily used on these Edison systems, and the amount of load taken by the rotary at Rowena Street is changed by the operator to meet the voltage conditions on the system. The change in load is effected by manipulating the induction regulator.

The amount of load at any time is indicated by the a-c. ammeters in connection with the indicating wattmeter and the power-factor meter.

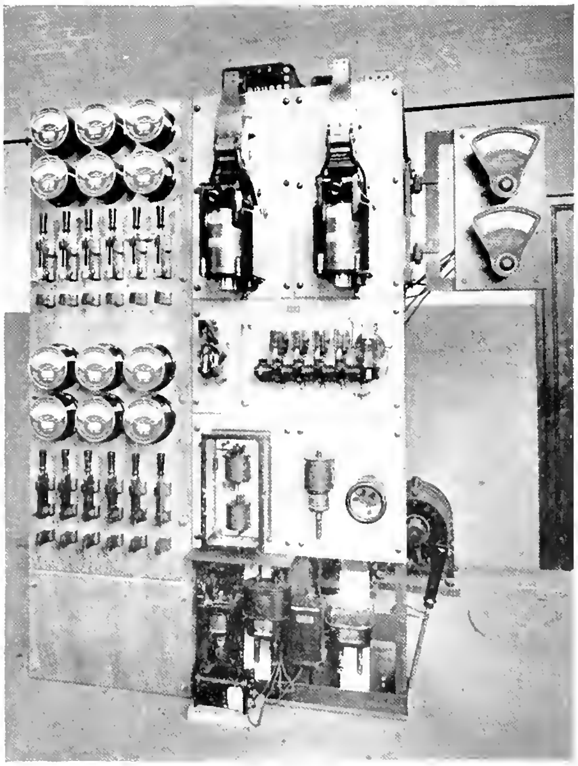

Fig. 8. Front View of the Switchboard in the Rowena Street Substation Showing the Automatic Control Device at the Right and Feeder Panel at the Left

Stopping

In order to stop the rotary converter, the running switch at Substation I is opened. This disconnects the a-c. supply and leaves the rotary converter running as a d-c. motor. The reverse current relays are set so that they will operate on the current which the rotary takes as a d-c. motor, and their operation opens the main circuit breakers and disconnects the rotary from the d-c. busbars. As the rotary slows down, the governor resumes its starting position and the field contactors open so that everything is ready for a new start.

Protection

In case of a short circuit on the a-c. system at some point between the main station and the switchboard at Station I, the direct current feeding back from the d-c. system through the rotary converter operates the reverse current relays and opens the solenoid circuit breakers, leaving the rotary connected to the a-c. system. When the a-c. short circuit disappears and the a-c. voltage comes up again to normal, the rotary is automatically connected in the d-c. system again, unless the current required to synchronize the rotary is heavy enough to open the main switch at Station I by means of the overload relay. In this case the rotary may be synchronized by the magnetizing and tap switches, as explained under "Starting."

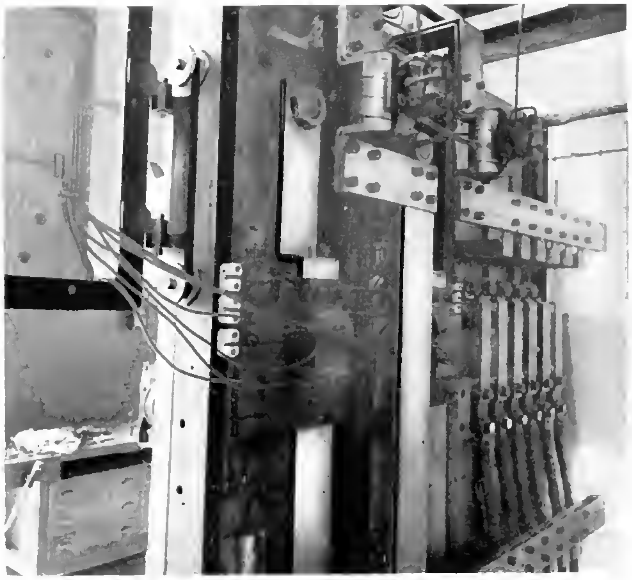

Fig. 9. Back View of the Switchboard Shown in Fig. 8. Main Reverse Current Relay in the Upper Right-Hand Corner

In case of a short circuit on the a-c. circuit or on the cable between Station I and Rowena Street, or in the armature transformers or regulator, the direct current feeding through the rotary into the short circuit operates the reverse current relays and opens the solenoid circuit breakers; and the alternating current, feeding into the short circuit, operates the overload relay and opens the main switch at Station I, disconnecting the rotary from the line. Furnished with the original equipment were time limit attachments which were added to the reverse current relays so that they would not operate in case of mere momentary surges. These relays are not being used in the actual operation of the equipment, as they are considered unnecessary by the illuminating company. Two reverse current relays are used so that safety is assured, unless both should fail.

In case of a short circuit on the d-c. side, the overload relay at Station I will open the running switch and the rotary will be disconnected as in the ordinary operation of shutting down. If this d-c. short circuit is a very severe one, the overload trip coils of the circuit breakers, which are set rather high, will also operate.

The field circuit of the rotary converter is protected by means of a double-pole overload relay. The shut-down of the rotary from any cause is indicated by the underload relay at Substation I.

This station has been operated without any regular attendant ever since it started, but, since the equipment was novel, it was the practice for the first few weeks to send a man over from Substation I to watch the operation when the outfit was being started, and in this way several points have been observed which have enabled the perfecting of the equipment.

The centrifugal switch originally used to close the field circuit was found to be unsuitable, and this has been replaced by one of different design, which is reliable and has given satisfaction. During the few days that the first switch was out of service, the field contactor circuit was closed by hand when the machine was being started. Shortly after installation there were two or three cases when the machine failed to start. Such failures have now been eliminated by proper adjustment and minor changes in the relays. It is the intention to have this equipment inspected once a day.

The illuminating company may later decide to put a thermostat on the bearings, recording the temperature through a telephone wire to Substation I so as to avoid danger from this source; but it is not believed this will be necessary. The bearings are of the ring oiling type generally used on machines of this class, so that very little trouble may be expected.

In addition to the governor used for closing the field circuit, the rotary converter is equipped with the usual centrifugal speed limit device.

The illuminating company expect to extend this remote control system to other substations.

Fire Risk

The fire risk is practically nil, except for the chance of the windings of the machine taking fire from an accidental burnout. This may be minimized by automatic extinguishers. It would not be possible to use automatic sprinklers in a cold climate unless the substations were heated, but some automatic extinguisher using a chemical preparation, freezing only at a lower temperature, may be devised, and would in fact be preferable to water for other reasons as well.

OTHER APPLICATIONS

In the station described, the converter is of the type without commutating poles. An automatic installation, including a commutating pole converter, would require a solenoid mechanism for raising the brushes when the field contactors open while the machine is shutting down, and for lowering the brushes when the machine has started and reached synchronism. This would be worked by the closing of the field contactors.

When an automatic substation is installed on an Edison system, the field contactors may be operated from the 250 volt bus, connected to the system outside, and it may be assumed there is always voltage on this system.

In case of an automatic substation on an electric railway system, it may be desired to start up the station when there is no voltage on the trolley wire. In such a case the machine may come up to speed with the wrong polarity, since there is no means of determining the polarity by exciting the field from the trolley. To meet this requirement, a special relay has been devised by Mr. J. B. Taylor; or a storage battery may be used. Since railway substations are generally located on the line of the railway, it is frequently found convenient to combine the substation with a waiting room and ticket office, so that the operator may serve both. Where it is not necessary to do this the automatic substation may be used.

Still another application of these principles may be to simplify the control of machines in a large station containing several rotaries. That is to say, the low tension switches near the machine may be eliminated and one operator at the switchboard take care of the entire starting.

While the starting of this automatic rotary as described in detail may seem complicated, in actual practice it is very simple, as it merely requires that the operator close four oil switches in rotation and manipulate an induction regulator, the machine being thrown on the system with very little disturbance.

CONCLUSION

The remote control of rotary converters enables a plant operating the Edison three-wire system to extend the economical limits of the system, since the cost of the labor of station and operators and the cost of heating the building form a large proportion of the running expenses of a substation. With the station heating expense and the regular watch of station operators eliminated and the labor expense limited to the cost of daily inspection, it becomes possible to operate substations where previously the density of the load would not warrant it.

In general, this means that in a city the Edison three-wire system may economically be extended to cover a greater territory than at present. It will be possible to reduce the investment in feeder copper by using smaller substations set closer together.

Acknowledgment is made to Mr G. W. Cato, of the Edison Illuminating Company of Detroit, for information and photographs used in this paper.

EUROPEAN VS. AMERICAN PRACTICE IN LIGHTNING ARRESTERS

Part II

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Nearly all the usual features of European practice in lightning arresters are embodied in a 15,200 volt Mexican installation, which, for the sake of a definite basis for comparison with American practice, was selected by the author for discussion. In the first section of the paper (August Review), a comparison was made between the space occupied by the European arrester and its equivalent in American apparatus, showing a ratio of something like ten to one to the credit of the latter. The American equipment was also shown to possess the advantage of lower cost as regards installation, operation and maintenance. European practice is divided into six distinct sections, five of which are found in the Mexican installation. All six are fully discussed; one in the first part of the article and the rest in the present installment. Of the lot, there seems to be no justification, theoretical or practical, for the employment of two of these arrangements. The remaining four, while possessing advantages under certain circumstances, are more prone to trouble-making than the aluminum arrester and do not provide adequate protection in the same high average number of cases.—Editor.

Second: Delta-connected horn gaps without series resistances:

The writer is unfamiliar with any theory advanced urging the necessity of the use of delta-connected horn gaps. So far as lightning is concerned, the strains on the lines are usually from line to ground, and less from line to line. By the use of the Y-connected gaps already described, the line to line conditions are sufficiently taken care of. In the Y-connected gaps there are two gaps in series from line to line, with the mid-point connected to ground, and the probability of the protection of only one gap from line to line as soon as one phase is grounded through its gap. It is therefore difficult to see the necessity for connecting two gaps delta from line to line, as was done in this Mexican installation. The use of two gaps in series has the one desirable feature over the use of a single gap in that the two acting together help to extinguish the heavy arcs that take place on the horns. If connections are to be made delta between line and line, there are conditions which favor the use of a single gap instead of two in series. The principal advantage is the setting of the single gap for a definite spark potential. When two gaps are placed in series the spark potential of the two in series will be considerably affected by a change in frequency. For example, if the spark potential of these two horn gaps in series is taken at 60 cycles, it will be found much lower on high frequency due to what may be termed the multigap effect. In other words, owing to the electrostatic capacity of the connecting conductors between two gaps, such a combination of gaps is also affected by the relative electrostatic capacity to ground of its different parts. For example, it is possible to arrange the parts of two gaps in series so that the spark potential is very little greater than the spark potential of a single gap. There is always a tendency for the spark potential of two gaps in series to be much less than the sum of the individual spark potentials. With one gap set smaller than the other, the spark potential of the two in series will be still further decreased. This is true either of 60 cycles or of lightning frequencies. There is not time at present to go into this subject completely with the experimental data, but it is sufficient to say that the use of two delta horn gaps in series renders the determination of the setting of the gaps for a given spark potential not only difficult, but usually uncertain due to the variations that may be made in the capacities of the connecting wires. This matter of delta-connected gaps may be summarized in the simple statement that there is no good technical reason for their use as lightning arresters.

Third: Y-Connected Horn Gaps with Medium Values of Resistance in Series:

In this case the gap settings at the horns may be made moderate. Such an arrester has both good and bad features. First of all, the limiting resistance, although bad in itself, is valuable to limit the dynamic current which follows a lightning stroke and thus allows the arc to be extinguished with less disturbance to the power currents on the system. Regret has often been expressed by engineers who have experimented with this system of protection that the matter of resistance has not been carefully enough studied to give satisfactory results. It will be the endeavor of the writer to show that there is no such thing as a satisfactory design of such an arrester, although it is always possible to design the resistance to give the best results for any desired condition. At the offset, it should be stated that any resistance in series becomes objectionable when the lightning current is high enough to produce a drop of potential across the resistance equal to double the line voltage. In other words, we may assume that double the line voltage for a brief period is usually safe for the insulation on a system. In some cases a higher potential is admissible where greater factors of safety in the insulation have been used by the designing engineer. If the desideratum of protection of insulation is the sole factor in view, a brief consideration of currents in lightning strokes is sufficient to prove that the smallest possible value of series resistance should be used. What rate of discharge in an arrester must be chosen as the minimum has been the subject of much experimental work and calculation extending over many years. Putting aside for the moment all theoretical considerations, the collection of data of damage where different rates of discharge have been permitted, has shown that the 600-ampere rate of discharge at double potential is ample for every case except the very rare extreme of an exceptionally heavy direct stroke of lightning. On the side of minimum discharge rate, years of use of arresters with currents limited to 5 and 10 amperes have shown, not only by the puncture of insulation in parallel with the arresters but also by sparks jumping from point to point on the resistances, that such a discharge rate is not sufficient to safely conduct to ground frequently occurring induced lightning strokes.

Let us consider briefly the results of different degrees of protection. Where no lightning arresters at all have been used, it is found that apparatus may, on the average, be operated over long periods of time without damage, which shows that many strokes of lightning are not of sufficient intensity to cause immediate damage to the apparatus. If a relief valve is now placed at the location of such apparatus, giving a discharge of 5 to 10 amperes, a greater number of lightning strokes may occur at the apparatus without causing immediate damage to the insulation. The sum total of experience, however, has shown that a considerable fraction of the total number of lightning strokes occurring at a station will cause damage. The problem that has confronted the designer of lightning arresters has been to obtain as high a discharge rate in the arrester as possible without interfering with the service of power, so as to include the highest possible percentage of the total strokes that can come on the line. Since lightning varies in potential all the way from no voltage to the disruptive potential from line to ground on a wooden pole, the solution of the problem must always be more or less of an engineering compromise.

A slight digression will now be made to indicate the extent of the compromise in American practice. The compromise is somewhat simplified by the fact that practice calls for arresters to protect apparatus and not transmission lines. Most direct strokes take place on transmission lines and are relieved locally at the point where the line is struck. Practically, this leaves the arrester to be designed so as to take care of everything but a direct stroke. The factor of safety given to an aluminum arrester that it may meet the condition of induced stroke has been so great that the arrester has a conductivity great enough to take many direct strokes, without damage to itself or to the apparatus. The most notable case was the protection of 30,000-volt air-blast transformers from a direct stroke at the station. Although an arrester could be designed to safely conduct to ground every direct lightning stroke, it would not be good engineering to do it. The interest on the extra investment in all the equipments on a system would be greater than the occasional loss that takes place in an arrester from direct stroke.

In attempting to use the minimum of resistance in a resistance horn-gap arrester, one is confronted with two problems: first, the disturbance of the power circuit by a considerable amount of power taken from the circuit; and second, the high cost of a resistance to carry the dynamic power during the interval necessary to extinguish the arc at the horns. This problem becomes more and more difficult as the transmitted potential is increased. A simple illustration of this follows. On a 2300-volt circuit a 10-ampere discharge rate of dynamic current corresponds to 13 kw. per phase, or a total of approximately 40 kw.; on a 23,000-volt circuit the loss of power in the resistance of the arrester would be approximately 400 kw.; on a 100,000-volt circuit the loss of power would be 1700 kw. The drawing of such a great amount of power by each arrester from a circuit becomes still more formidable when several arresters discharge simultaneously, as frequently occurs during a lightning storm. On top of this is the assurance that many lightning discharges will not be relieved by a 10 ampere discharge rate. If a greater rate of current is considered, the loss of generated energy is increased proportionately.

If we consider the problem of absorbing the energy of discharge in such an arrester, it is necessary to fix a duration of discharge. Under the usual conditions of horn gaps, the duration is of the order of one or two seconds. It is not difficult to design a resistance which will carry ten amperes for this length of time without overheating. It frequently happens, however, that an arrester is called on to discharge successive strokes, and occasionally it is called on to discharge continuously for a number of minutes during an arcing ground. For this last named condition the cost of a resistance suitable for either absorbing or radiating the energy loss becomes objectionably high and, in addition, the space occupied is large. If it is intended to radiate this amount of energy the design of resistance will depend mainly upon one of two things: first, on the maximum allowable temperature; and second, on the volume. To put the matter in a slightly different way, the design will depend on whether some material is used which can be raised to a high temperature and thus radiate and convect a considerable value of watts per square inch, or whether the resistance will be immersed in some such liquid as oil and depend upon the greater volume and surface to absorb and radiate the energy at lower temperature. In the use of air-cooled resistances which get rid of their heat directly by high temperatures, conglomerate materials have been applied unsuccessfully. The designers of such arresters have never been able to obtain suitable materials to withstand, without change, the high temperatures. This has led to the use of oil immersed resistances in the design of the resistance-horn-gap type of arrester. The design then becomes a simple matter of choosing a volume of oil, and an exposed surface such as to give a safe value of watts per square inch of radiating surface. In the high-tension arresters the cost of such a resistance is so excessive that no usual length of discharge for the arrester can be attained without exceeding a reasonable cost. As a result of this, the designer of such an arrester must choose between two evils, namely: cutting down the total energy by still further restricting the discharge current, and thus producing a less efficient arrester; or running the risk of the destruction of an arrester by a sustained arcing ground. Neither of these compromises is desirable.

As a result, we find that the use of the series resistance horn-gap type of arrester is confined mostly to circuits of comparatively low potential. At best, the use of this type of arrester is a material assertion either that nothing better can be done, or else that no dangerous lightning discharges come on the circuit which require more than a very small discharge rate in the arrester. On the engineers who assert that a 10 or 20-ampere discharge rate in a lightning arrester is sufficient, the burden of proof is laid. The odd thing about this condition is that it requires many installations and a long period of time to show the inadequacy of this protection. This, as already stated, is due to the fact that such an arrester does care for a considerable fraction of the discharges, although the fraction is not high enough to say that such an arrester constitutes a solution of the problem.

The reader with a bias toward the resistance horn-gap arrester may require more definite proof than the general statements given in the foregoing paragraphs. Out of the many experiments that have been made along this line, the following set is chosen. The materials required for these tests were as follows:—first, a considerable number of new 2300-volt transformers; second, transient disruptive discharges of sufficiently high value to easily puncture the insulation of the transformers; third, lightning arresters in which the resistance could be varied from the smallest permissible value to a high value (the smallest permissible value is set by that value of dynamic currents which will injure the lightning arrester); fourth, a power circuit at 2300 volts to energize the transformer; and fifth, protective devices for the generator to prevent damage to it by the artificial lightning.

Commenting still further on the tests, 2300-volt transformers of 5 and 10 kw. capacity were chosen, because in these transformers the windings are very much concentrated and therefore there is less chance for local oscillations to take place between parts of the winding, as would occur in larger transformers where the high tension coils are subdivided into several sections. This choice was made to eliminate the possibility of resonance. Furthermore, in the 2300-volt distribution transformers the factor of safety in the insulation is exceedingly high, being not less than five. This makes the condition favorable to the use of higher resistance in the arrester than would be permissible where the factor of safety is only two or three.

Tests were made which showed that the available disruptive discharge had sufficient strength to puncture a transformer on the first stroke. Lightning protection was then used in connection with the transformer under test, the protection consisting of the compression chamber lightning arrester. A low resistance of about 7 ohms was placed in series, which gave a discharge rate of about 600 amperes at double line to line potential. Many thousands of artificial lightning discharges were then produced at the terminals of the transformer, with no resulting damage. The resistance in the lightning arrester was then increased by steps. When the resistance reached a value above 200 ohms, corresponding to a discharge rate of 23 amperes, it was found that the transformers were damaged by the lightning strokes. The first lightning stroke would not cause an internal short circuit in the transformer but after several repeated discharges a short circuit was produced. This test proved without any doubt that with the frequency and potential of the artificial lightning in the laboratory an arrester allowing a discharge rate of only about 20 amperes at double normal line to line potential will give but poor protection, and permit damage to be done to the transformer by the lightning strokes. The question then arises: What is the relation of the artificial lightning to the actual lightning on lines? We know very little of the various forms of lightning on a transmission line. We know specifically, from studies on a line, that some lightning strokes produce high frequencies on the lines, and disruptive potentials of dangerous values. There may be other lightning strokes of lower frequency, or single impulses, but knowledge of such, when obtained, will not take away the proofs that much of the lightning is of high potential and high frequency. The quantity of electricity on a line induced by thunder clouds is no doubt considerably greater than the quantity of electricity used in the laboratory tests, and the energy involved is no doubt frequently greater. In the laboratory tests we have the essential elements of the lightning stroke on the line, although these elements of quantity of electricity, frequency, and potential may be combined in somewhat different proportions in the usual stroke on the line. Nevertheless, it seems safe to presume that the artificial lightning generated in the laboratory is not a more severe test on the transformer insulation and lightning arrester than actually occurs from the effects of cloud lightning. This is one of the elements that has led to the conclusion that if a 10 to 20 ampere rate of discharge in a lightning arrester cannot protect against artificial lightning, it is not permissible to design an arrester with this high resistance for actual practice. If it were absolutely necessary to use this high resistance, then it would be its own excuse as the best possible solution obtainable, but it is not necessary.

Some of the mathematical calculations of permissible resistance in a lightning arrester circuit made by Dr. C. P. Steinmetz give another viewpoint, and also some noteworthy values to compare with a resistance horn-gap arrester. On a 60,000-volt single transmission line "the maximum permissible lightning arrester resistance" figures out to be "50 ohms." Resistance horn-gap arresters taking ten amperes dynamic current per phase would have a resistance of 3500 ohms, seventy times the calculated value. In terms of discharge rate at double potential the mathematical calculations give 2400 amperes, the resistance horn-gap arrester 34 amperes, and the aluminum arrester (not taking into account the electrostatic current but only the valve effect) 600 amperes.

The inductance of the series resistance should receive careful attention. Resistance wire requires a mechanical support. Where slabs of porcelain of considerable thickness are used as supports the resistance takes the form of a choke coil. Unless special care is used in the construction the inductance may be actually greater than that of the lightning choke coil used in the line to deflect the lightning through the arrester. Resistance rods and water rheostats give much less inductance.

In designing a resistance for use with the horn gaps, recourse has often been had to the water rheostat. When properly designed and cared for, such a resistance gives the most economical form for an arrester. This is due to the fact that energy can be convected by the boiling electrolyte and thus diminish the whole superficial area that would otherwise be necessary. It has been found, however, by those who have tried liquid rheostats, that the cost of inspection and regulation becomes a serious item. The electrolyte becomes contaminated and changes its resistance, and the water is either boiled out or evaporated, causing a greater concentration or an open circuit; and in the winter time the freezing of the electrolyte frequently damages the container, resulting in a leak and an entire open circuit. The effect of freezing has led to the practice of drawing off the electrolyte during the winter time. This could scarcely be considered more than a temporary engineering solution of the problem of protection against high potentials.

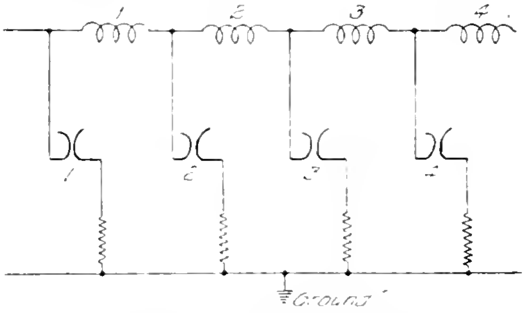

Fig. 13. Multiple-Horn-Gaps Connecting to Ground, Through a Resistance, the Points Between Series Choke Coils in the Line

In the following table are given the losses of power and energy for a 10-ampere, a 100-ampere, and a 600-ampere discharge rate, with comparative values of the aluminum arrester based on a film in good condition:

DISCHARGE RATE	RESISTANCE ARRESTER		ALUMINUM ARRESTER	
Amperes	Kw.	Joules	Kw.	Joules
13 KILOVOLT CIRCUIT				
10	66	66,000		
34	230	230,000	0.150	2.5
600	3930	3,930,000	0.150	2.5
60 KILOVOLT CIRCUIT				
10	300	300,000		
34	1038	1,038,000	0.7	12.0
600	18000	18,000,000	0.7	12.0
100 KILOVOLT CIRCUIT				
10	503	503,000		
34	1734	1,734,000	1.2	20.0
600	30000	30,000,000	1.2	20.0

These figures speak for themselves. In brief, they show that the power and energy absorbed by the aluminum arrester is negligible as compared with the resistance horn-gap arrester.

Fourth: The Use of Multiple Horn Gaps Connected Between a Number of Series Choke Coils in the Line:

This practice was used in America a number of years ago by the former Stanley Electric Company. This specific arrangement of choke coils and arresters has been the subject of a number of researches in the laboratory, and on transmission lines. It has been found that the discharges of high frequency lightning strokes will at times take place, not at the arrester nearest the line, but at some point farther in at an arrester between choke coils, Fig. 13. This can be explained by the fact that the points between the choke coils respond to different frequencies. If the impressed frequency corresponds to the natural frequency of one of these internal points, the final potential will be built up higher than at the entrance to the first choke coil on the side from which the impulse comes. This, it will be seen, is a case of resonance. Resonance is a phenomena involving time. A consideration of this problem has led the American engineers to the abandonment of this protective device, not because the choke coils had no real value—for they have—but rather, that the cost of such devices for protection against lightning was entirely out of proportion to the value that could be received from them. Let us assume, for illustration, that we have an incoming line connected either to a gap or lightning arrester, which we will call gap 1, Fig. 13. Next in the line circuit comes a choke coil designated as choke coil No. 1, then another gap designated as gap 2, etc. Now, if an impulse comes in from the line which is insufficient to jump gap 1, it will pass on through coil 1, and will thus be impressed on gap 2 while it is being retarded by choke coil 2. This impulse will be partially reflected back to the line by coil 2, and there will, therefore, be an oscillation produced by the different reflected waves from different parts of the circuit. Assuming that gap 2 does not discharge, the charge then penetrates to gap 3 and becomes partially reflected by choke coil No. 3. Let us now assume that the natural frequency of the coils and the circuit is such that the point where the horn gap No. 3 is connected is in resonance with the natural frequency of the lightning induced by the clouds on the main circuit. Then, every impulse from the lightning charge that comes through to gap 3 will be so timed as to add on to the previous impulse, and the potential will be gradually built up at 3 until it is relieved by a spark at the gap. This combination, it will be noted from this theory, is not being used so much as a lightning arrester as a high frequency, or surge, protector. For, if the lightning were of dangerous potential, and gap No. 1 were not excessively large, the first impulse of the lightning charge, as it was impeded by choke coil No. 1, would have caused a discharge of gap No. 1 and a relief at that point. In other words, the fact that the lightning could penetrate to gap Nos. 2, 3, 4, etc., is an indication that the gaps nearest the source of impulse did not receive sufficient potential for a long enough time to cause them to spark over. Reasoning along this line has led to the practice in America of using a small gap in the position of gap 1, and a comparatively small choke coil in the position marked choke coil 1, thus picking off all abnormal high potentials regardless of the frequency. This is using the lightning arrester to protect against high potentials, and not against high frequencies of less potential than 25 per cent above the line to line potential.

When considered as a protection against high frequencies this combination of choke coils and horn gaps has a very limited range. For example, in the diagram shown in Fig. 13 the combination would protect against four different frequencies, and their odd multiples or harmonics. If we should consider the fundamental 3rd, 5th, and 7th harmonics at each one of the gaps, such a combination would resonate for 16 different values of frequency. To pick out 16 frequencies from a range extending up to over a million cycles per second seems an excessive expense for a trifling gain. If we are to attack the problem of high frequency protection independent of high potentials, it is better to abandon entirely the use of a lightning arrester which is adapted particularly to high potentials, and adopt a new type of device which will absorb high frequencies over the entire range, to a billion cycles per second if necessary, entirely independent of the limitations set by resonance in the combination shown in Fig. 13. That is precisely what is being done in America at the present time to solve this problem.

Fifth: The Water Jet Lightning Arrester:

The water jet lightning arrester may be attributed entirely to European engineers. It has never found use among American engineers, and unless some yet undiscovered principle in its use is brought out, it never will.

In the analysis of different classes of disturbances which can take place on a power system there has been enumerated the effect of gradually accumulated static. This is a direct current phenomenon. Wind, rain, and snow striking against the line will sometimes give it an accumulative charge which will gradually raise the potential of the system above ground. Occasionally it happens that lightning arresters on power lines are caused to discharge repeatedly during very fine clear weather. This, in most cases that have come to the writer's attention, has been due to the gradually accumulated static on the line. The water jet arrester will relieve this static from a power line. It is, however, a very expensive method of getting rid of a very trifling phenomenon. The lightning arresters with any reasonable gap setting will also relieve these strains. A high resistance from any neutral connection of the circuit will also relieve the accumulated static as efficiently as the water jet arrester, and will at the same time cause no loss of power on the circuit.

The writer claims that this is the only practical value of the water jet arrester so frequently used in European practice. The claim is based on experimental evidence which has never been controverted. There have been unwarranted claims that the water jet arrester will take a lightning discharge and relieve the apparatus. If there is any virtue in this column of water there should be some experimental method available for demonstrating it. There is no intrinsic mystery about lightning phenomena. When this lightning gets onto the power wires, it follows the same laws of alternating current that the power currents follow; the main difference being that the frequency is far above the power frequency and therefore brings into prominence all sorts of capacity effects which are negligible at 60 cycles. Frequencies ranging all the way from zero cycles per second up to a billion cycles per second have been produced in the Protective Apparatus Laboratory, as have potentials of a sufficiently high value to puncture any of the known insulations, and currents large enough to melt down conductors of appreciable size. We have here the fundamental elements of lightning, and there is no reason why a water jet arrester subjected to these conditions in the laboratory should be obstreperous and not give good conditions of protection, and then reverse its peculiar features and give protection when applied to a transmission line. The fact of the matter is that the water jet arrester is nothing but plain high resistance absorbing energy from the circuit continuously. Its protective value depends upon two things: first, its total conduction; and second, the length of the water jet. If its total conduction is the usual value of a tenth of an ampere or less, then it will discharge a lightning stroke safely which can be taken care of by a discharge rate of about 0.3 of an ampere. The most fundamental experiments on equivalent needle-gap will show the absurdity of the statement that such an arrester will protect. Equivalent needle-gaps at a million cycles per second have been taken in the laboratory on both tubes of still water and jets of moving water. The motion of the water has no observable effect on the discharge rate of lightning. The statement that the moving water has a virtue has so often been made that special tests were applied in an endeavor to find it, but without success. The equivalent needle-gap of a column of water is extremely high. For a column of small diameter the equivalent needle-gap is equal to the length of the column. In other words, for the discharge of Leyden jars, as used in the test, the rate of discharge is so high as compared to the conduction of the water that the water acts like an insulator. It will be seen, then, that the second condition only in regard to the water jet arrester as enumerated above, comes into play in protection against strokes of lightning. If the column is so short that the discharge can take place from electrode to electrode through the air, then the water jet arrester is an efficient protection, although the result is a short circuit on the system. As a matter of fact, in actual installation, the water jet is comparatively long, and therefore any discharge that takes place along the water jet through the air is due to a dangerously high potential. To save the water jet arrester from the designation of a foolish fad of a lightning arrester dreamer, it will be necessary for some scientist to produce experiments which show that the water jet arrester has qualities that we have been unable to discover.

Sixth: Condensers as Protectors:

Another form of protection used in Europe is that found in the dry condenser. As usually installed, the condenser is placed directly between line and ground and absorbs continuously a small wattless current from the line. What the condenser will do as a protector can be easily shown by theory and experimentation. Probably the easiest and simplest method of illustrating its protective qualities is by considering it as a shunt from line to ground, and determining what current will pass through the shunt at different frequencies and different potentials. To bring out, first of all, one of its valuable features, it has no series gap, and therefore, no dielectric spark lag. Furthermore, having no series gap it absorbs high frequencies regardless of their potentials. The potentials, in fact, may be far below the normal line potentials. On the other side, it has its limitations as a protective device. Before taking this up, however, let us consider how it protects. For a capacity of 10 milli-microfarads (10×10^{-9} farads) from line to ground, and a potential double normal line potential, such a condenser on a 10,000-volt circuit will absorb 0.075 ampere at 60 cycles; at 100 cycles the absorbed current will be 0.126 ampere; at 1000 cycles, 1.26 amperes; at 10,000 cycles, 12.6 amperes; at 100,000 cycles, 126 amperes; at 1,000,000 cycles, 1260 amperes. It is seen from this simple calculation of electrostatic current in a condenser that its value as a shunt to the electrical apparatus increases directly with the frequency which has to be shunted out of the apparatus. As an example, if a line has impressed on it a frequency of 100,000 cycles at 20,000 volts, the condenser will hold the potential at the apparatus to 20,000 volts by absorbing 126 amperes. If, however, 126 amperes is not sufficient to absorb the oscillation of 100,000 cycles, the potential will rise above 20,000 volts, and will, therefore, become correspondingly more dangerous. In other words, everything depends upon the requisite rate of discharge of the high frequency on the circuit.

In the foregoing, it is shown that the condenser has the value of shunting high frequencies from the apparatus, and if the capacity is great enough it is possible to prevent an abnormal rise of potential at the terminals of the condenser. In order to say that a condenser is going to give satisfactory protection, it is necessary to know the values of current and the natural frequencies of lightning surges which play over a line. This is a field which has not been sufficiently investigated to give definite experimental data. We must trust in this case to calculations of the current of the surges from the mathematical analysis of the problem. Among other things, the mathematical analysis shows that the higher the frequency of the lightning the more efficiently does the condenser shunt the lightning charge from the apparatus.

This brings us to another viewpoint, namely: that of investigating the conditions of potential for any frequency whatever. This can be done by considering the fundamental relation that the quantity of electricity in a condenser is equal to the product of the capacity times the potential across the condenser. With a condenser of 10 millimicrofarads (10×10^{-9} farads) the quantity of electricity for different voltages is given in the following: At 1000 volts the quantity of electricity is 10^{-5} coulombs; at 10,000 volts, 10^{-4} coulombs; at 100,000 volts, 10^{-3} coulombs. If, now, we consider different lengths of line charged up by lightning clouds to these various potentials, we will find that so long as the length of line is comparatively short the quantities of electricity correspond to the quantities that can be absorbed by the condenser without raising the potential across the condenser to a high value. When, however, we consider any great length of line as charged up, even with a relatively low potential, the quantity of electricity becomes far too great to be absorbed by the condenser without overtaxing its dielectric strength. To jump immediately to the other extreme of quantity of electricity that is generated on the line, we have the effects of interrupted short circuits on a line. This energy tied up in the form of electromagnetism is always great as compared to the energy in the electrostatic charge of a localized lightning induction. For example, while about one mile of line charged up to 100,000 volts contains an electrostatic energy of 50 joules, ten miles of the same line will contain 24,000 joules of electromagnetic energy when a short-circuit current of 1000 amperes flows along the line. This line of reasoning leads one to the very definite conclusion that the condenser cannot prevent a rise in potential at its terminals when the quantity of electricity is considerable or when the frequency is anything but extremely high. In this statement it is assumed that the capacity of the condenser is not unlimited, but is restricted to a reasonable value by the actual cost of construction.

Let us now look at other unfavorable features regarding the use of a condenser as a protector. It has already been stated that the condenser is a high frequency shunt to the apparatus. It does not destroy the lightning charge or conduct it to the ground. It simply absorbs the charge during each half cycle of the natural frequency and throws it, undiminished in quantity and energy, back on to the line in the form of electromagnetic energy. In other words, the high frequency, although usually of less value than would have been the case if the condenser were not there, still is caused to oscillate in the insulation of the apparatus. During the past few years it has been determined that high frequency in itself is liable to be dangerous to insulation, due not to the potential strains it causes, but to the hysteritic loss in the insulation. The condenser leaves the surge free to oscillate for a comparatively long time until it gradually fritters itself away along the line. Thus, the condenser reduces the surge potential to a greater or less degree according to the frequency of the surge, but does nothing to relieve the duration of the application of this potential to the insulation.

In brief review, it may be remarked at this point that there are three main effects in circuits that it is desirable to avoid: First, abnormally high currents; second, abnormally high potentials; and third, abnormally high frequencies. The apparatus for relieving abnormally high currents is usually confined to switching mechanism with their corresponding relays. Apparatus for protecting transient high potentials are usually confined to lightning arresters, and apparatus protecting against abnormally high frequencies is usually confined to surge protectors and high frequency absorbers. The condenser as a protector falls under the category of lightning arrester with specific limitations in its value to partial protection against very high frequencies.

Another objection to a condenser in the circuit comes from the possible resonance that may take place between this condenser and some localized inductance in the apparatus. Although the condenser is nominally in parallel with the coils of the apparatus, it is possible to produce resonance by local oscillations. In any case resonance is rare, as it depends upon the chance coincidence of the lightning frequency and the natural frequency of some part of the circuit. While such coincidence may not occur frequently, still the menace remains and is destructive of insulation when it does occur. Experimental applications of condensers to electrical apparatus have shown by measurements that their presence changes the frequency at which resonance takes place, but do not decrease in the least the dangerous rises of potential due to resonance.

It may be due to occasional resonance that condensers have been so frequently destroyed by surges on lines. It may be recalled that at one time one of the large manufacturers in America used a condenser as a protective device, and operating engineers have informed me that this condenser was frequently punctured, although the factor of safety of insulation in the condenser was high. The writer has talked to many eminent engineers on the subject of high potential condensers, and the concensus of opinion is that no one has yet solved the problem of building a condenser for high potentials of reasonable capacity and reasonable safety, at a cost that is not objectionably high. Condensers for low potential circuits up to 2300 volts are apparently satisfactory. It seems very probable that the dielectric losses in the condensers have considerable to do with their failures. Experimental tests would indicate that the dielectric losses in the insulation of the condensers has much to do with the puncture of the insulation. While the condenser has a value, it must be used in conjunction with other devices which destroy the surges rather than simply shunt them.

BRIEF SUMMARY OF EUROPEAN PRACTICE AND A COMPARISON WITH AMERICAN PRACTICE

In previous numbers of the GENERAL ELECTRIC REVIEW the writer has covered in detail the features of American practice in lightning arresters. It remains simply to pick out the salient features of the European practice as given in this article, and compare them with the corresponding features in American practice.

First. Horn gaps without series resistance. These have the desirable characteristic of unlimited discharge rate for lightning. They have the undesirable characteristics:

(a) Of giving poor protection on account of large gap settings.

(b) Of producing a short circuit of the power at every simultaneous operation of two or more gaps.

(c) Of producing the most vicious kind of arcing grounds on the system.

(d) Of causing synchronous apparatus to drop out of step.

(e) Of causing, usually, a complete interruption of power on the circuit to which they are connected.

All of these undesirable features are accepted in order to get the one desirable feature of large discharge rate.

In the American practice the aluminum arrester is used, which gives a large discharge rate without any of the undesirable conditions of the simple horn gaps. Furthermore the gap length on the aluminum arrester is very much less than on the simple horn gap, and consequently, the protective value is correspondingly greater. The discharge rate in the aluminum arresters, although not as great as in the simple horn gap connection to ground, still is great enough to have taken direct strokes of lightning without destructive effects.

Second. Delta-connected horn gaps with large settings connected line to line without series resistance: The writer doubts if this practice is used to any extent even in Europe and it certainly has no counterpart in America. In brief, it is an unnecessary protective device.

Third. Y-connected horn gaps with moderate settings and with enough resistance in series to limit the dynamic current to a range of 3 to 12 amperes: This is the most recommended practice of any of those enumerated. It has the advantage of permitting reasonably good gap settings at the horns. Its spark potential, therefore, can be made satisfactory. It protects against minor discharges on the system satisfactorily. It has its disadvantages, which depend upon the voltage of a circuit to which it is applied. On very high potentials this arrester takes too much power from the circuit, is expensive to build, and gives poor protection due to insufficient rate of discharge. At low potentials the technical conditions are most favorable to this arrester. At 2300 volts it can be made to give a good discharge rate. There is no need, however, for this arrester at 2300 volts, as the multigap arrester is cheaper and better in that it takes less energy from the circuit.

At medium voltages the resistance horn-gap arrester has found more application than at other voltages due to the fact that no inexpensive arrester of any other type has been available. Work has been progressing on such an arrester during the past two years with a promise of an efficient arrester at small cost, and of high protective value. At 13,000 volts the resistance in series with the horn gap arrester is objectionably high, and with a dynamic current of 10 amperes it absorbs about 224 kw. It requires about one second minimum to operate, and cannot withstand long continued discharges.

Comparing this to the aluminum arrester, we find that the aluminum arrester has all the good characteristics of the horn-gap, medium-resistance arrester. In fact the aluminum arrester has a circuit through its charging resistance which duplicates in discharge rate the horn gap arrester, but takes only a fraction of a kw. from the circuit instead of 224 kw. This is due to the current-limiting action of the aluminum films. The aluminum arrester thus takes all small discharges through a small gap setting and resistance, and performs the same functions as the gap arrester in one-half cycle, whereas the horn gap requires from 50 to 120 times as long to extinguish the dynamic arc.

Fourth. Multiple horn gaps connected between a number of series choke coils in the line: Since the object of this protective device is to make it sensitive to several frequencies, it cannot be considered purely a lightning arrester, protecting against abnormal potentials. The practice has been discontinued in America because of the fact that the gap setting on the aluminum arrester can be set so near line potential that it will discharge at very slight increases in abnormal potentials. Furthermore, high frequency absorbers are used in the specific function of absorbing high frequencies that are of insufficient potential to cause a spark at the horns of the lightning arrester set at 25 per cent above normal.

Fifth. Water jet lightning arrester: Since the resistance of this arrester is too great to give it any appreciable value in discharging lightning strokes it need not be considered seriously. Accumulated static which gives a potential of only $1\frac{1}{4}$ normal line potential will find relief through the aluminum lightning arresters, or through high resistance connections to Y-connected transformers, or through similar means. In brief, any one aluminum arrester on a circuit will drain off all the accumulated static before it becomes of dangerous potential.

Sixth. Electrostatic condensers used as lightning arresters: This device is a high frequency shunt and has no value for medium or low frequencies. It performs one function not in the category of lightning arresters, namely: Shunting of high frequencies that have a potential less than 25 per cent above normal line potential. This function in American practice is confined specifically to high frequency absorbers which destroy the surges in addition to shunting them. Lightning arresters will absorb with a fair degree of efficiency the high frequencies which have sufficient potential to jump the series gap of the arrester. The high frequency absorbers will take all the residue.

FROM THE CONSULTING ENGINEERING DEPARTMENT OF THE GENERAL ELECTRIC COMPANY

WHY REACTANCES MUST HAVE AN AIR GAP IN THE MAGNETIC CIRCUIT

The alternating current transformer contains two separate electric circuits, the primary and the secondary. The auto-transformer (formerly also called "compensator") is a transformer using parts of the same circuit as primary and as secondary. The reactor or reactive coil contains only one circuit. Magnetically, however, an essential difference exists, in that the transformer or auto-transformer practically always contains a closed magnetic circuit, while the reactor must have an open magnetic circuit, that is, an air gap in the magnetic circuit.

In the transformer (and auto-transformer) power is transmitted from primary to secondary, and the primary current consists of two components: the primary load current, which is transformed, by the ratio of turns, into the secondary circuit and there gives the useful output, and the exciting current, which produces the magnetic flux of the transformer, but does not have an equivalent in the secondary, thus does not contribute to the secondary output, but is wasted. Thus, the smaller the exciting current (and its energy component, which gives the hysteresis loss), that is, the better the magnetic circuit, the better is the transformer. Therefore, in transformers a closed magnetic circuit is used.

In the reactor, no power transformation occurs, but the total current in the reactor corresponds to, or is the exciting current, and the reactor thus differs from the transformer by having the reluctance of the magnetic circuit made so high that the exciting current is the full-load current. That is, magnetically, the reactor is an unloaded transformer having full-load exciting current.

Full-load exciting current could be produced either by saturation of a closed magnetic circuit, or by an air gap in the magnetic circuit. In a closed magnetic circuit, the current wave—with a sine wave of voltage—is badly distorted by the third harmonic. In the transformer, where the exciting current is only a small part of full-load current, the wave shape distortion of the exciting current does not appreciably affect the total current wave. In the reactor, however, where the total current is exciting current, the wave shape distortion of the closed magnetic circuit would not be permissible, especially the very great distortion at over saturation; and therefore a saturated closed magnetic circuit is usually not permissible in a reactor, but an air gap has to be used.

Most of the ampere-turns of the reactor are consumed in the air gap. Thus, if a single large air gap [illegible], there is a strong stray field across this air gap, and large conductors located near the air gap [illegible] very thoroughly sub-divided or [illegible] losses by eddy currents result. [illegible] modern construction of the reactor, [illegible] considerable number of small air gaps [illegible] circuit, which give a more uniformly distributed reluctance, hence little stray field, and [illegible] use of larger conductors. In many cases [illegible] small gaps can be bridged at their edges by narrow iron bridges, so affording a better [illegible] construction.

C.P.S.

BY-PRODUCTS

In industrial manufacture, very often in addition to the product which is the object of manufacture, other products result, which are not aimed for, so-called by-products. Thus in the manufacture of the Welsbach mantel, large masses of cerium compounds remain, for which no use exists. Economy of manufacture then requires to find a use for these by-products, so as to create a market at least for a part of them, and thereby have them help to share in the cost of production. Thus energetic efforts have been made to find a use for these cerium compounds, one has been found in arc lighting as the light giving material in white flame carbons, another in cerium-iron alloys for igniting devices, etc. As such by-products if not used would have to be thrown away, practically any price for them would be economical as long as the demand is below the supply. Interesting conditions then result if the demand for a by-product of some manufacture increases beyond the supply. The by-product then becomes the main product, and its price fixed by the cost of production, while the former main product becomes the by-product. Such an instance we had in the last years: amongst the products of refining of crude oil, kerosene gives a certain percentage, gasolene another. For many years kerosene was the main product, and crude oil refined for supplying the demand of kerosene, while gasolene was by-product, and all efforts were made to find a sufficient market for it, by its use for illumination, in stoves, torches, as solvent, etc. With the advent of the automobile the demand for gasolene has now increased far beyond the supply as by-product of kerosene production, and gasolene now is the main product while kerosene is the by-product: hence the increase of the price of gasolene.

For the engineer, who looks around for new materials, to be put to new uses, this relation between by-product and main product with regard to their prices; is very important for consideration, since it means that the engineer, before considering the extensive use of a material, must ascertain not only whether the material is sufficiently low in price, but also, whether it will remain cheap if extensively used, or whether its low price is not merely the result of it being a by-product, which has no market, but which, when a sufficiently large market appears to have it produced as main product, would become too expensive for the contemplated use. For instance, the development of a heavy vapor, high temperature turbine would materially increase the thermodynamic efficiency. In studying the problem, bromine compounds would naturally first be considered, as due to their high molecular weight, the stable bromine compounds give very heavy vapors, and bromine is very cheap. Still for this purpose, bromine is excluded, since its cheapness now is due to it being a by-product which has a very limited market, and with a very extensive use, its price could, therefore, not remain the same.

The question then arises to the electrical central station manager; is not electric power during the off-peak period also a by-product?

C.P.S.

QUESTION AND ANSWER SECTION

The Q. and A. Section has been started with the sole object of increasing the practical usefulness of the REVIEW; and in order that it may be made of real value, we invite correspondence from any of our readers who are looking for information on any technical matter in the field covered by this magazine, and which they think we can furnish.

Where possible the answers to such inquiries will be the work of this office; where desirable we shall obtain our authority from that engineering or commercial party in the General Electric Company's organization best fitted for handling the particular subject. We hope our readers will not hesitate to avail themselves of the expert engineering opinion which should be made available through this section of the REVIEW. Information on matters of general importance and interest will be published here; questions of interest solely to the querist will be handled by mail.

Sketches should accompany questions in all cases where this is necessary to give us complete and accurate information on the point at issue. Scale drafts will be made up here from correspondent's rough pencil sketches. Questions must be accompanied with the name and address of the sender, although these will not necessarily be for publication, and should be addressed to the Editor, Q. and A. Section, GENERAL ELECTRIC REVIEW, Schenectady, N. Y.

VOLTAGE WAVE OF INDUCTOR ALTERNATOR

(56) Is the voltage wave of a Stanley alternating current inductor generator (S.K.C. system) an approximately "pure" sine wave, or is it distorted in a manner peculiar to this type of machine? The rating of the machine under consideration is as follows: Size = 750 kv-a.; 2500 = E; 60 = p.p.s.; two-phase. Operating conditions: One, two, and sometimes three of the foregoing direct-connected, steam-driven units are operated in parallel with from two to five, three-to-two-phase transformers (primary 13,200, secondary 2500 volts). These transformers operate on a three-phase supply from an overhead transmission line, from Curtis turbine generators. It may be worthy of note that the stator coils are rectangular in shape, with nearly square corners. The 86 per cent taps for circuit regulation have been discontinued. These machines have been accused of superposing a peak on the wave, thereby interfering with the satisfactory operation of mercury rectifiers fed from the same system.

In general, it may be said that on open circuit the inductor alternator gives an approximately "pure" sine wave, as a result of skillful shaping of the pole pieces. Under load conditions, however, it would be extremely difficult to predict just what might be the shape of the wave on account of the distorting magnetic effect caused by the concentrated winding, one slot per pole per phase. The most positive determination of the conditions as existent in the circuit is to be obtained from oscillograph curves.

I.P.T.

INDUCTION MOTOR HEATING

(57) It is desired to operate a form-wound induction motor, which is connected to a triplex pump, over a wide range of speed for maintaining pressure on a direct-pressure water system. As the pressure of the water system is constant, the load on the motor varies directly with the speed. Since the load on the motor decreases with the speed, will the heating effect, under these conditions, increase as the speed of the motor decreases? If so, to what extent?

When at rest an ordinary induction motor is able to radiate approximately 25 per cent of the full-load losses with the same temperature rise as at full-load, full-speed. As the motor is accelerated it can radiate more loss, the amount increasing proportionally with the speed. Based on these values, the temperature of a motor developing full-load torque should rise approximately 50 per cent more at half-speed than at full-speed.

Almost all standard induction motors will operate with a 50 per cent increase in temperature rise without injury to the winding. It is, therefore, quite possible for a form-wound induction motor to operate satisfactorily down to half-speed without injurious temperature rise when developing full-load torque.

H.M.

DIVISION OF LOAD AS AFFECTED BY INTERCONNECTED REACTANCE COIL

(58) Two three-phase circuits lead from a common set of busbars in a power house and, after passing through two separate groups of transformers, leave the station and constitute a twin-circuit transmission line. In order that a short-circuit on one of the receiving lines may not seriously affect the voltage of the other, and also to allow of an interchange of current between the two circuits under normal conditions of operation, a suitable reactance coil is inserted in the tie busses joining the secondaries of the two sets of transformers, as shown in the diagram (Fig. 1). The capacity of the two sets of transformers N_1 and N_2 equals the sum of the line loads P_1 and P_2. If only the power and power-factor of the receiver is known, how can the load distribution in the parts of the circuit be found?

In the problem it will be observed that the only data given for the receiver end is the load in kilowatts and the power-factor. If the current of the load was known the problem would be comparatively simple, but it would seem particularly difficult to find an equation that can be developed from the very meagre data furnished. It seems probable, however, that the current on the receiving end would be known and, assuming this, there follows a set of equations which enable the problem to be solved.

The first step in the calculation is to express the values of resistance, reactance, current, and voltage of the low-tension side in terms of the high-tension side, i.e., to multiply the resistance and reactance, by the square of the ratio of transformation, the voltage by the ratio of transformation, and to divide the current by the ratio of transformation. This allows the system to be represented by a one-line diagram (see Fig. 2).

The following notation is used in the working out of the formulae. (All voltages and currents are understood to be given in vector values and all

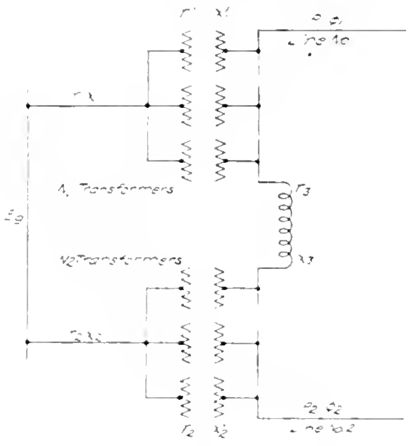

Fig. 1

quantities which include resistance and reactance are for one wire and to neutral.)

E_g = generator voltage
I_1 = current in line No. 1
I_2 = current in line No. 2
Z_{L1} = impedance of line No. 1
Z_{L2} = impedance of line No. 2
Z_{T1} = impedance of transformers No. 1
Z_{T2} = impedance of transformers No. 2
Z_c = impedance of reactance coil
I_c = current in reactance coil
E_1 = voltage of receiver circuit No. 1
E_2 = voltage of receiver circuit No. 2
I_{R_1} = current of receiver circuit No. 1
I_{R_2} = current of receiver circuit No. 2

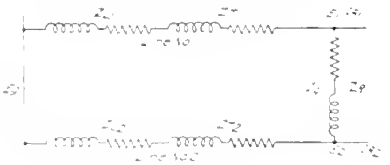

Fig. 2

[illegible] the impedances of the line and trans[illegible], they can be added directly.
[illegible] impedance of transformers and [illegible] No. 1.
[illegible] impedance of transformers and [illegible] 2

[illegible]

Also

$$I_{R_1} = I_1 + I_c$$
$$I_{R_2} = I_2 - I_c$$

and

(4) $I_1 = I_{R_1} + I_c$

(5) $I_2 = I_{R_2} + I_c$

As I_{R_1} and I_{R_2} are the only values known, it is necessary to find the value of I_c before the current in the transmission line can be obtained.

Hence, substitute the values of I_1 and I_2 in (1)

$$I_cZ_c = (I_{R_2} + I_c)Z_2 - (I_{R_1} - I_c)Z_1$$
$$I_cZ_c = I_{R_2}Z_2 - I_{R_1}Z_1 + I_c(Z_2 + Z_1)$$
$$I_cZ_c - I_c(Z_1 + Z_2) = I_{R_2}Z_2 - I_{R_1}Z_1$$
$$I_c(Z_c - Z_1 - Z_2) = I_{R_2}Z_2 - I_{R_1}Z_1$$

(6) $$I_c = \frac{I_{R_2}Z_2 - I_{R_1}Z_1}{(Z_c - Z_1 - Z_2)}$$

Now, if both of the transmission lines and transformers are similar, i.e., $Z_1 = Z_2 = Z$, the equation simplifies to the following:

(7) $$I_c = \frac{(I_{R_2} - I_{R_1})Z}{Z_c - 2Z}$$

Knowing the value of I_{R_1} and I_{R_2}, I_c can be calculated.

Knowing I_c, I_1 and I_2 can be found from equations (4) and (5).

In case of a short-circuit on one line, i.e., a short-circuit from one line to ground, the following equations will give the distribution in the transmission line.

Consider, for instance, a short-circuit on the receiver circuit No. 2. E_2 will then drop to zero potential. (It is assumed that the generator voltage remains constant.)

Then

$$E_g = I_2Z_2$$

and I_2 is easily calculated as E_g and Z_2 are known.

Also

$$E_g = I_1Z_1 + I_cZ_c$$

Now

$$I_1 = I_R + I_c$$
$$E_g = I_RZ_1 + I_cZ_1 + I_cZ_c$$

If it is assumed that I_{R1}, i.e., the receiver load on circuit No. 2, remains constant, then I_RZ_1 will become a constant and I_c will be the only variable.

Formula (8) can be expressed in a slightly different form as

(9) $E_g = I_{R_1}Z_1 + I_cZ_1 + E_1$

for E_1 must equal I_cZ_c as circuit No. 2 is at zero potential.

To find Z_c, E_1 must be taken such that it is a certain percentage of E_g, this being fixed by the value to which it is permissible for E_1 to fall under short-circuit.

Then the current in the reactance under short-circuit may be found from (9).

$$I_c = \frac{E_g - E_1 - I_{R_1}Z_1}{Z_1}$$

and Z is found from the equation

$$E_1 = I_cZ_c$$

W.W.W.

General Electric Review

Published Monthly by the
GENERAL ELECTRIC COMPANY'S PUBLICATION BUREAU

Manager, M. P. RICE | Editor, JOHN R. HEWETT | Associate Editor, B. M. EOFF | Assistant Editor, E. C. SANDERS

Subscription Rates: United States and Mexico, $2.00 per year; Canada, $2.25 per year; Foreign, $2.50 a year, payable in advance. Remit by post-office or express money orders, bank checks or drafts, made payable to the *General Electric Review*, Schenectady, N. Y.

Entered as second-class matter, March 26, 1912, at the post office at Schenectady, N. Y., under the Act of March 3, 1879.

VOL. XVI., No. 10 OCTOBER, 1913

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Photograph by New York Edison Company

THE SKYLINE OF NEW YORK BY ELECTRIC LIGHT

The justly celebrated skyline of our great metropolis is all the more impressive when seen by the glow of the myriad of lights that issue from its buildings at night. It is a truly wonderful sight, a great tribute to the engineering achievements of man, in which the electrical engineer may take his full share of glory. The incandescent lamp, of all electrical inventions, has been of the greatest service to the greatest number; and this fact is never more forcibly impressed upon one than when approaching New York at night by water. The tungsten filament lamp was a tremendous improvement over its predecessor, and it will be noted in this issue that another great step forward in efficiency has been realized in the nitrogen filled lamp.

GENERAL ELECTRIC REVIEW

THE PATHS OF PROGRESS

Necessity is the mother of invention; and the many developments, discoveries and evolutions that we are constantly witnessing in the scientific and engineering world, while perhaps less spectacular than some great inventions, are foster children of the same parent. All honor is due to the inventor, as the progress of the world must always be dependent upon original thought; but an invention, as a rule, is only a foundation stone on which we erect a structure of usefulness by development.

As a matter of fact during the last few years, or even decades, we have not been witnesses to great epoch-making discoveries or inventions in the same measure as we have been to wonderful and sound developments and gradual but effective evolutions. While this is largely accounted for by the fact that developments have made such rapid strides, by some it is taken as a sign of lack of progress, or even of retrogration; but in reality this is not the case. It is easier to invent than it is to develop, as the former is the brilliant child of a fertile imagination, while the latter is a host of corelated thoughts brought down to action and given a useful form at the cost of much work, energy and patience; and moreover a development must be tempered by economic principles, while an invention needs no such fetters. And again, an invention may cost nothing or next to nothing, but a development may cost anything, even up to millions of dollars; indeed, many instances might be cited in which an invention has been of no practical value till a vast sum of money and many years of work have been expended on development before the finished product was produced in a commercial form.

Our individual and collective efforts today largely consist of an endeavor to establish a state of equilibrium between supply and demand. Demands are becoming increasingly exacting, and while this shows a healthy growth in progressive ideas, without which a state of stagnation would soon be brought about, it would be absolutely impossible to maintain such a state of equilibrium if we were dependent upon invention alone. This state must be, and is being, maintained by development. Each year the science of development is being perfected, that is to say, we are leaving haphazard methods behind for a well-defined scientific process of development, where the demands are first more or less accurately determined, and then the line of development is settled and the individual problem attacked in an orderly, scientific manner with a minimum of waste and the elimination of duplications and useless and ineffective work.

The large corporation is a pioneer in this work, which, unless done in an orderly and predetermined fashion, is likely to be abortive of results and extravagant in the duplication of work by separate uncorelated units. The large manufacturing industries are in a unique position to determine the demands, and it would seem that they alone, or nearly alone, are able to spend the enormous sums required for equipment, both human and material, that are the essentials to a scientific development in any particular line of work.

Such articles as "The Nitrogen Filled Lamp" and "The Physical Phenomena of the Mercury Arc Rectifier," which we publish in this issue, are forcible reminders of the splendid work, both theoretical and practical, and also in invention and development, that is being accomplished in the research laboratory. Mr. Alexanderson's article on "The Split Phase Locomotive" also shows a development in another direction, and we hope that from time to time we shall be able to include other articles in the REVIEW which will show further developments in other classes of work, and tell of further steps taken along the paths of progress.

THE NITROGEN FILLED LAMP

A NOTABLE DEVELOPMENT

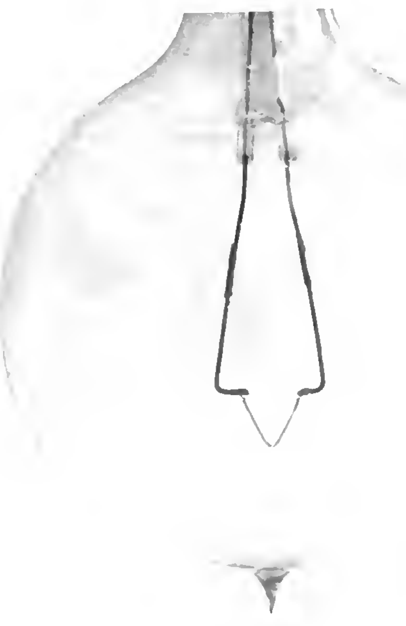
Dr. Irving Langmuir of the research laboratory at Schenectady will, at an early date, read a paper before the A.I.E.E. describing this interesting and important development. It has already been announced that tungsten lamps having an efficiency of approximately one-half watt per candle were soon to be placed on the market. While similar announcements have been made abroad, it is interesting to note that these improvements were the result of several years' work on the part of a corps of efficiently trained men in the research laboratory.—EDITOR.

The so-called nitrogen lamp, or more properly the nitrogen-filled lamp, is a tungsten lamp of high efficiency. It is interesting to note that ever since tungsten first came into use for lamp filaments there has been a constant endeavor to produce lamps of higher efficiency. The early work, however, was more or less a groping in the dark, for the causes that limited the life of ordinary lamps were not definitely known. The work was, therefore, largely of an empirical kind. All sorts of variations in the methods of making the filaments as well as in the methods of exhausting the lamps were tried in the hope that some might lead to an improvement in the life of the lamps.

Anything which would accomplish this result would render it possible to do the more desirable thing, namely, to increase the efficiency without sacrificing the life.

The results of this empirical work were not very encouraging. It was possible to improve the lamps from 10 to 20 per cent in life by certain means [illegible] corresponded [illegible] possible improvement in the efficiency of [illegible] hundredths of a watt per candle.

It was [illegible], however, that tungsten lamps could be run [illegible] efficiency as high as 0.20 watt per candle [illegible] a few seconds. The melting point of the filament prevented any further increase of the efficiency beyond 0.20 watts per candle. Even at 0.5 watt per candle the bulbs blackened badly within a couple of hours. The blackening of the bulb was thus the chief cause which prevented the running of tungsten lamps at very high efficiencies.



1500 Candle-Power Nitrogen-Filled Lamp

There were the most diverse opinions among those familiar with the manufacture of lamps, as to the cause of this blackening. There were many indications that the life might be greatly improved if a perfect vacuum could be obtained. Direct experiments to better the life by improving the vacuum were not very successful. This, however, might be taken to mean that the vacuum had not actually been improved, since there were practically no reliable methods of measuring such low pressures as exist in well-made lamps. It was, therefore, decided to grasp the bull by the horns and find out, once for all, the real cause of the blackening of the bulb, and determine the laws governing it. It was hoped that in this way a great deal of ill-directed experimenting might be avoided and possible clues to methods of preventing the blackening might be found.

It had long been a theory that blackening was largely, if not entirely, due to the presence of gas in the bulb. A careful quantitative study of the sources of gas within a lamp bulb was made. The gases given off by the filament, by its supports, by the bulb, and the residual gases left on exhausting were measured and analysed chemically, although often the quantities involved were less than a cubic millimeter. With this knowledge of the nature and amounts of gas that might exist in a lamp, a systematic study was made of the effects that were produced in lamps by the introduction of these (and other) gases in varying quantities into lamps. This work showed clearly that of all the gases that might exist in lamps only one, namely, water vapor, always known to be detrimental, ever produced blackening of the bulb.

The action of water vapor was, therefore, studied in detail. It was found that the water vapor attacked the filament, producing a volatile oxide of tungsten and atomic hydrogen. The oxide that thus collected on the bulb was then reduced by the atomic hydrogen. The deposit was thus changed to a black layer of metallic tungsten while the hydrogen combined with the oxygen to form water which again acted on the filament. The action of water vapor was thus a cyclic process by which large amounts of tungsten could be carried from the filament to the bulb by very small quantities of water.

Efforts were then made to study the relation between the amount of water vapor on the bulb and the rate of blackening by this cause. Pressures of water vapor even as low as 0.0001 mm. were found to produce very rapid blackening. By methods of exhaust especially adapted to the removal of water vapor, it was finally proven that the blackening of bulbs with filaments at high temperature goes on even in the absence of water vapor. This kind of blackening was considered probably due to ordinary evaporation.

To test this theory, quantitative experiments have been made to determine the rate of loss of weight of tungsten filaments in vacuum when run at various temperatures. This work has conclusively shown that the cause of the blackening of ordinary well-made tungsten lamps, as well as those run at higher than their rated efficiency, is simple evaporation. On the other hand, the rapid blackening of poorly made lamps is due largely to the presence of water vapor.

When it was thus definitely known that the blackening of the lamps was due to evaporation, the problem of improving the efficiency assumed more definite form. To increase the efficiency either the rate of evaporation would have to be decreased or the evaporated material would have to be prevented from blackening the bulb. These considerations have led to several different methods of attack, of which the following are particularly interesting:

1. Introduction of gases, such as nitrogen or mercury vapor at atmospheric pressures into the lamp bulb.
2. Changing the location of the deposit by means of convection currents in gases, so that the bulb opposite the filament does not darken.

Each of these methods has been tried with marked success.

The use of a gas at high pressure causes the loss of heat from the filament by convection. This makes it necessary to run the filament at a higher temperature than in a vacuum even to get the same efficiency.


2000 Candle-Power Nitrogen-Filled Lamp

The question arises: Are the advantages to be gained by the use of a gas sufficient to offset the tendency for an increase in the rate of evaporation owing to the higher operating temperature?

Simultaneously, with a large part of the preceding work, several investigations on the heat losses of wires in various gases had been under way. It had been found that the heat lost by convection increases only slowly with the temperature of the filament, approximately proportional to the $\frac{3}{2}$ power of the temperature. The radiated energy, on the other hand, increases with about the 4.7^{th} power of the temperature. At very high temperature the effect of convection currents therefore becomes *relatively* small. It had also been found that the heat loss by convection from small wires at high temperatures is very nearly as great as that from wires several times as large in diameter. In other words, the cooling effect of the gas on the filament is much more serious in the case of small filaments than in the case of large ones. For example, a straight filament 0.001 in. in diameter run in nitrogen at atmospheric pressure and at a temperature corresponding to that of a filament running at 1 watt per candle, will give an efficiency of only about 4.8 watts per candle. On the other hand, a filament ten times as large (i.e., 0.010 in.) will give at the same temperature an efficiency of 1.59 watts per candle.

It is thus of great importance to use filaments of large diameter. Practically the same effect can be obtained by winding the filaments into the form of a tightly coiled helix.

From the above considerations it is clear that the larger the diameter of the helix the higher the efficiency that may be obtained. The diameter of the helix is ordinarily limited by the sagging which is apt to occur if the mandrel on which the helix is wound is too large in proportion to the size of the wire.

With helically wound filaments in nitrogen very high efficiencies can be obtained and yet the life of the filament may be more than 1000 hours. The blackening of the bulb is avoided; and in properly designed bulbs the tungsten that evaporates produces only a slight brownish deposit in the upper part of the bulb, where it does no harm. A number of types of nitrogen filled lamps have been made and tested. Among these the most interesting for the present are perhaps the following:

1. *Large units of very high efficiency.* (0.4-0.5 watt per candle with a life of 1000 hours or more.) These take currents of at least 20-30 amperes and (except in units over 4000 candle-power) are therefore best run from alternating current circuits by means of small transformers giving a voltage depending on the size of unit desired.

2. *Smaller units of low voltage.* These take currents of ten amperes or less, at voltages, in some cases, as low as four or five volts. The efficiencies with 1000 hours life vary from 0.6 to 1 or even 1.25 watt per candle, according to the current used. These lamps are adapted for series street lighting on 6.6 ampere circuits (at about 0.7 watt per candle); for stereopticon lamps, automobile headlights and in general, wherever a source of high intrinsic brilliancy, steadinesss and white color is needed.

3. *Lamps* to run on *standard lighting circuits* (110 volts). Large units of this type (several thousand candle-power) have efficiencies of 0.5 watt per candle or better. With smaller units the efficiency is ordinarily not so high.

Special Advantages

Besides their high efficiency, there are certain features of the new lamps which may prove of advantage for certain cases.

1. *Color of the light.* The temperature of the filament being several hundred degrees higher than that of ordinary tungsten lamps, causes the light to be of a very much whiter color, so that it comes closer to daylight than any other form of artificial illuminant except the direct current arc and the special Moore tube containing carbon dioxide. The color is almost exactly like that which can be obtained for a few minutes by running an ordinary tungsten lamp at double its rated voltage.

By the use of special color screens it is possible to obtain a true daylight color at an efficiency of about 2 watts per candle whereas with ordinary tungsten lamps the efficiency obtained with the proper screens is only 10-12 watts per candle.

2. *High intrinsic brilliancy.* The intrinsic brilliancy is five to ten times that of the filament of the ordinary tungsten lamp. This renders it especially suitable for projection work such as headlights and stereopticons. Although the intrinsic brilliancy is less than that of the arc, this difference is often more than offset by the fact that the wandering of the crater of the arc prevents as sharp focusing as is possible when the source of light is fixed in position.

3. *Constancy of the characteristics during life.* Because of the freedom from blackening of the bulb in these lamps and because the helically wound filaments may be so designed that the sagging compensates other changes during life, it is possible to make nitrogen filled lamps which maintain their volt-ampere candle-power characteristics practically constant during their whole life. The ultimate failure of these lamps is due to the breakage of the filament. The candle-power is usually well above 80 per cent, even just before failure.

PHYSICAL PHENOMENA OF THE MERCURY ARC RECTIFIER

By F. Parkman Coffin

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The mercury arc rectifier, which is based largely on the work of Peter Cooper-Hewitt and Dr. Weintraub, has been extensively employed during the last eight or nine years for charging storage batteries for automobiles, telephones, etc., and for supplying constant current circuits for magnetite arc lamps. In the latter case it has practically supplanted the Brush arc machine. The physical principles underlying the operation of the mercury arc rectifier can be clearly understood only when studied in connection with the general phenomena of gaseous conductivity. The author has therefore reviewed at length some of the more important related phenomena.—Editor.

The rectification of alternating currents of electricity can be accomplished in two general ways: (*a*) by mechanical means, where the circuit is opened and closed in synchronism with the cyclic changes of polarity by rotary or vibratory mechanism; and, (*b*) by selective conductors which act as automatic electric check valves and allow the current to flow in one direction with a relatively small resistance, while offering a great resistance to a current of opposite polarity. Selective conductivity occurs in certain cases in solid, liquid and gaseous conductors.

Certain crystalline conductors giving a relatively high thermo-electromotive force at points of contact with dissimilar materials have a rectifying action for alternating currents of extremely small value. This is probably due to the generation of heat at the junction by the passage of alternating current and the regeneration of a portion of this energy in the form of unidirectional current of thermo-electric origin. Crystal rectifiers have been used as receivers in wireless telegraphy, silicon, carborundum, and other materials having been employed.

Valve action of an electrochemical nature occurs at the surface of an aluminum electrode when immersed in certain electrolytic solutions. A small initial flow of current forms a non-conducting film on the surface of an aluminum cathode which prevents any further flow of current in this direction. Upon reversal of polarity this film immediately dissolves and allows free passage of current with the aluminum as anode, a dissimilar material (such as iron) being used as cathode. Electrolytic rectifiers have been used on a small scale for charging batteries and for differential relays.

When gases form part of an electric circuit, many cases of selective conductivity at the electrodes may be observed, and a number of such phenomena may be utilized for current rectification.

The two most useful forms of gaseous rectifiers are the "mercury arc rectifier" and the "incandescent rectifier." The principles underlying the operation of these two are very similar, but in order to make them clear it will be well to digress a little from the subject in order to review some of the general phenomena of the conductivity of electricity through gases. Electric discharges through gases may be divided into three general classes; namely, the spark, the arc, and the Geissler discharge.

The Spark Discharge

The spark is a disruptive discharge at high voltage in air or other gas, and may be regarded as a series of discontinuous arcs of threadlike dimensions. It is generally of the nature of a high frequency oscillation. The arc, on the other hand, is a continuous discharge of relatively heavy current with a low potential drop. When the potential across an air gap is raised to the breakdown point a "static spark" first jumps across and, if the power behind the spark be sufficient for the length of gap, it may immediately develop into a "dynamic arc." Thus the spark breaks down the initially high resistance of the air and allows the current to increase suddenly, with an accompanying decrease of potential drop. This phenomenon occurs in the alternating current arc lamp during the early part of each succeeding half cycle, since the arc is totally extinguished at the end of each wave and must start anew on the next wave. The starting, in this case, is facilitated by the high temperature of the electrodes. In fact, an alternating current arc will only hold between electrodes of materials which are sufficiently refractory to maintain extremely high temperature without rapid disintegration, like carbon and titanium carbide.

The Electric Arc

In the continuous current arc there is a marked difference in the phenomena at the anode and the cathode. Examine, for instance, the arc in the "magnetite" lamp. The arc takes the form of a cone with the apex (cathode) downward and terminating in a small bright spot which wanders slowly over the surface of the cathode, the material fusing as the arc passes, only to solidify again when the cathode spot moves elsewhere. The base of the luminous cone spreads over the surface of the copper anode without developing sufficient temperature at any point to fuse the metal. During the trial of certain experimental electrodes for magnetite lamps, a common fault was the formation of a crater on the cathode one quarter inch deep or more. At the bottom would be a pool of liquid material over which the cathode spot was ceaselessly moving, while the wall of the crater intercepted most of the light.

There is an interesting similarity between the magnetite arc in air and the mercury arc in a vacuum. In the mercury arc lamp or rectifier we have a bright cathode spot wandering rapidly over the surface of the mercury pool. Immediately above the spot is an expanding zone of faint luminosity merging into the luminous positive column. At the anode the arc diffuses over the surface of the graphite cylinder, raising its temperature to a bright red heat. The temperature of the glass walls will be found low enough to touch without burning the hands in spite of the luminous column within. Let a little air into a tube containing a mercury arc and the appearance of the arc changes at once. In place of the relatively cool diffused glow expanding to fill the tube, we now have a hot constricted arc with high potential drop and a cross-section considerably less than the diameter of the tube. At the anode the arc is less evenly diffused, and tends to shorten and to concentrate on the lower end, heating this to a higher temperature than before. This illustrates the difference between arcs in high vacuum (or rather in an atmosphere of the attenuated vapor of the cathode) and arcs in an atmosphere of foreign gas. However, raising the pressure of the mercury vapor by running the arc at a higher temperature in a quartz or metal tube will have a similar effect and will increase the potential drop. This is the case in the quartz mercury arc lamp.

The magnetite and mercury arcs present the general phenomena of the arc more clearly than does the carbon arc, although the latter is the usual type described in the older literature on the electric arc. The carbon arc in air is really a special case, insomuch as carbon is an element with unusual physical properties, being infusible, always vaporizing directly from the solid state, and burning only to gaseous oxides. Carbon electrodes in air are consumed principally by oxidation.

In the case of the metallic arcs the material of the cathode determines the color of the light and other characteristics of the arc stream, while the anode may be of carbon or any conducting material, provided it be large enough to radiate the heat. A metallic anode, if too small for the current, will melt. A carbon anode in vacuum can be run at a white heat without appreciable wasting away, the only limitation being the melting of the metal lead, or injury to the insulation, or to the glass container. The heat is generated by a potential drop of from 4 to 7 volts or more at the surface of the anode where the current passes from solid to gas.

The vaporization of material to maintain the arc stream takes place entirely in the cathode spot where the current is concentrated on a very small area of surface in passing from gas to solid. The temperature of the cathode spot in the mercury arc has been estimated to be about 3000 deg. C.

The energy resulting from the fall of potential of 4 volts or more in the cathode spot is expended principally in vaporizing the mercury, while a smaller proportion of the heat is conducted away from the spot by the mercury or is radiated. With large currents vaporization is so violent that a vigorous vapor blast emanates from the spot and carries with it more or less spray, consisting of large and small drops of liquid mercury. In the 50 ampere rectifier the larger drops are thrown nearly to the top of the condensing chamber, or about 18 inches above the cathode. The vapor blast is faintly luminous throughout the condensing chamber.

A small proportion of the energy released in the cathode spot is required for ionizing the vapor to render it conducting. Ionization consists in a partial disintegration of atoms by setting free some of the electrons of which they are composed. A gaseous molecule, or group of molecules, will be given a positive or a negative electrical charge when one or more electrons have been torn away from, or added to, any of the component atoms; and such charged molecule, or group of molecules is known as a "positive ion." The vapor in the arc stream is positively charged by the abstraction of electrons from the molecules.

The Geissler Discharge

Air and other gases are good insulators at atmospheric pressure with low potential gradients. As the potential gradient increases toward the breakdown point where a spark discharge takes place, gases become slightly conducting, until, with high potentials a luminous "brush discharge" appears at the electrodes. Owing to limited cross-section of conductive gas next to the electrodes, the potential gradient is increased at this point and the gas is strained beyond the critical point. The corona phenomena on high tension wires are of this nature. The brush discharge and corona in dense gases are really special cases of the spark discharge, in which the distance between electrodes is too great to be bridged by a continuous spark.

The dielectric strength as measured by the sparking potential for a given distance between electrodes is proportional to the absolute pressure of the gas from the highest pressures downward until we reach a comparatively high vacuum. In the neighborhood of 1 millimeter pressure of mercury many gases attain their maximum conductivity, or lowest dielectric strength, and with further decrease of pressure their conductivity decreases rapidly until, in a perfect vacuum, the conductivity is nil. See Figs. 1 and 2. This phenomenon is apparent in the X-ray tube, where a continual absorption of gas is caused by the discharge, and means are provided for generating enough new gas to maintain the conductivity.

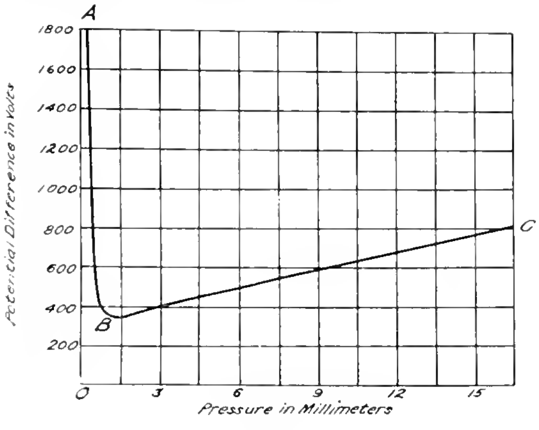


Fig. 1*

In the curve shown in Fig. 1 the ordinates represent the spark potential, the abscissae, the pressure. The electrodes were parallel planes and the spark length 3 mm. The vacuum portion, AB, represents a region of very different phenomena from the dense air portion, BC, which extends from the region of maximum conductivity to atmospheric pressure, and beyond to pressures of many atmospheres. Discharges in this region take the form of the spark or brush discharge, according to the length of the path. In the region of high vacuum, AB, the high voltage discharge becomes a steady diffused glow which is known as the Geissler discharge. The change observed with decreasing pressure in the case of the high voltage discharge is coincident with the change in the appearance of the mercury arc in an atmosphere of dense vapor as compared with the diffused arc of lower temperature in a vacuum, where the gas present is rarefied mercury vapor.

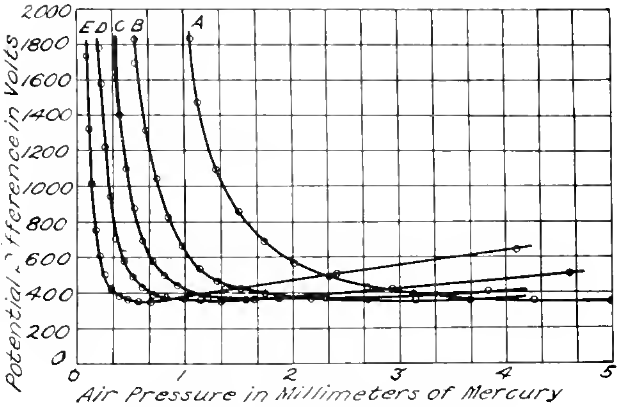


Fig. 2. Distance Between Electrodes

Curve A = 1 mm. Curve B = 2 mm. Curve C = 3 mm. Curve D = 5 mm. Curve E = 10 mm.

The Moore tube for electric lighting is a Geissler tube containing air or other gas at a pressure of about 1 millimeter of mercury where the conductivity is a maximum. In this case, also, there is a continual absorption of gas which renders it necessary to replenish the supply by letting in more through an automatically regulated valve. The choice of gases for use in the Moore tube is determined by the color of light desired; air gives a pink light, while carbon dioxide gives white. The gas pressure maintained in the X-ray tube is infinitely less than in the Moore tube, while the voltage per inch of tube length is of correspondingly greater magnitude in the case of the X-ray tube. In a Moore tube there is a terminal drop of some 2000 volts at the two electrodes, in addition to a distributed drop in the luminous portion of the discharge depending upon the length of the tube. For a $1\frac{3}{4}$ in. tube this is about 200 volts per foot.

*Figs. 1 to 5, inclusive, are reproduced from J. J. Thomson's "Conduction of Electricity Through Gases."

The electric arc in a vacuum is a relatively simple phenomenon when once established, while the phenomena encountered in studying the Geissler discharge are complex and difficult to observe. Fig. 3 gives an outline of a typical discharge in gas of good conductivity. The structure of the discharge is as follows: next the cathode is a dark zone known as the cathode dark space; then a bright patch, the "negative glow;" and then the "second negative dark space," of less magnitude, followed by the uniform positive column. Under favorable pressure conditions the latter frequently becomes striated with alternate light and dark bands, as shown in the illustration.

Fig. 3. Geissler Tube

The beam of cathode rays which is shown emanating from the cathode is visible only at very high vacuum and with high voltage, as in the X-ray tube. At more moderate voltages the current is so small at high vacuum that the discharge is not visible. The negative glow and positive column appear brighter and brighter with increasing gas pressure. At low pressures the cathode dark space is sufficiently expanded to fill the whole of a short tube.

The curve in Fig. 4 represents the distribution of potential gradient as measured by a pair of exploring electrodes. Neglecting the striated condition of the discharge, the essential features are the cathode dark space, the negative glow, and the positive column. There is a small potential fall at the anode, a small potential gradient in the positive column, and a large fall of potential across the cathode dark space. In fact, we may neglect the positive column in a short tube and consider that practically all the applied potential will appear between the negative glow and the cathode. The length of the cathode dark space varies inversely with the pressure of the gas or vapor; the negative glow appears as a halo completely surrounding an electrode if the walls of the containing chamber be not too near. This halo is at all points equi-distant from the surface of the cathode, and contracts or expands if the gas pressure be increased or decreased.

The width of the cathode dark space has been found to be equal to the sparking distance between flat electrodes when the voltage and the gas pressure are the same in each case. In Fig. 2, curve C is the same as in Fig. 1, except for the scale. The other curves are for other sparking distances; and it will be noticed that for small distances in the portion *AB*, Fig. 1, the sparking potential increases as the distance decreases, while the reverse is true in the portion *BC*. The left part of the curves in Fig. 2 may equally well represent the variation in width of the cathode dark space with change in gas pressure and voltage. When we pass the minimum point of the curves the cathode dark space practically vanishes and the negative glow appears close to the cathode.

In Fig. 5 is shown the distribution of the negative glow, at a relatively high gas pressure, about an electrode consisting of a long wire centrally located in a glass tube. In this case just enough voltage was applied to overcome the minimum value of the cathode drop and the small drop of about 35 volts at the anode and cause a little current to flow. The cathode drop has a definite minimum value for any one combination of electrode material and gas composition. In the case of a platinum cathode in mercury vapor this minimum drop has been found to be 340 volts, and it is probably about the same for a graphite cathode in mercury vapor, since the more stable elements do not differ much in this respect. If less voltage than this be

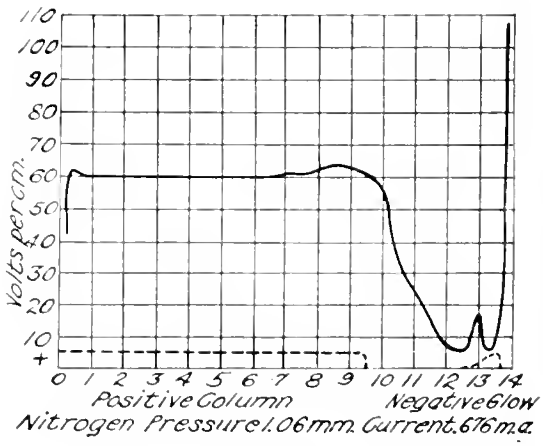


Fig. 4. Distribution of Potential Gradient in Geissler Discharge

applied no current will flow. Upon gradually raising the voltage until a small current flows, as in Fig. 5, a glow will appear surrounding the tip of the cathode only. In this case the tube contained air and the current was limited by resistance in series; by cutting this resistance out gradually the current will increase sufficiently for the glow to develop the entire length of the cathode, while the current density in the glow remains constant. Now if more voltage be applied the current will continue to increase proportionately; but the glow cannot spread over any more cathode surface, since it is limited by the insulation on the lead. The glow, however, will brighten with the increase in current density.

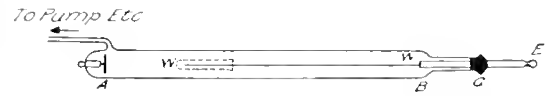


Fig. 5. Sketch Showing Glow Partially Covering Cathode

If now we pump out some air and reduce the pressure, the dark space expands until it becomes greater than the distance from the electrode to the walls of the tube (Fig. 3). When this occurs, the end of the tube which the electrode enters is all dark space, while negative glow is to be found further down the tube, extending from wall to wall. Since the anode drop is small, and decreases with increasing current, the entire increase in voltage must be taken up by the cathode dark space, even if several thousand volts be applied. With increase of the voltage across the dark space there will be a slight contraction of the latter for any given gas pressure; but this is of much smaller magnitude than the change in the length of dark space with the gas pressure. See Fig. 2.

The conduction is carried on by a stream of negative electrons flowing from cathode to anode, with a complementary stream of positive ions flowing in the opposite direction. When the positive ions reach the border of the dark space they are strongly accelerated by the electric field and are drawn rapidly across the dark space. Upon striking the cathode, they set free negative electrons which are shot off normally from the cathode surface with great velocity, since their mass is much smaller than that of the more sluggish positive ions, while the two kinds carry equal amounts of energy. The distance to which the negative electrons are shot depends upon the freedom of the path from molecules, that is, upon the rarity of the gas. The electrons shoot across the dark space until they hit gas molecules in the region of the negative glow. They either pierce or are deflected by many molecules on their way and are slowed down by these collisions. When they reach the negative glow they are moving slowly enough for many of them to recombine with positive ions moving in the opposite direction, thus releasing energy which produces the light in the negative glow and ionizes other gas molecules, setting free more ions. Also, during the passage of the electrons through the positive column, they are moving slowly enough to continue this process and produce light.

There is probably no essential difference between the conduction in the mercury arc in a vacuum and in the Geissler discharge, except at the cathode. In the Geissler tube the current, in its effort to pass from gas to solid, spreads itself over the surface of the cathode, and is limited in strength by the inherent resistance of that surface. If the temperature of the cathode increases sufficiently to cause vaporization of the material, the Geissler current increases very rapidly in the neighborhood of a white heat, and the discharge may suddenly flash into an arc. The minimum value of the potential required to maintain a discharge also falls and approaches the low value of the cathode drop in the arc. This facilitates the sudden formation of a cathode spot under these conditions.

Thus the fundamental difference between the Geissler discharge and the arc is that in the former case there is a small current uniformly distributed over a large and relatively cool surface. Its magnitude depending on: (1) the area of the cathode; (2) the applied voltage; (3) the temperature of the cathode above certain limits; (4) in some gases, upon their pressure, although in mercury vapor it appears not to vary with the pressure. In the arc the total fall of potential is small and is independent of the applied voltage. The current therefore is determined by the conditions of the external circuit. At the cathode the entire current is contracted in one spot, which it maintains at a temperature so high that the drop is very small.

In the case of a Geissler discharge there can be a very abrupt change into an arc, if the equilibrium of current distribution over the cathode surface be disturbed in any way so as to cause a sudden concentration of current with local increase of temperature and reduction of drop. Thus a local spark discharge on the surface of the cathode may cause the immediate formation of an arc. Since the dark space contracts with increase of the gas or vapor pressure, the potential gradient next the surface of the cathode increases until, when the negative glow closely surrounds the cathode and the dark space has practically vanished, the discharge readily flashes into an arc. The greater the applied voltage the more readily does this occur. This seems reasonable, owing to the increased potential gradient; but it also agrees with the fact that at constant gas pressure the dark space contracts with increase of the voltage. Therefore we reach arcing conditions sooner with increasing gas pressure, when the voltage is high.

Some experiments were made by the author to determine the conditions under which the change takes place from a Geissler discharge to an arc with increasing pressure of air and mercury vapor. Alternating voltage was applied between two graphite electrodes about one inch in diameter and one inch and a half long, located three inches apart in a metal vessel containing mercury, and air at low pressure. The Geissler discharge and negative glow were observed through a mica window. When the vessel was cool enough to make the mercury vapor pressure negligible, the gas pressure was gradually increased by letting in air until arcing occurred. The air pressure was measured by a McLeod gage and read in microns (one thousand microns equal one millimeter of mercury). The insulation at the back of the electrode was shielded by a tubular hood. The frequency was 60 cycles.

With an applied voltage of 2300, occasional arcing occurred with a current of 10 milli-amperes when the pressure exceeded 800 microns. At 1500 microns the arcing became continuous, with a current of 30 milli-amperes. Then the vessel was immersed in a tank of oil, which was heated to maintain various temperatures up to 130 deg. C. Meanwhile a vacuum pump was kept running to pump out all permanent gases, the mercury vapor condensing in the exhaust pipe and draining back to the vessel. With 2300 volts the Geissler discharge in mercury vapor was about 10 milli-amperes at all temperatures up to about 130 deg., where arcing occurred. This point was about where the cathode dark space disappeared with increasing vapor pressure.

In Fig. 6 is shown the saturation curve of mercury vapor, the ordinates representing vapor pressure in microns and the abscissae the temperature in degrees centigrade. Mercury vapor reaches a pressure of one millimeter at 127 deg. C., and increases very rapidly as the temperature rises; and therefore it is apparent that the arcing point is reached at about the same pressure in air and mercury vapor, although air is the better conductor for the Geissler discharge. The contraction of the dark space, with the accompanying increase in potential gradient in the gas next the cathode, is evidently the limiting feature of the Geissler discharge. At 20 deg. C. the pressure is about one micron.

In these experiments it was found very important to shield the insulation on the electrode leads, otherwise arcing developed at much lower air pressures, and the cathode spot always formed where the edge of the insulation touched the graphite. At this point there must exist a sort of shearing stress in the electric field; the discharge being limited to a restricted amount of exposed cathode surface, and forced to build up in current density with a high voltage across the dark space.

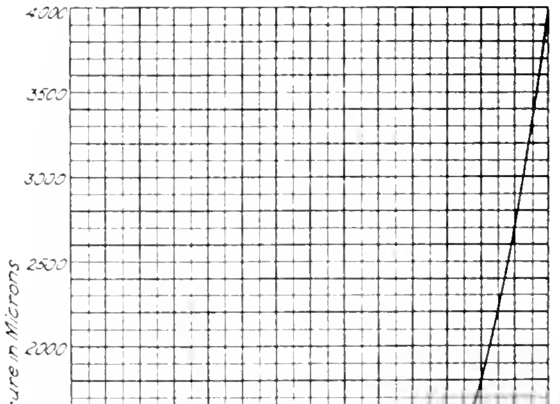


Fig. 6. Mercury Vapor Pressure

The Incandescent Rectifier

The simplest application of the principles of gas conduction to the rectification of alternating current is embodied in the incandescent rectifier. This consists of an incandescent lamp which is provided with an extra electrode, located preferably in the loop of the filament and supported by a lead sealed through the glass. This electrode is usually of platinum and acts as the anode of the rectifier, while the filament is the cathode. If an auxiliary current be used to heat the filament, and an alternating voltage be applied between the filament and the cool electrode, current will flow through the rarefied gas in the lamp from the cool electrode to the hot filament, but not in the reverse direction. The conduction which takes place is known as the "Edison effect."

As ordinarily constructed heretofore, this form of rectifier is only adapted for very small currents, and the negative end of the filament is gradually disintegrated by being used as cathode to maintain the discharge. It has been applied in connection with receivers in wireless telegraphy.

The Mercury Arc Lamp

In Fig. 7 is shown one form of the mercury arc lamp. At the upper end of the long glass tube is the graphite anode, A; at the bottom is the mercury cathode, C, and the "side-branch" starting anode, E.

A short distance above the cathode the tube is expanded into a bulb, which acts as a condensing chamber for the mercury vapor. The arc is started by tilting the tube until the mercury in the cathode makes contact with that in the side-branch, and then righting it again; this draws an arc between *E* and *C*. If the distance between *A* and *C* be not too great the main arc will start immediately and will maintain itself after the starting arc has been interrupted by opening the switch *G*. A cold tube more than 16 inches long may be slow in starting, but heating the glass will assist it.

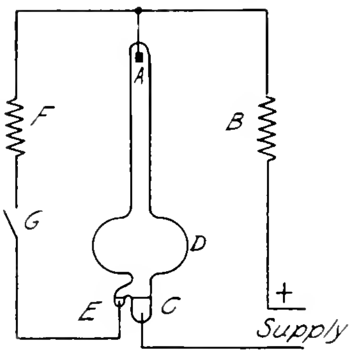


Fig. 7. Mercury Arc Lamp

The ballast resistance, *B*, is placed in series with the arc to take up the difference between the line voltage and the arc voltage and thereby limit the current, as with any arc lamp operating from a source of constant potential. The starting resistance *F* has a similar function, since it is desired to limit the current in the starting arc to a small value.

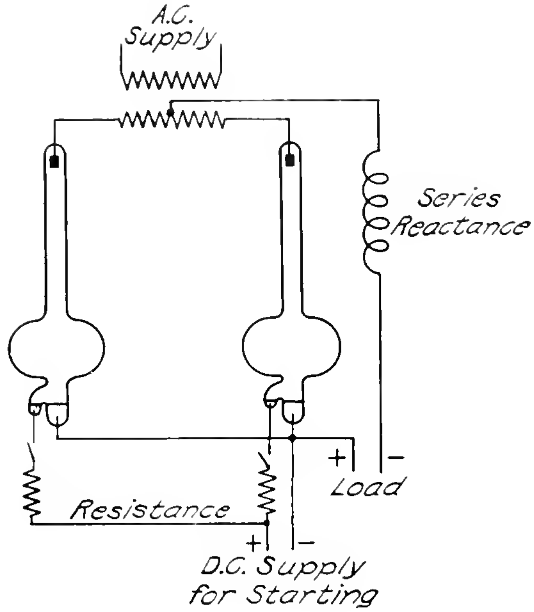


Fig. 8. Mercury Arc Lamps Connected to Act as Rectifiers

The apparatus, being of glass, makes it necessary to keep the operating temperature fairly low so that the glass will not soften and suck in under the pressure of the atmosphere. Therefore we must keep the temperature and pressure of the mercury vapor at a low value by providing a relatively cool condensing chamber, *D*, independent of the main tube, which is heated by the arc stream.

The main feature which differentiates the mercury arc in a vacuum from an arc in the atmosphere is the low value of the potential gradient in the arc stream and the consequent low temperature of the vapor, and the fact that the cathode is non-consuming, since it is continually replenished by the condensation of the mercury vapor.

Practically all the light is generated in the arc stream, since that produced at the electrodes is negligible. The color of the light is a characteristic greenish blue, which is determined by the spectrum of mercury.

The Mercury Arc Rectifier

If an alternating voltage be impressed across the lamp, Fig. 7, no current will pass until the exciting arc is started, as is the case with continuous current. Now if we tilt the lamp and establish an exciting arc from a source of continuous current, with *E* as anode and *C* as cathode, current waves will pass from *A* to *C* during the positive half cycles, but no current, apparently, will pass in the opposite direction while the graphite electrode, *A*, is negative with respect to the mercury electrode, *C*. As a matter of fact, if the alternating voltage be high enough there will be a small inverse Geissler discharge during the negative half-cycle or a few micro-amperes, or a few milli-amperes, according to conditions in the tube; while the strength of the positive current is determined by the conditions in the external circuit. Hence, the rectification is very nearly perfect except for the loss of about 20 volts required to overcome the drop in the arc.

If now we interrupt the exciting arc, current will cease to flow in the main arc, since there is no way for the main arc to re-establish itself at the beginning of each positive half wave. The continuous current exciting arc is required to maintain the hot cathode spot on the surface of the mercury.

In Fig. 8, two lamps are shown as half-wave rectifiers, so connected in circuit as to supplement each other by rectifying both half waves of the alternating current. Each tube, with its adjacent half of the transformer secondary winding, acts as a generator feeding positive half-wave impulses into the d-c. circuit. The rectified current from a single-phase source is necessarily pulsating, and a series reactance may be used to smooth out the pulsations. Half wave rectifiers require an auxiliary source of continuous current to excite the tubes. In the commercial forms of rectifiers this is avoided by combining both tubes in one structure with two anodes and a common cathode. The external reactance causes the arcs to overlap slightly so that they are self-maintaining, and separate excitation is not required.

Figs. 9, 10 and 11 show the different forms in which rectifiers are made for voltages of 100, 200 and 4000 respectively, and Fig. 12 shows a 100 volt tube in outline with the customary connections. The side branch electrode (c) is used in starting only, for which alternating current excitation is sufficient. The negative terminal of the d-c. circuit goes to the neutral point of an auto transformer connected across the a-c. line. This also serves as a reactance for overlapping the arcs and smoothing the voltage pulsations while charging a storage battery. In this way current is kept flowing through the battery continuously in spite of the steady

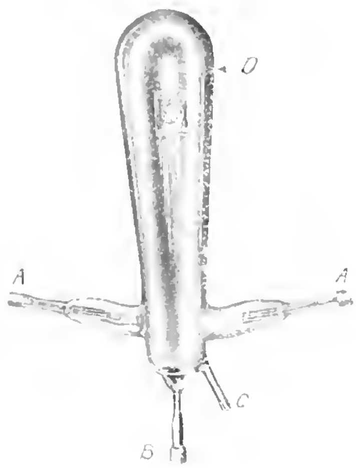


Fig. 9. 100 Volt Rectifier

Fig. 10. 200 Volt Rectifier

counter e.m.f. of the latter, although the current is necessarily pulsating. In order to obtain reactance, the auto-transformer is wound with the two coils E and F on the opposite sides of the "type H" core, thus forming consequent magnetic poles at the top and bottom of the core; in other words, "bucking" the two coils against each other and setting up a considerable magnetic leakage through the air. These consequent poles are always of the same polarity, since the direct current enters at the center of the winding and divides between the coils. This leakage flux is superposed on the alternating flux set up by the alternating magnetizing current. Another way of looking at it is that the electrical neutral point shifts from side to side owing to the superposition of these two components.

The ratio of the d-c. voltage to the a-c. voltage is a little less than half, since only one half the applied voltage is effective during

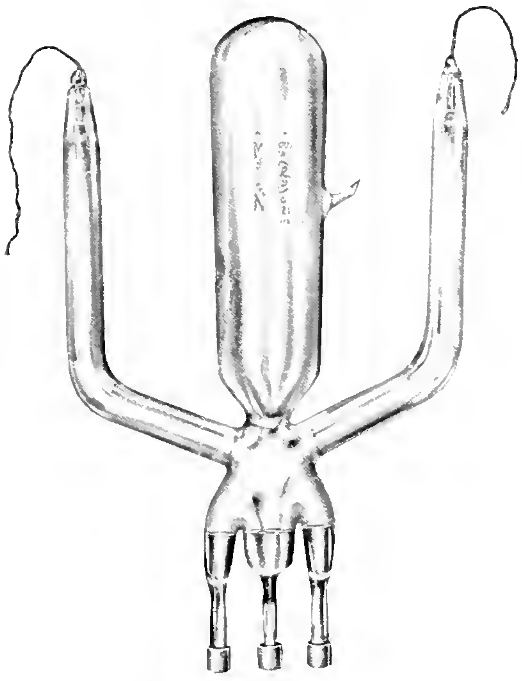


Fig. 11. Constant Current Rectifier

a half-cycle, and the d-c. current is approximately double that in the a-c. line. The voltage ratio is modified by the fact that the portion which is useful in battery charging is measured by a permanent magnet meter which indicates the average value of the pulsating voltage or current, while the alternating current meters are of the dynamometer type and indicates effective or root-mean-square values. Since the average

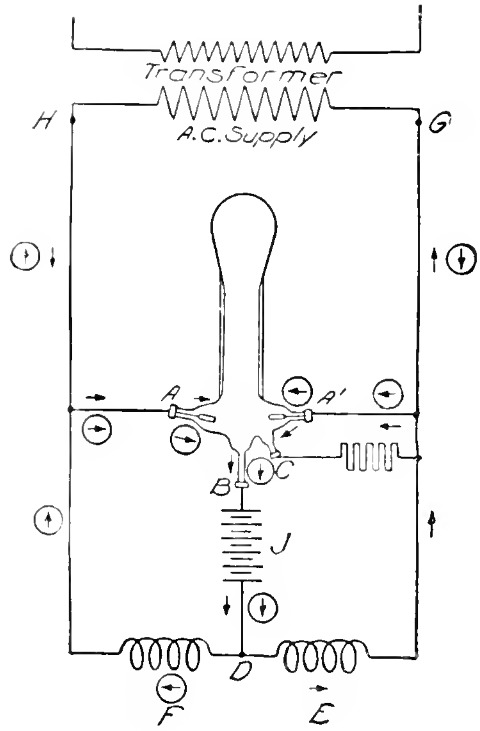


Fig. 12. Diagram of Connections for Constant Potential Rectifier

value of a sine wave is 0.9 the effective, the d-c. voltage will be,

$$D = 0.45\ E - 20$$

where E is the a-c. voltage across the anodes and 20 volts the usual value of the arc drop. This ratio may be lowered a little more by the drop in the reactance and by the shifting of the neutral. The proportion of the total energy lost in the tube depends upon the magnitude of the rectified voltage, since the arc drop is practically constant. Hence the higher the voltage the higher the efficiency.

Some oscillograms are shown in Figs. 13 and 14 of voltage and current curves for a rectifier with a counter e.m.f. load and a series reactance. The external connections as regards transformer and series reactance, were as shown in Fig. 8. In each figure the upper curve represents the a-c. voltage. In Fig. 13 the middle curve represents the a-c.

line current and the lower curve the d-c. current. In Fig. 14 the middle curve represents the voltage across the series reactance, and the lower curve the current in one arc.

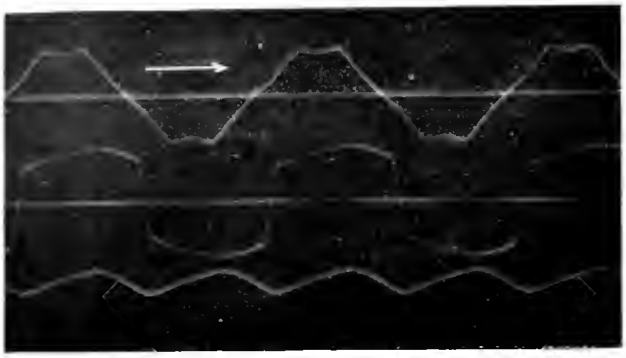


Fig. 13. Upper Curve, Voltage Between Anodes; Middle Curve, A-C. Current; Lower Curve, D-C. Current

The 200 volt rectifier, Fig. 10, differs from the 100 volt type, Fig. 9, in having the anodes located in long side-arms bent at a right angle to protect the anodes from mercury spray. The anodes are of graphite and operate at a bright red heat when carrying full load. The condensing chamber is made very large in order to keep the mercury vapor pressure low, since there is very rapid vaporization of mercury in the cathode spot.

Since the full alternating potential is impressed between the anodes, the inverse Geissler discharge is going on all the time. It is invisible at no load, owing to the rarity of the mercury vapor and the consequent length of the dark space which may fill the whole length of the arm. When the arc is running its far greater luminosity renders the faint inverse discharge invisible. It is always there, however, and is waiting for an excuse to flash into an arc, which will short-circuit the a-c. line. This may happen in an old tube in which the vacuum has deteriorated. But it will also happen in a good tube if mercury spray strikes a red hot anode. The violent vaporization of the mercury will frequently cause concentration of current and the formation of a cathode spot on the graphite. This is not likely to happen in the 100 volt type because the a-c. voltage is too low to maintain a true Geissler discharge, but the higher the voltage the greater must be the precaution taken to avoid arcing. Thus in the 200 volt tube the anode arms are bent, while in the 100 volt type short straight arms are used. Both types are made in sizes ranging from 10 to 50 amperes output.

In the 200 volt type the bent portion of the arms are inclined at an angle of about 45 degrees in order to protect the anodes from the dripping mercury which condenses in the stems where the platinum wire seals are located. The method of sealing in the leads is similar to that used in incandescent lamps, only several platinum wires are sealed through the glass in the larger tubes and connected in multiple.

The type shown in Fig. 11 is used in connection with a constant current transformer for supplying series arc circuits, usually for magnetite lamps. They are made for rectifying 4 or 6.6 amperes at from 2000 to 4000 volts output. They differ from the low voltage tubes in having longer and narrower vertical arms to protect the anodes, and in being provided with two side-branch electrodes for continuous excitation from a source of alternating current. These are connected to the secondary terminals of a small transformer as the anodes of an independent low voltage rectifier, with a series reactance in the neutral lead to overlap the arcs. Separate excitation is desirable in this case for continuity of service. These tubes

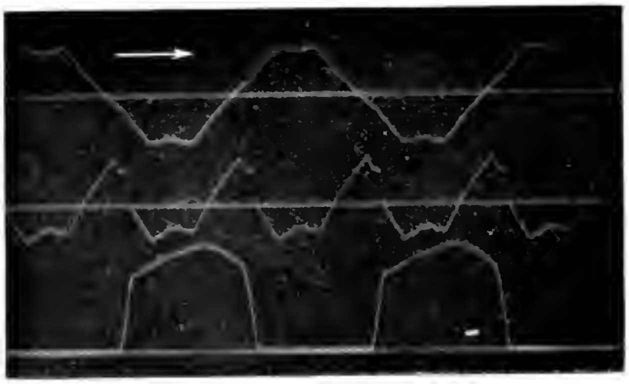


Fig. 14. Upper Curve, Voltage Between Anodes; Middle Curve, Voltage Across Reactance; Lower Curve, Current in One Arc

are submerged in a tank of oil to cool them, and the oil in turn is cooled by an immersed coil of pipe through which water is circulated.

The series reactance connection is used in the case of the "constant current rectifiers" as shown in Fig. 8.

In all three types the anodes are similarly located in the closed end of a glass tube which protects the glass covering on the leads by providing a constricted passage for the inverse discharge. When arcing does occur the cathode spot frequently forms on the graphite at the point of contact with this bordering insulation, as noted in the Geissler discharge experiments. The narrow tubes constrict the negative glow of the inverse discharge as long as the vapor pressure is low (see Fig. 3) so that the anodes are entirely surrounded by dark space. (It is necessary to speak of them as anodes in the case of the rectifier, even though they act as cathodes for the inverse discharge.)

When the low voltage tubes are operated with the temperature of the condensing chamber surface approaching 125 or 130 deg. C., arcing is apt to occur, which is to be expected from the experiments on Geissler discharges. The condensing chambers are made large enough to keep the temperature at the coolest part from exceeding 110 to 115 deg. C., and usually it does not exceed 100 deg. Owing to the higher voltage at which the constant current rectifiers are operated, it is necessary to keep the temperature of the oil-cooling bath within narrower limits. The lower limit is 50 deg. F., below which the tubes are hard to start, and static discharges sometimes occur over the outside surface of the glass. The upper limit for which the tubes are guaranteed is 90 deg. F., although occasional tubes have been operated at temperatures up to 150 deg. Fahrenheit.

The Geissler current is only one component of the inverse discharge, since there is another component at all voltages which appears to vary with the load current to some extent. At the beginning of the negative half cycle the inverse current starts with a high peak, which rapidly falls off during the first quarter of the period, leaving only the Geissler current, which is roughly sinusoidal in form.

In Fig. 15 the upper curve represents the transformer secondary voltage. The flat points, where it crosses the neutral axis, are caused by the overlapping of the arcs. The rectifier was loaded upon a 275 volt generator circuit, and the rectified current was fed into this through a water rheostat and a series reactance to give the rectifier a total load of 550 volts The middle curve represents the

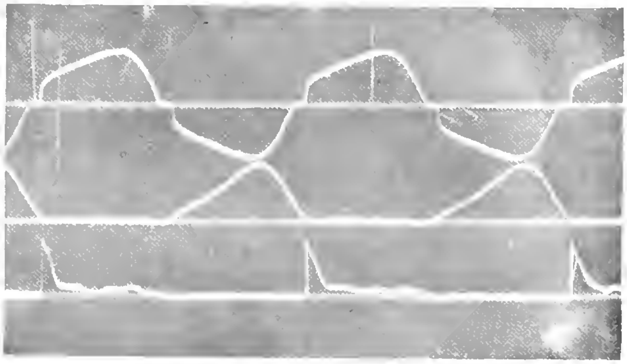


Fig. 15. Upper Curve, Voltage Between Anodes; Middle Curve, Current in One Arc; Lower Curve, Inverse Current

current in one arc, and the lower curve the inverse current. The latter is shown upon a much larger relative scale than the arc current, since it is not visible at all in the middle curve, which represents the current passing through an ammeter shunt in series with one anode. In photographing the inverse current, special means were employed for separating it from the positive current. The polarity of the inverse current, of course, is reversed relatively to that shown.

In conclusion it may be added that rectification is possible in other arcs than the mercury arc, but mercury presents decided advantages as a cathode material. In one form of rectifier, solid electrodes are used, of iron or carbon, and the arc is re-started at the beginning of each positive half-cycle by a high potential spark timed by a commutator, which is driven by a synchronous motor. Automatic rectification has been obtained in a crude way in the magnetite arc in air. A vacuum rectifier has been operated in the laboratory with a low melting alloy as cathode—Wood's metal—which was kept liquid by immersing the rectifier in boiling water. The primary advantage of mercury is the fact that it is the only elementary metal which is liquid at all ordinary temperatures, and a liquid cathode is non-consuming, since it is replenished by condensation of the vapor. Also, the vapor pressure is low within the range of ordinary operating temperatures, and the vapor has good conductivity for the arc so that the voltage drop in a long arc is low. The resistivity of the cathode dark space in mercury vapor is relatively high. These electrical properties may be due to the fact that mercury vapor is a monatomic gas; that is, the molecules are simple in structure as they are composed of only one atom each.

THE SPLIT PHASE LOCOMOTIVE

By E. F. W. Alexanderson

Consulting Engineer, General Electric Company

Mr. Alexanderson, who has been closely identified with the development of apparatus, gives an interesting account of the split phase locomotive. As so much attention is being drawn at the present time to the general subject of steam railroad electrification, we believe that Mr. Alexanderson's views on this more or less novel type of electric locomotive will be of considerable value, while the results to which he refers will be of great interest to the many students of this important subject.—Editor.

The method of starting polyphase induction motors that are operating on single-phase circuits by means of another induction or synchronous motor running light as a phase converter is old, and has been applied commercially to a small extent for various purposes. One of the reasons why this method of operation has been used only in exceptional cases is that the scheme, in its simplest form, is inefficient. The starting torque that can be obtained in this way is only about one-half of the torque that the same motor will develop on an ordinary polyphase circuit. The application of the same principle to a single-phase locomotive has been proposed by various engineers in the past, and attention may be called to a paper by the late Ernest Danielson in 1903. The reason why Danielson's proposition was not fully developed at that time can be traced, not so much to any technical imperfection in the system as proposed, but rather to the fact that the advantages of such a locomotive were not realized by the engineering world [illegible] at the time the proposition was [illegible]

When [illegible] some years ago actively took up the problem of developing methods for operating induction motors from single-phase circuits by means of a phase converter, in order to apply such a system for single-phase traction, it was with the conviction that a locomotive with polyphase induction motors operated from a single-phase overhead trolley would be recognized as a desirable type of locomotive for mountain traction and for heavy freight work in general. This conviction was based partly on the success that had been achieved with three-phase locomotives, both on the Great Northern railroad in this country and on several railroads in Europe, and partly by the advantage that has been effected through electric braking with regenerative control. Advantages were secured in operation, economy of power, saving of brake shoes and wheels, and diminished wearing of the rails. It has also become clear to the majority of engineers interested in electric traction that the single-phase commutator motor does not possess the characteristics that are needed to fully exploit the advantages of the high tension alternating current distribution systems. While several successful types of single-phase locomotive have been developed, it is recognized that such a locomotive, even if designed with such skill as to attain a technically successful result, will be so much more expensive than the three-phase locomotive or the direct current locomotive that the higher cost of such a locomotive will largely offset the economies of the alternating current system.

Motor Design

It may be of interest at this time to examine somewhat more fully the determining factors in the cost of an electric locomotive. The problem has proven to be much more complex than it was anticipated in the first stages of locomotive design, and the discussion of such questions as cost and weight per horse power of the different kinds of motors is apt to give misleading results if the problem is approached only from this point of view. A question which has attracted much attention during later years is what mechanical designs of locomotive may be considered as most desirable, for during the process of evolution a great many radically different types have been developed.

The use of idle axles or idle trucks is sometimes a controlling factor on account of the running qualities at high speed; whereas in other cases a more essential requirement is the ability to use the whole weight of the locomotive for traction purposes, every axle being motor-driven. Side rods and quills have been introduced in order to reduce the dead weight on the axles; while on the other hand the method of using a greater number of smaller motors mounted directly on the axle is in many cases the most expedient Without attempting to predict what type or types of locomotive will be most favored in the future, it is fairly safe to say the type of motor which will be preferred is the one that proves itself most adaptable to all different types of locomotive that are being considered as having points of advantage. From this point of view the use of the polyphase induction motor is highly attractive. The space factor and adaptability of the induction motor is as great, if not greater, than the direct current motor, whereas the single-phase commutator motor, although well suited to some types of locomotive, is at a great disadvantage in others. In comparative designs of locomotives, the single-phase equipment is often handicapped, not so much by the higher cost of the motors as by the undesirable and expensive type of running gear which must be adopted on account of the greater space occupied by the single-phase motor as compared with the polyphase or direct current motor. Among the various types of electric locomotive for slow speed freight work, those represented by the Great Northern 6600 volt three-phase, the Detroit River Tunnel 600 volt d-c., and the Butte and Anaconda 2400 volt d-c. locomotives are particularly desirable. These locomotives are characterized by having all the axles motor-driven, so as to utilize the whole weight of the locomotive for traction purposes. The motors are geared to the axles and are of the twin gear type. The locomotives mentioned have four axles, but the same principle is being extended to larger locomotives with six or eight axles in order to concentrate more power under the control of one operating cab. A split phase locomotive of this type with six axles and six motors is being constructed, each motor

Fig. 1. Demonstration Split Phase Locomotive, Showing Phase Converter

being designed for a continuous output of 300 horse power and a tractive effort of 45,000 lb. at 15 m.p.h. and 30,000 lb. at 22 m.p.h.

Early Tests

The electrical equipment of the above split phase locomotive is built substantially along the lines indicated by the author in a paper before the A.I.E.E. in June, 1911. This paper gives a theoretical discussion of the method of operating polyphase induction motors from single-phase circuits that was worked out for use in electric traction. The tests referred to were made on two standard 25 h.p. quarter-phase motors, one of which was used as a phase converter. Results from these tests show that a practical method has been found of changing single-phase current into a polyphase current without a loss in starting torque, which loss has previously been thought inherent in this method of operation. The solution is probably not the only one that is practically operative, but results were much superior to those obtained by the old methods. A demonstration of a split phase locomotive, Fig. 1, was made and the results were so successful that the conclusion was reached without hesitation by all those present that this type of locomotive was thoroughly practical for railway service. The various questions that have naturally been raised as to the behavior of the phase converter

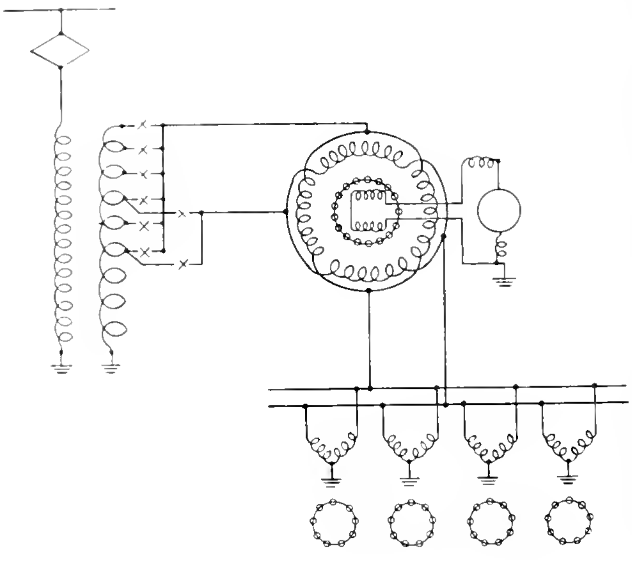


Fig. 2. Wiring Diagram of Split Phase Locomotive

under overloads, interruptions of the trolley circuit, etc., were thoroughly disposed of. Among the various tests that were made the following might be mentioned:

The locomotive was started from standstill and accelerated up to full speed, while the trolley was constantly being pulled up and down, each time interrupting the circuit. There was no tendency of the phase converter to break down, although the acceleration was made at maximum, near the slipping point of the wheels.

While the locomotive was at standstill and the phase converter running, the trolley was lowered and kept off for one minute, during which time the converter continued to run by its own momentum down to approximately one-half speed. In the meantime the controller was turned to the full speed forward position and as soon as the trolley was raised the phase converter immediately speeded up, while the torque of the motors increased correspondingly up to the slipping point of the driving wheels.

While the locomotive was running at full speed forward the trolley was lowered and kept down for one minute, during which time the controller was being reversed. When the trolley was raised again the converter immediately took its load as before, the motors developing sufficient torque to slip the driving wheels in a backward direction in accordance with the new position of the controller.

The phase converter used in these tests was a standard induction motor with an ordinary squirrel cage rotor. This rotor was afterwards replaced by a special rotor with an exciting winding placed under the squirrel cage, in order to demonstrate the improvements in the power-factor that can be accomplished in this way. The same tests as above were repeated, showing that the addition of the exciting winding does not change the general behavior of the machine.

The equipment used for this demonstration was an old single-phase locomotive with one of the motors temporarily changed into a polyphase motor. In order to save time this reconstruction was done in the simplest possible way by making the secondary out of a plain steel cylinder without any windings whatever. Although this crude way of constructing an induction motor is not recommended as a final form for attaining the best characteristics, it may be of interest to know that even in this primitive form the motor had a great deal more overload capacity than the single-phase motor and was able to slip the wheels on a sanded track with only two-thirds of the normal line potential.

Theory of Phase Converter

The theory of the operation of the phase converter was covered in all its essentials in the paper before the A.I.E.E., previously referred to. The exact treatment of this problem is very involved, and further mathematical analysis might be of small interest in general. The article will therefore be confined to a discussion of the principles from a popular point of view. For the benefit of those who might be interested in the analytical side of the problem, a typical vector diagram for the motor and phase converter is given. This vector diagram differs from the one given in the previous paper only by taking into account the synchronous excitation of the phase converter. The theory indicates immediately what this change should be: the addition of synchronous excitation to the phase converter neutralizes the magnetizing current furnished through the stator, and eventually the leading current. The vector diagram for synchronous excitation can therefore be developed from the vector diagram for the pure induction phase converter by assuming reversal of the magnetizing current. The logical result of this is to improve the power-factor of the whole combination.

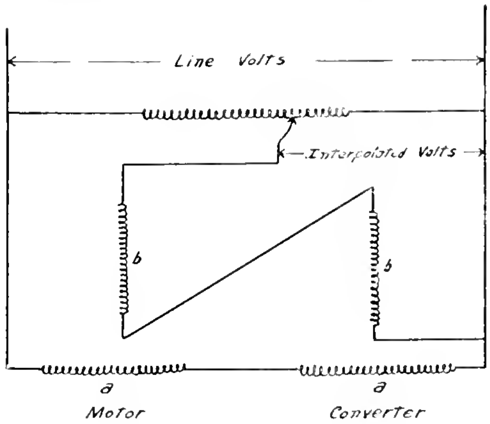
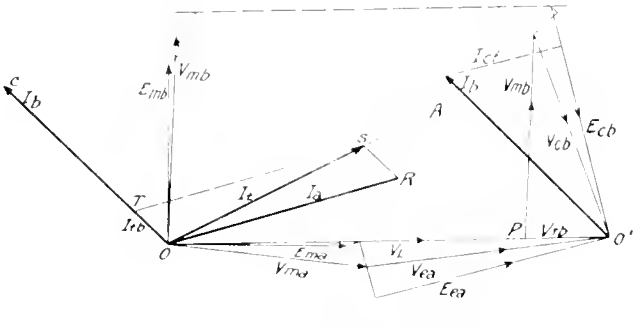


Fig. 3

From a more popular point of view the operation of the phase converter can be explained as follows: The phase converter is a series transformer connected in one phase of the two-phase induction motor and supplies energy to the second phase. It differs from a transformer of the ordinary type only in the characteristic that the secondary current is substantially 90 degrees out of phase with the primary current instead of being in phase with it. It is therefore convenient to look upon this phase converter as a series transformer and to apply the general theory of series transformers, with the exception of the changing of the phase as explained. In any ordinary transformer with a ratio of 1:1 turns, the secondary current differs from the primary current only by the amount of the magnetizing current. The same holds true with the phase converter. However, with the synchronous excitation of the phase converter, it is possible to change the magnetizing current from positive to negative and eventually make it exactly equal to zero. For the sake of simplicity it will therefore be assumed that the excitation of the phase converter is supplied by the direct current magnetizing winding. Thus the stator carries only the load current. In an ordinary transformer we furthermore have to deal with leakage reactance and resistance, one-half of which can be considered as located in the primary and one-half in the secondary.



Full Load Vector Diagram

Fig. 4

Line	Designation	Meaning
O-O'	V_L	Volt line (measured at transformer secondary).
O-S	I_L	Ampere line (measured at transformer secondary, being the combined amperes turns in the different parts of the transformer winding).
O-R	I_a	Amperes in phase No. 1 of motor and converter.
O-T	I_{tb}	Component of line currents due to current in phase *b* through the section of the transformer winding interpolated in phase *b*.
	I_{ct}	Component current in converter primary which corresponds to super-excitation of converter field.
	V_{ma}	Volts motor, phase *a*
	V_{ca}	Volts converter, phase *a*
	E_{ma}	EMF motor, phase *a*
	E_{ca}	EMF converter, phase *a*
	V_{mb}	Volts motor, phase *b*
	E_{mb}	EMF motor, phase *b*
	V_{cb}	Volts converter, phase *b*
	E_{cb}	EMF converter, phase *b*
	V_{tb}	Volts of winding section of transformer interpolated in phase *b*.

However, for a general analysis of the flow of energy from the primary to the secondary, it is immaterial whether the leakage reactance and resistance are considered to be a part of the transformer proper or a part of the apparatus connected directly to the transformer; in other words, whether part of the generator that supplies the transformer or the motor that receives the secondary energy. Therefore, if in such an analysis the impedance is removed from the transformer and placed in the generator and motor, the transformer becomes an ideal transformer without impedance. If, furthermore, the magnetizing force is applied from another source, as explained, the action of the transformer becomes the same as if the transformer were entirely removed and the primary terminals connected directly to the secondary terminals. The same simplification can be used in analyzing the performance of the phase converter. Looking at this problem in this way, the

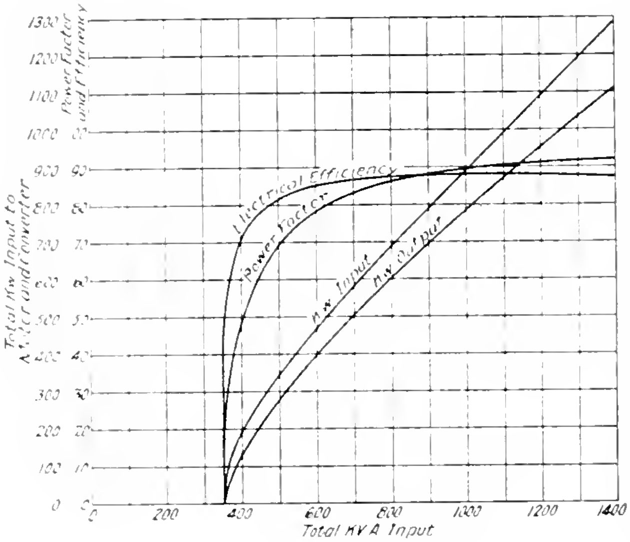


Fig. 5. Characteristic Curves of Split Phase Locomotive

quarter-phase motor operating with a phase converter is exactly equal to a quarter-phase motor operating in the ordinary way from a quarter-phase circuit, with the impedance of the phase converter connected in series with the corresponding phases of the motor. Thus it is apparent that the motor will receive balanced quarter-phase current.

Compensation for Power-factor

[illegible] the theory of the ordinary transformer has sufficed to explain the performance of the motor and the phase converter. [illegible] that have been devised to compensate [illegible] the impedance drop in the phase converter [illegible] to attain full output of the motor [illegible] explained only by taking into account [illegible] characteristic of the phase converter [illegible] the phase relation of the secondary [illegible] primary current. In the simplified [illegible] as considered above, it is obvious that the primary of the phase converter must absorb sufficient voltage to feed the second phase of the motor, and in addition, the voltage necessary to overcome the impedance drop on the secondary winding of the phase converter. Thus a phase converter should be designed large enough so that one phase of the phase converter can absorb not only the whole input of the second phase of the motor but also the wattless volt-amperes necessary to overcome the impedance of both phases of the phase converter. Thus the input per phase of the converter would become appreciably larger than the input per phase of the motor.

If, however, it is possible to supply the wattless component of the second phase to the secondary side of the phase converter instead of the primary, the size of the phase converter can be correspondingly reduced, and the additional impedance drop incident to transferring this wattless energy can be eliminated. The vector diagram shows that the current in the first phase with reference to the main transformer is substantially an energy current. The current in the second phase, while an energy current with reference to the motor itself, has substantially the phase relation of a wattless current with reference to the main transformer. If, therefore, the current of the second phase is led through a section of the main transformer, the action of the transformer on the circuit of the second phase becomes a source of supply of wattless current, because the transformer voltage inserted in the circuit is 90 deg. in advance of the current that flows in this circuit. The amount of wattless current thus supplied to the second circuit is adjusted so as to give the desired characteristics. The combined characteristics of the motor and converter obtained in this way are the same as the well known characteristics of an induction motor.

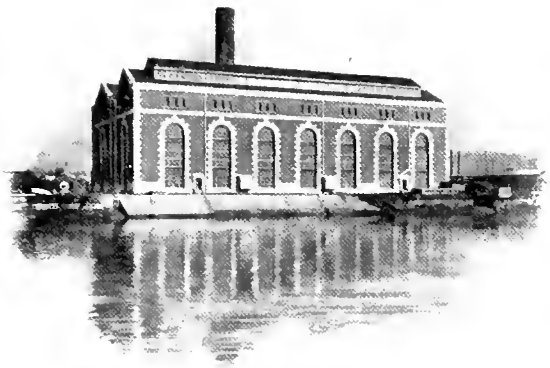
Features of Control

Any method of polyphase induction that is applicable to a three-phase locomotive can be used on a split phase locomotive, and the various methods of control that have been developed can be used for either type. However, the single-phase source of power and the series connection between the motor and the converter offer certain advantages from the point of view of control, inasmuch as a number of simplifications in the circuits are possible.

In the Great Northern locomotive, which is a typical three-phase equipment, rheostatic control for the motors is used and is located entirely on the secondary circuits of the motors. The locomotive has four motors geared independently to four axles, and it therefore becomes necessary to use four independent rheostatic circuits with contactors for gradually cutting out the resistances.

A considerable part of the complication incident to the independent secondary control circuits could be avoided by using only a few rheostatic points and by regulating the torque during acceleration by voltage control in the primary. In such a case the primaries of all the motors could be connected permanently in multiple, and only one control circuit would be used for regulating the voltage. However, the motors being three-phase, it would be necessary to regulate the voltage of all three phases and the duplication of contactors in the different phases would be about as great as the duplication of rheostatic circuits for each motor. In the split phase locomotive, where the converter and motor together can be treated as a single-phase motor, the method of voltage control works out very advantageously and an additional advantage is gained in that the locomotive becomes less dependent upon variations in the line potential, because the voltage supplied to the motors during the starting period is gradually increased until the maximum torque that the locomotive can utilize is reached; in other words, when the wheels slip. With the control arranged in this way the maximum torque of the motors is not limited by the minimum voltage of the line but by the maximum kilovolt-amperes that are available.

It is therefore only required that the line should be able to deliver a volt-ampere output corresponding to the maximum tractive effort that can be utilized



FUEL AND LUBRICANTS FOR INTERNAL COMBUSTION ENGINES

By B. H. Arnold

Erie Works, General Electric Company

The great demand for gasolene as a fuel for internal combustion engines has inflated the price of this commodity to a point where the expense of operating gasolene engines of large size has become a matter of considerable moment. Lower fuel costs have been the subject of much recent investigation by corporations and engineering societies, specially along the line of improved engine design and the adoption of specifications for petroleum distillates. The author shows that the prevailing practice of specifying gasolenes according to their specific gravities affords a much less accurate indication of the fuel values than specifications based on fractional distillation. Curves are included which show that, although the specific gravity of one grade of gasolene may be less by 10 or 15 per cent than that of another, by analysis the fuel of greater density may be the better. Typical specifications for gasolenes for slow and medium speed engines and for high speed engines are given. A satisfactory economical lubricating oil should possess the qualities of wearing well and burning clean. What the viscosity of the oil should be is a matter that is determined by the design of the engine.
—Editor.

As experience with internal combustion engines has been based to a great extent upon those of the widely distributed automobile and motor-boat types, the popular idea of gasolene is that of a fuel which can be successfully used in automobile and motor boat engines. Until recently but little has been known of gasolene; and its low price and the fact that the majority of users purchased it in small quantities offered no incentive for its investigation. For many years previous to the advent of the gasolene engine, gasolene was a by-product in the manufacture of kerosene, and its disposal a problem to the refiner.

Conditions are now reversed, for the large number of gasolene engines has created a big demand for gasolene and kerosene is being over-produced. This demand has increased the price of gasolene to such an extent that many engineering societies are investigating both engine design and petroleum refining with the idea of securing lower fuel costs.

Gasolene and its associate naphtha are generally known to be volatile, colorless and inflammable distillates of crude oil or petroleum, graded and sold by some gravity method, usually the Beaumé scale. The higher a gasolene tests by this scale the more desirable it is supposed to be. This method of grading is, however, inaccurate and misleading, and where definite information is desired of the characteristics of any distillate, it must be superseded by the method based upon fractional distillation. If all other conditions were equal, the gravity method would be a fair means of comparison, but at the present time when the distillates are obtained from petroleum of many fields and having different characteristics, the mere fact that gravity by the Beaumé or any other scale tells very little of the relative suitability of various gasolenes or naphthas. In order to show the reasons for this and the meaning of fractional distillation, we will discuss briefly the antecedents of gasolene and naphtha, as well as their use.

This discussion is to be considered under the following heads:

(1) Petroleum, Its Occurrence and Composition.

(2) Refining of Petroleum.

(3) The Use of Gasolene and Naphtha in the Engine.

(4) Specifications and Purchase.

(5) Possibilities of Other Liquid Fuels.

(1). Petroleum, Its Occurrence and Composition

The U. S. Geological Survey issues each year a bulletin containing complete figures in regard to the United States' production of petroleum and that of the last ten years of other countries. Those interested are referred to this bulletin, which will be supplied gratis by the survey.

Petroleum has been found in all parts of the world, without any definite scheme of distribution. An inspection of any map indicating the distribution of the world's known petroleum fields will show that practically all of the producing regions are in or near civilized communities. From this, it is believed that those regions not now producing contain much oil as yet undiscovered, rather than that these regions are barren, as some would have us believe. Regardless of recent newspaper comments on the decrease of the world's petroleum production, it is believed that while the production may not be increasing in proportion to the demand, the trouble is largely due to lack of transportation facilities and not to any immediate limitation of available source of supply.

Recently published articles have announced the discovery of large quantities of petroleum in various South American countries and of enormous quantities in North China. Mexico's world breaking records have been common property for some time. During the next two or three years the opening of the Panama Canal and the increase in number of tank steamers and pipe lines will make available these great supplies and have much effect on the price of crude oil.

Chemical analysis shows that crude oil is a very complex mixture of a large number of chemical compounds, which can be arranged in eight groups or series, two of which predominate in and characterize practically all petroleums. One of these series, called the Methanes or paraffines, predominates in certain petroleums known as the paraffine-base oils. This is a stable series of compounds of the general chemical formula C_nH_{2n+2} The members as arranged in ascending values of "n" show a regular increasing specific gravity and temperature of boiling point. As an illustration of this series:

Methane CH_4 is a gas at ordinary temperatures and pressures.

Nonane C_9H_{20} is a liquid down to 59 deg. F. (51 deg. C.) and has a boiling point of 300 deg. F. (150 deg. C.).

Nonadecane $C_{19}H_{40}$ is a solid at 89 deg. F. (32 deg. C.) and boils at 626 deg. F. (332 deg. C.).

Another series known as the olefines are characterized by the general chemical formula C_nH_{2n} and predominate in those petroleums known as the asphalt-base oils. Members of other series are also present, but in small quantities; therefore, we need concern ourselves with but the two series above mentioned. The members of both series are hydro-carbons and have similar structure and characteristics. Each member has its own specific gravity and boiling point different from those of any other in the same series. However, a member in another series may have either the same boiling point or the same specific gravity, but both specific gravity and boiling point will not be the same.

The most important practical distinction between distillates obtained from different oils is that the distillates derived from the asphalt-base oils at the same boiling point are heavier than those derived from the paraffine-base oils.

(2). Refining of Petroleum

In refining petroleum the first step is to separate it by distillation into a series of cuts. In distillation, the compounds of low boiling point and light gravity pass over first and the heavier compounds pass over at a higher temperature. When the average gravity of the distillate reaches a certain fixed value, the distillation is cut over into another tank and another series of compounds are obtained of higher gravity, until the average gravity of this distillate reaches the next limit. In this way the crude oil is separated into the following cuts or fractions:

1. Benzine. All distillates of a gravity down to and including 53 deg. Beaumé.
2. Burning oils. Those distillates of gravity between 52 deg. and 38 deg. inclusive.
3. Fuel oils. Distillates between 37 deg. and 25 deg. inclusive.
4. Residuum. The remainder of the petroleum either liquid or solid.

The gravity limits of the various fractions given above are more or less indefinite and vary among different manufacturers, but these divisions are the ones generally adopted Those who have followed the development of the industry in the last few years have noted that the tendency has been toward gradually lowering these limits, particularly those of the benzine group.

After the first fractioning, as above, the benzine is put into a second or steam still and subjected to another distillation during which it is separated into gasolenes and naphthas of gravity according to the demand of the trade, or the standards of the particular manufacturer. It will be seen from the method described above that any gasolene may embrace a number of compounds of different densities, and the hydrometer tells only the average density of the composition. A mixture of a certain gravity may be obtained either by straight distillation, as described above, or by blending very light distillates and heavy distillates in the proper proportions. While the gravity can be varied by proper blending, the boiling points of the components are unchangeable and by redistillation a blend can always be separated into its original components. In other words, an examination by redistillation makes it possible to accurately determine the composition of any gasolene or naphtha.

(3). Utilization

In general, internal combustion engines utilize light distillates by means of an apparatus variously called a carburetor, vaporizor, or mixing valve. The action in this apparatus consists in breaking up the fuel into minute particles and thoroughly mixing it with air: for the best results the fuel should be so broken up as to be practically a vapor. The more volatile the fuel, the more easily it can be broken up and mixed with air. The nearer the boiling point of a compound is to its working temperature, the greater its volatility. Hence of any mixture the fractions of low boiling points are most easily volatilized and a knowledge of the boiling points of the various fractions are necessary to a knowledge of the behavior of the fuel

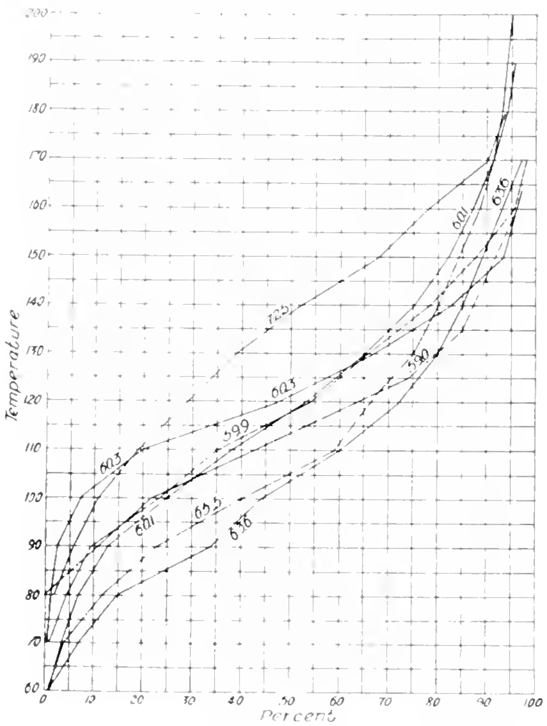


Fig. 1. Curves of Fractional Distillation of Gasolenes of Various Specific Gravities and Widely Differing Fuel Values

as a whole. All of the fuel need not be of low boiling point, that is, easily vaporized; but there must be a sufficient percentage in order that starting will be assured. The remainder of the fuel must, however, be sufficiently volatile to be easily broken into a fog, or mist, and drawn into the cylinder without undue precipitation.

From the above consideration of practical conditions governing the burning of gasolene and naphthas, it can be seen that a knowledge of the boiling points is of much greater value in comparing relative suitability than knowledge of the gravity; and even if the gravity were desired, we can get only the average gravity of the entire mixture. It is, therefore, recommended that these light distillates be specified and purchased by the boiling point method. By this method the purchaser specifies the characteristics of the fuel as determined by a fractional distillation test. Such a test consists in placing a certain quantity of liquid in a flask, vaporizing it, condensing the vapor and catching it in a graduate. The percentages of the original volume obtained at the various temperatures may then be plotted on curves as shown in Fig. 1 and Fig. 2, which are characteristic curves of gasolenes. If all conditions of petroleum composition and refining were the same the world over, gravity would then be a satisfactory means of comparison, for all curves would be of the same shape and parallel to each other as shown in Fig. 2, each curve representing a different gravity. Such, however, is not always the case, the true state of affairs frequently being as shown in Fig. 1. By the gravity method one would naturally expect a 72.5 deg. Beaumé gasolene to give better results than one of 63.6 deg. Beaumé, but in reality this particular 63.6 deg. Beaumé gasolene is much the better, as can be readily seen from the curves. This is contrary to the usual understanding and clearly indicates the fallacy of the gravity method of grading.

(4). Specifications and Purchase

The problem of fuel for motor cars is amenable to the same solution as that of coal for steam boilers. By test the most suitable fuel must be determined, then the characteristics of this fuel definitely specified and competitive bids invited on fuel to meet the specifications.

The specifications based on fractional distillation should give initial boiling point, that is, the point at which the liquid starts to vaporize, the final boiling point at which all liquid has disappeared from the flask, and possibly two or three points in between, and the percentage of the quantity which should boil over at these temperatures. The initial boiling point should be the maximum temperature which will insure easy starting. Final boiling point should be set as high as possible so as to produce a fuel which will not burn too rapidly; in fact all points should be as high as practical, as high boiling points mean low prices. Fuel should, of course, be free from water and other impurities.

When the specifications of distillates are being prepared, it is well to consider the design of the engine and the purpose for which it is to be used. For instance, the ordinary automobile engine, usually of high piston speed, working under varying loads, needs a distillate having a narrow range of boiling points, that is, quick burning fuel. Heavy duty engines of slow piston speed and fairly constant loads operate better with fuels having the initial and final boiling points a considerable distance apart, as the slow burning fuel develops a higher mean effective pressure. Automobile engines are also subject to another condition. Being required to start easily in cold weather, they must use a fuel having a larger percentage of components boiling at low temperatures than engines that are installed in buildings kept at a reasonable degree of warmth.

The following specification for liquid fuels will be found satisfactory for use on gas-electric cars.

a. Fuel shall be an unrefined petroleum distillate free from refuse, water, sand, etc.

b. The initial boiling point shall not be in excess of 185 deg. F. (85 deg. C.).

c. Dry point shall not be in excess of 550 deg. F. (228 deg. C.).

d. The first 10 per cent should distill at a temperature not in excess of 230 deg. F. (110 deg. C.).

g. 60 per cent should distill at a temperature not exceeding 374 deg. F. (190 deg. C.).

f. Not less than 95 per cent of the liquid should be recovered from the distillation.

g. The above figures are based on the Engler process; if other methods of distillation are used results must be corrected to equivalent values.

For engines requiring quick acceleration and widely varying loads, a fuel having a narrow range of boiling point is desired. For these conditions the following specifications are recommended:

A. Fuel shall be free from impurities.

B. The initial boiling point shall not be in excess of 185 deg. F. (85 deg. C.).

C. Dry point shall not be in excess of 356 deg. F. (180 deg. C.). (Dry point will be indicated by a small puff of white vapor from residue in flask.)

D. The fractional distillation proceeding at the rate of one drop per second should be recorded in ten per cent cuts.

E. The first 10 per cent should distill at a temperature not in excess of 230 deg. F. (110 deg. C.).

F. 50 per cent should distill at a temperature not exceeding 270 deg. F. (132 deg. C.).

G. Not less than $97\frac{1}{2}$ per cent of the liquid should be recovered from the distillation.

Those who have been interested in the purchase of coal to specifications will immediately note that there is no mention, whatever, of heat value in the above specifications. The reason for this apparent omission is as follows:

All petroleum and petroleum products have practically the same heat value, i.e., 19,000 to 21,000 B.t.u. per pound, and as there is, at present, no suitable distillate

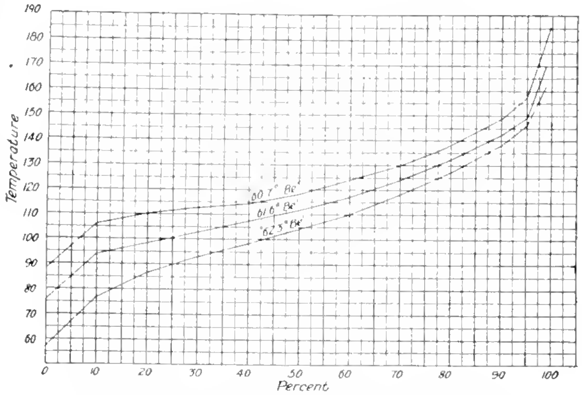


Fig. 2. Curves of Fractional Distillation of Gasolenes the Values of Which as a Fuel Are Proportional to Their Hydrometer Readings

commercially practical, the heat value of petroleum products can be safely assumed.

Possibilities of Other Liquid Fuels

At the present time there is a widespread demand for a cheaper and more efficient fuel than the gasolene and naphtha discussed above. The demand seems to have been met by a type of internal combustion engine utilizing heavy oils, generally known as the Diesel or high-compression oil engine. Much has been claimed for this apparatus, and the claims have been well substantiated in stationary and marine service, but as yet no engine of this type has been developed that is available for motor car service.

Any article considering liquid fuels for internal combustion engines would be manifestly incomplete without a word in regard to alcohol and coal distillates, more generally known as benzol.

Generally speaking, alcohol, either wood, grain or denatured, is a fuel even better than gasolene, and undoubtedly will figure more prominently in the future than it has in the past. Its advantages lie in the fact that it can be obtained from any vegetable matter and is, therefore, available in nearly all parts of the world.

The apparatus required is simple, inexpensive, and the cost of production small. Chemically, alcohol is a much more simple substance than gasolene and will be found more uniform.

The only reason that prevents its use is the price, and perhaps certain government restrictions in regard to inspection, bonding, and storing. Constant search is being carried on for a vegetable which will yield large quantities of alcohol at minimum cost. In Cuba, sugar cane refuse will furnish alcohol that may be sold at 12 to 15 cents per gallon.

When the problem of production has been satisfactorily worked out, alcohol with even a lesser heat value than gasolene, that is, 14,000 B.t.u., will be a competitor on the fuel market.

In Europe there is a gasolene substitute called benzol which is meeting with considerable success. This fuel is produced by the destructive distillation of coal. In the matter of advantages and disadvantages it ranks between unrestricted alcohol and gasolene. Like alcohol, it is a simple mixture and uniform. Like gasolene, it has a high heat value ranging from 18,000 to 19,000 B.t.u. It is heavier than gasolene and, therefore, more work is obtained per gallon.

The price of benzol is against its use, however, for unless gasolene be over 25 cents a gallon, the cost of production of benzol from coal at $1.75 per ton, even with the revenue derived from the other products of distillation, will prohibit its use. It seems probable that with our enormous coal deposits there will be developed a means for producing benzol more economically.

LUBRICATION

The successful lubrication of internal combustion engines has in the past been considered a difficult proposition and one surrounded by more or less mystery, the difficulty being to obtain an oil that will work under the little known conditions that exist in the combustion chamber.

The prevailing idea of a gas engine oil was that it should have a high flash and fire test, supposedly in order to withstand the high temperature of the combustion chamber. The flash and fire test temperatures have usually been between 400 and 500 deg. F., but it is manifestly impossible to expect that an oil of this test will not burn in a temperature variously estimated to be between 1800 and 2500 deg. F. Whatever have been the troubles with internal combustion engine lubrication in the past, the problem is now satisfactorily solved and much is known as to the lubrication conditions of the cylinder, and oils for this purpose can be and are prepared which produce entirely successful results.

The idea of lubrication is the same with all pieces of apparatus, that is, to successfully lubricate at minimum expense. To lubricate is of prime importance. The matter of economy should be secondary. As the first feature must be obtained, we will therefore assume successful lubricating oils. To attain economy, we must have an oil of which little is used, or which wears well. Therefore, the aim should be to prevent excess oil getting to the combustion chamber, thereby using as little as possible, and second, to obtain a clean burning oil, that is, one which upon burning leaves as little carbon as possible.

The quantity of oil passing by the piston rings to the combustion chamber is governed by the viscosity of the oil and the construction of the engine and its lubricating system. A gravity feed inherently permits the quantity of oil consumed to be accurately controlled. As the storage for this oil is usually set away from the engine and kept at low temperatures, a much different oil is required than with either the force feed or splash lubrication system. As the storage for oil in the latter system is generally the lower portion of the crank case, all oil is speedily warmed to a rather high temperature, with a consequent loss of viscosity. As in different makes of engines there are differences in piston fit, number and size of rings, and heating of the oils, different viscosities are naturally needed for best results. The question of the most suitable viscosity is one to be settled by each manufacturer, although the personal equation of the operator has great bearing on the success to be obtained from the use of any oil.

A clean-burning oil must primarily be free from dirt and sediment, but aside from this there will be a certain amount of carbon deposit from the combustion. The amount of this deposit is usually determined by the carbon residue test, which consists in vaporizing and burning a certain amount of oil and measuring the percentage of carbon residue remaining after all liquid has disappeared. All carbon deposit is not, however, due to excess or poor quality of oil. Excess of fuel or dirty fuel may cause much more carbon than it is possible to obtain from the lubricating oil.

The importance of high-flash and fire tests have been greatly over-estimated. However, the oil should test sufficiently high to prevent undue loss by vaporization from the hot wall of the cylinder and piston. Engines which are subject to cold weather use should have an oil of low cold test, otherwise when the engine is first started the oil may be so stiff as not to splash or flow, and the engine be without lubrication for a considerable period. In general, it may be said that any good gas engine oil from a reputable manufacturer can be used successfully, although, depending on the conditions of operation and construction of the engine, certain oils can be used with a greater degree of satisfaction than others.

Thus far no specifications or laboratory tests of oil have been found that are satisfactory for general use. The practical work-out test is by far the best means of determining the merits of a lubricating oil. When purchasing an oil its first cost should not be given undue importance. The cost of motor car operations is figured on a car mile basis, and the life of an oil—that is to say, the number of car miles per gallon or the cost per car mile—must be regarded as the only final criterion of the value of an oil.

HOW MUCH ELECTRICITY DOES THE AVERAGE FARMER USE?.

By C. J. Rohrer

Lighting Department, General Electric Company

Some comments were made in the editorial pages of our August number on the growing interest that is being shown by central stations in the development of business in rural districts, and in the same issue was published an article by Mr. E. B. Merriam, descriptive of what has been done by the manufacturer to make possible the economical tapping of high tension transmission lines for just such service. In the present article, after some statistics relative to the power requirements of the farmers of the United States and the possibilities of the electric motor for this class of service, the author presents in concise tabulated form a quantity of data that he has collected from some 130 farms supplied with electric power from transmission lines in their vicinity. Five power companies are represented and the character of the rural service of each is analyzed in detail. From the figures given it is obvious that a purely lighting load would afford poor returns in most cases on the necessary investment; but experience goes to show that once the farmer is made acquainted with the capabilities of the electric motor, he is quick to adopt it, thus providing a profitable source of revenue to the power company. Of the total service supplied by these five companies, fully two-thirds is for power, the principal demand for which comes during the day time, and is thus a most desirable day-load builder.—Editor.

For several years past the newspapers and magazines have published numerous articles describing the wonders of electric power when applied to the farming industry, but only in rare instances have figures been given in these articles which would enable the farmer or central station manager to determine whether or not rural distribution of electricity is or ever will be a profitable investment. The writer will endeavor in this article to point out by means of tables and load curves just what the farm business amounts to at the present time, and, in addition, try to give an adequate idea of what its future development may be.

The present tendency in the electrical industry seems to be toward the centralization of the smaller stations into one large distributing station; the towns, villages and small manufacturing concerns in the vicinity of this station being supplied with electric current by means of substations and interconnecting high tension lines. At the beginning of this movement no thought was given to the farmer as a possible customer for electric power, and the companies who are pioneers in rural distribution were driven into the farm business by being compelled to supply farmers with electric light in order to secure the rights-of-way for their transmission lines. These first installations were practically all for lighting service, very little, if any, power being used. Consequently the returns to the central station from such installations were not large or profitable. In the meantime, however, irrigation had come to be extensively practiced in the western states and this offered a new outlet for electric power, which promised immediate returns on the money invested. The use of electric power for irrigation is rapidly increasing and today the farm load forms a large percentage of the total load of most of the large operating companies in our western states. Where irrigation is a necessity for the growth of crops and where most of the land is under cultivation there is no question that the farm business is a profitable one for the central station. However, where irrigation is not a necessity the general tendency among the central station managers is to take a sceptical view as to the advisability of supplying the farm with electric light and power. This view is partly justified, as it is generally admitted by everyone familiar with the subject that it will not pay at this time to build transmission lines with the sole idea of farm supply. However, as pointed out before, there are at present thousands of miles of transmission lines running from town to town. These lines have been built with the expectation that they will pay dividends on the money invested

Now, if the farmers residing in their vicinity will use enough electric current to pay a profit on the cost of tapping these transmission lines and the up-keep on them, they are desirable customers, especially in view of the summer day load which they bring to the central station. A power solicitor who is familiar with the farm situation can sign up a large number of farmers in the vicinity of almost any transmission line of moderate voltage who will fulfill these conditions.

The extent to which power is used on the farm is indicated by the enormous number of gasolene and small steam engines in service all over the country. It is estimated by reliable authority that 500,000 gas engines will be bought for farm use this year, and there are probably in use at the present time one and one-half million gas engines with an aggregate capacity of about 4,000,000 horse power. There are now about 760 different companies manufacturing gas engines. The best authorities on the subject agree that this business will be doubled within the next two years.

It is estimated that 30,000,000 horse power can be used to advantage on the farms of the United States. At the present time most of this power is supplied by gas engines and this state of affairs will continue until the central station becomes convinced that farm business will offer a profitable outlet for electric power. In time electric power will displace the gas engine on the farm, as it already has done to a large extent in the city. The farmer is awakening to the advantages of electricity and his demands for it are becoming more and more insistent; in fact, a large number of farmers are now installing isolated plants because the central station in their territory will not supply them with electric light and power. At the present time the average farmer in the central and eastern states first thinks of electricity for lighting his house and barns, and if he is induced to install a low voltage isolated plant his main want is gratified; and then the effort necessary to get him to take out this isolated plant and use central station power is made doubly severe. On the other hand, the experience of the companies who have been serving the farmers for a number of years has been that the central station customer is soon on the market for electric motors to drive his washing machine, ensilage cutter, churn, feed cutter, etc., and it is much easier to convince him that he can use electricity to advantage for some of the other 125 farm operations which can be and are now performed by electric power.

It will not pay the central station to supply the farmer with lighting alone, unless indications point strongly to the fact that he will install some electric motors later on. From figures secured from a number of companies in the central west, having a total of some 250 farmers on their lines, it was found that the average size of farm was 190 acres and that the average electrical installation consists of 35 per cent lighting and 65 per cent power. Under these conditions it was found that the revenue amounted to about $0.27 per acre per year or $172 per square mile. In these statistics are included a number of dairy farms which are large users of electric power, and if these are excluded the average will be in the neighborhood of $.15 per acre per year, or $96 per square mile. Extensive investigations of farms supplied in Germany show that practically the same amount of electric current is used per unit area when only lighting and very small power applications are considered, the returns per acre per year being about $.22, or practically $140 per square mile. However, the lighting and small power applications return only about 20 per cent of the revenue derived, the other 80 per cent being made up by threshing, field railways and plowing.

The average German farm will yield a gross revenue of about $1.32 per acre, or a total revenue of about $844 per square mile; for the central station will supply electricity for lighting at $.095 per kw-hr., for power purposes at $.0475 per kw-hr., and electricity for plowing at $.031 per kw-hr. This proves conclusively that the application of electricity to the farms of the United States is only begun. Perhaps it may be said that Germany practices more intensive agriculture and that the population per square mile is much greater than that of the United States, but the marked difference between the revenues derived per unit area in the United States and those in Germany is so great as to convince any sound thinking individual that there are great prospects in the adoption of electricity on the farm. These details are given below in tabulated form:

GERMAN RATES

Lighting	9.5 cents per kw-hr.
Power	4.75 cents per kw-hr.
Power for plowing	3.1 cents per kw-hr.

AVERAGE ANNUAL CONSUMPTION IN KILOWATT-HOURS OF A GERMAN FARM OF 63.1 ACRES

Use	Kw-Hr. Per Yr.	Kw-Hr. Per Acre per Yr.	Returns per Year Per Farm	Returns per Year Per Acre	Returns per Year Per Sq. Mile
Lighting	80	1.26	$7.20	$0.114	$73.00
Small power uses	138	2.19	6.55	.104	66.50
*Total of light and small power uses	218	3.45	13.75	.218	139.50
Threshing	330	5.24	15.65	.248	158.80
Field rwys.	90	1.43	4.28	.068	43.45
Plowing	1600	25.4	49.50	.785	502.50
Grand total	2238	35.52	$83.18	$1.319	$844.26

*Comparable to the following table.

DATA FOR FARM LINES IN THE HUMID SECTIONS OF THE UNITED STATES

Company	No. of Farmers	Cost of Current	Aver. Size of Farm in Acres	Kw.-Hr. per Acre Per Year	Returns per Year Per Farm	Returns per Year Per Acre	Returns per Year Per Sq. Mile
1	41	4 c.	248	4.75	$47.10	$0.19	$122.00
2	12	8 c.	205	15.5	245.20	1.24	795.00
3	41	10 c.	164	1.41	23.10	.141	90.25
4	9	10 c.	180	1.2	21.60	.12	78.20
5	40	10 c.	173	1.63	28.20	.163	105.00
Averages			190	3.85	$51.00	$0.269	$172.00

The load of the average farm has an excellent diversity factor, as it may be made up of any or all of the following items: water pumps for irrigation, fire protection and domestic water supply, cream separators, churns, milking machines, refrigerating machinery, milk clarifiers, fanning mills, grain elevators, feed grinders, ensilage cutters, root cutters, emery wheels, wood saws, portable drills, soldering irons, etc. In addition to all these quite an appreciable amount of current will be used to light the home and buildings of the farmer.

The farm load offers several advantages which are not common to the average city customer. In the first place, the peak load of the average farmer comes during the summer months and is essentially a day load with the exception of the small amount of lighting, and even this lighting load does not interfere with the central station peak, for the farmer is up in the morning and in the field before the average city man is out of bed. In fact on strictly country lines a very appreciable peak is noticed from 4:30 to 5:30 on a summer morning and from 5 to 7 d ring the winter. At night, especially during the winter lighting peak, the evening chores are usually finished by 6 p.m. and after that the farmer uses only the current required for a few lights in his house.

The table above gives in condensed form the nature of the farm load of seven different operating companies in the central and eastern states.

Company No. 1 supplies current for lights and small motors, none of the motors being over 5 h.p. in size. The average installation of these 41 farmers is 2.64 kw., and each farm uses on a average 41.7 kw-hr. per month, or an equivalent of 15.8 kw. per month per kilowatt of installation. The company is supplying over one hundred farmers, but the writer was able to get complete reports on only 41 of these. A flat rate of $.10 per kw-hr. is charged, with a minimum of $2.00 per month. The lines of this company run through typical Illinois farming territory and if an active and aggressive campaign were made the current consumption of each individual farm could probably be doubled.

Company No. 2 have about 200 farmers on their lines; however, complete and detailed information was available on only 31 of these. These data were taken from farms in a strictly dairy district and show what may be expected from the typical dairy farm. A large number

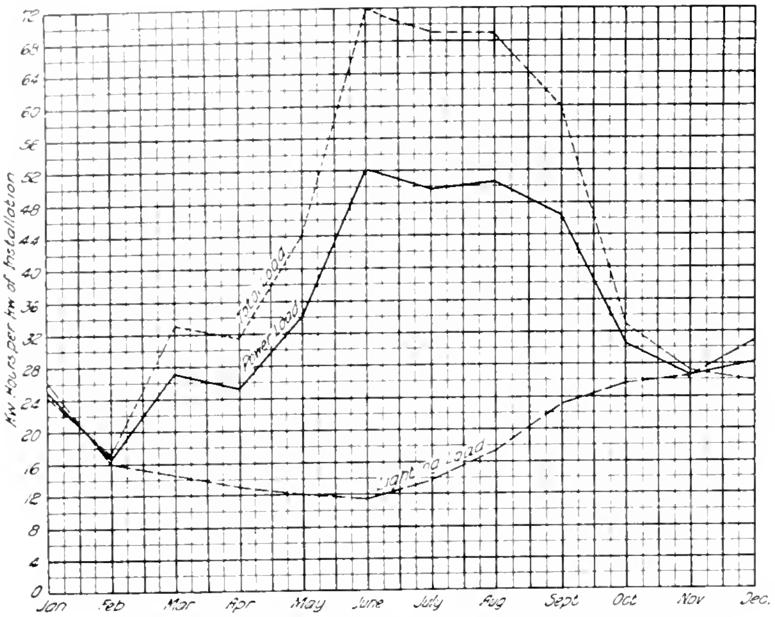


Fig. 1. Current Consumption on Typical Dairy Farms having Refrigeration and Pumping Loads. Total Installation 140 Kw., 94 Kw. in Motors, 46 Kw in Lights. 45,642 Kw-Hours used during Year

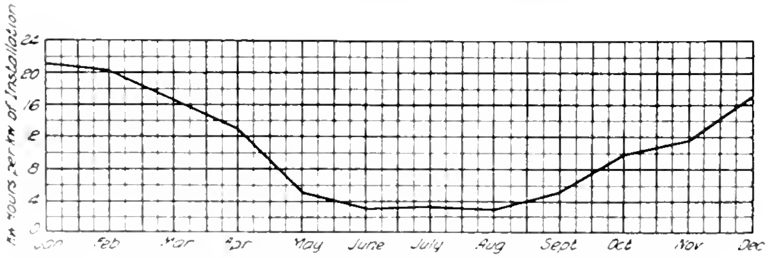


Fig. 2. Current Consumption on Dairy Farms using Feed Grinders, Huskers and Shredders, but not using Refrigerating Machines. Total Installation 302 Kw., 284 Kw. in Motors, 18 Kw. in Lights. 38,150 Kw-Hours used during the Year

have cold storage plants and practically every one uses an electric motor to pump water, operate a milking machine and cream separator, etc., which accounts for the large amount of current used per kilowatt of installation.

Company No. 3 serves an altogether different type of dairy farm. Most of these farmers use electric power which is taken from a 550 volt d-c. trolley wire, and consequently very little lighting is used. Very few of these farmers have cold storage plants, as the milk is sent to the creamery direct and the large motors indicated in the table are used mostly for cutting fodder, which is essentially winter work.

Company No. 4 gives an idea of the returns to be derived from truck gardeners who use electric motors to supply water for irrigation purposes. This is strictly a day load and, unless greenhouses are used, it could be said to be a strictly summer day load. The current consumption per kilowatt of installation is fair, and indications are that it will continue to improve.

ELECTRIC CURRENT USED BY THE AVERAGE FARMER IN THE CENTRAL STATES

	No. of Farmers Served	Electricity Used Mostly for	Average Size of Installation per Farm in Kw.			Average Monthly Consumption per Farm in Kw-hr.	Kw-hr. Used per Month per Kw. of Installation
			Lights	Power	Total		
1	[illegible]	Lights and small motors	1.70	0.94	2.64	41.7	15.8
2	31	Pumping, lighting and refrigeration	2.10	4.65	6.75	213.0	31.6
3	[illegible]	Large motors	0.58	10.00	10.58	98.0	9.3
4	60	Pumping and lighting	0.73	1.34	2.07	39.5	19.1
4-A	157	Lighting, pumping and power	0.64	0.87	1.51	38.2	25.4
5	11	Lights and small motors	1.25	0.07	.132	19.3	14.6
6	3	Power and light	1.00	16.5	17.50	529.0	30.2

Under *Company No. 4-A* is given the combined farm and truck garden load of No. 4.

The fifth company represents what might be called a strictly lighting load, as the motors are very few in number, and none that came under observation were over 1 h.p. In the great majority of cases, however, a very desirable motor load can be secured on these farms.

Company No. 6 shows returns from three very practical farmers, two of them being beef cattle breeders and the third a dairy farmer. These men have made their money on the farm and are farmers in every sense of the word. They know the value of electric power and are using it wherever possible.

Figures 1 to 5 inclusive show the characteristics of farm loads of the different companies; i.e., whether a summer or winter load.

Figure 1 is that of company No. 2; Figure 2 of company No. 3; Figure 3 of company 4; Figure 5 of company No. 6. Figure 6 is a composite curve showing how nearly constant the kw-hr. consumption would be month by month, provided one company had the above 250 farmers on its lines. Figure 7 shows the comparative current consumption of four of the above companies. From these curves it will be noted that where pumps are extensively used the peak comes during the summer months, but when huskers and shredders are used extensively as they are in the case of company No. 3 (Figure 2) the peak load comes during the winter months. The farm lighting peak as far as total kw-hrs. are concerned, comes during the month of September.

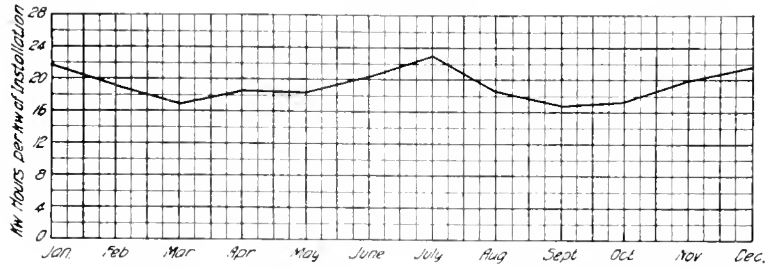


Fig 3 Current Consumption of Truck Gardeners, using Pumps for Garden and Greenhouse Water Supply. 60 Installations. Total Installation 88.6 Kw., 58 Kw. in Motors, 30.6 Kw. in Lights. 20,412 Kw-Hours used during the Year

Fig. 4. Current Consumption of Truck Gardeners and General Farmers. 157 Installations. Total Installation 237 Kw., 137 Kw. in Motors, 100 Kw. in Lights. 72,085 Kw-Hours used during the Year

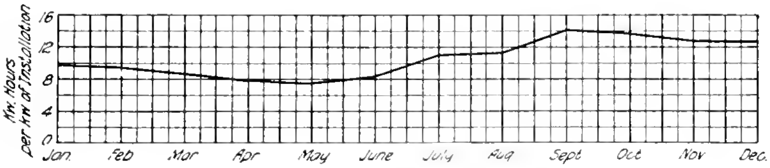


Fig. 5. Current Consumption of Farmers using Electricity for Lighting only. 41 Installations. Total Installation 73 Kilowatts 9,382 Kw-Hours used during the Year

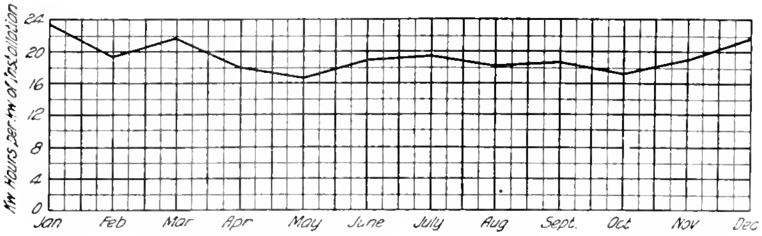


Fig. 6. Composite of Curves 2 to 6 inclusive. Total Installation 725 Kw., 525 Kw. in Motors, 227 Kw. in Lights. 175,755 Kw-Hours used during the Year

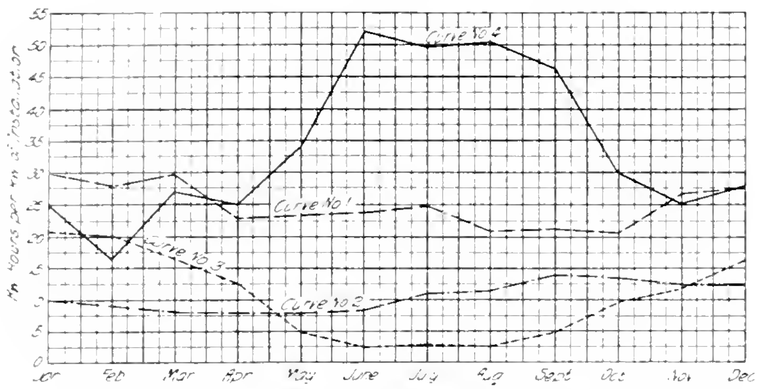


Fig. 7. Curves Showing Comparative Current Consumption of Four of the Principal Types of Farm Loads. Curve 1, Lighting, Irrigation, and General Farming. Curve 2, Lighting. Curve 3, Huskers, Shredders and Feed Grinders. Curve 4, Pumping and Refrigeration

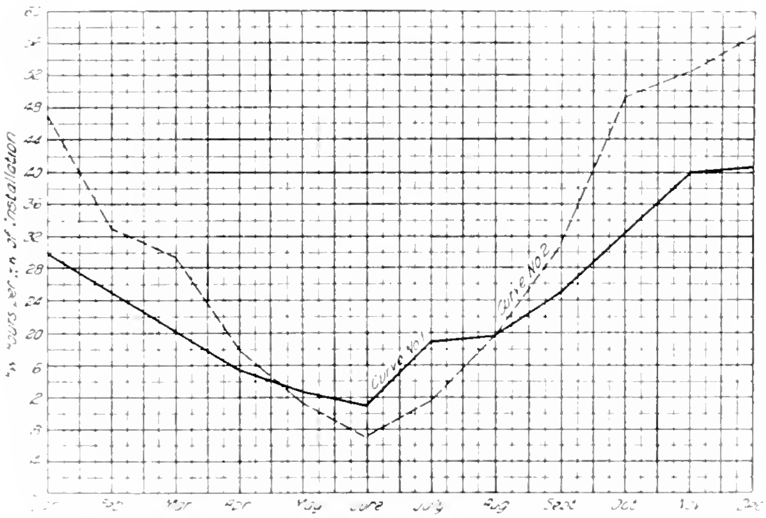


Fig. 8. Dairy Farm Lighting (Nine Farms). Curve 1, House Lighting. Curve 2, Barn Lighting

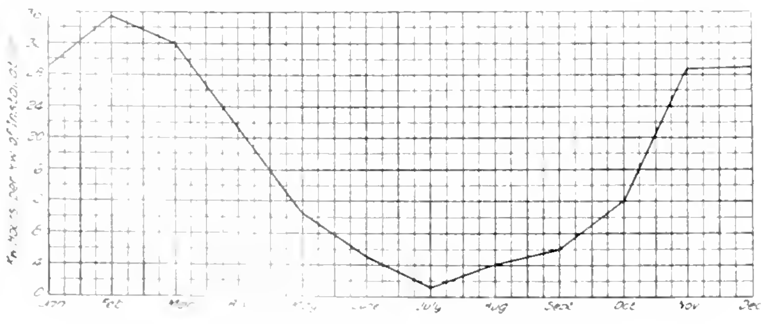


Fig. 9. Lighting Curve of Dairy Farm, whose Heaviest Milk Production comes during the Winter Months

An analysis of the peaks of the different types of farm load is interesting. Figure 5 shows that the monthly lighting peak of the average farmer comes in September. Figure 8 shows current consumption for lighting by months for nine dairy farms. From these curves it will be seen that the barn consumption is by far the greatest during the winter months and that it follows diligently the almanac curve of daylight and darkness. The house on the other hand does not drop as much in summer, neither is it as high in winter. The reason that this curve differs from that of No. 5 is that the amount of work in the barns and house on the dairy farm is about the same the year round, while the farmers in the case of company No. 5 did not have to get up so early or work so late from September to January.

Figure 9 represents the lighting load of a large dairy farm. In this case the curve is somewhat different due to the fact that this particular dairy make a specialty of having the largest number of cows producing milk during the months of January, February and March when milk is very scarce. In Figure 10, the top line, labeled No. 1, represents a strictly truck garden pumping load. No. 2 is made up of about 38 per cent light and 62 per cent pumping. You will note that No. 2 runs proportionately higher in winter and lower in summer, as would be expected under the circumstances. Figure 11 represents the current consumption by months of three pumps used for dairy water supply. Figure 12 is a detailed analysis of company No. 2. Line No. 1 represents the current consumption of huskers, shredders and feed grinders, but no lights. Line No. 2 represents huskers, shredders, feed grinders and lights. However, the lighting in line No. 2 is only 6½ per cent of the total connected load; but even this small percentage makes a difference in the curve.

Huskers and shredders should not be confused with ensilage cutters, as the latter are used during the months of September and October.

All of the machines mentioned above are used during the daylight hours and this day load will steadily increase from year to year while the lighting load will remain about stationary. In other words, if farmers are taken on the lines they will install new motors, which will add just the kind of load which is most desirable to the central station.

In conclusion the point should be emphasized that almost every farmer in five or ten years from today will have electric power, and it rests wholly with the central station as to whether he will generate it himself or buy it.

Electricity as applied to farming is virtually in its inception, even on the lines where farmers have been using electricity for several years.

With the advent of good roads the electric truck is going to be used more and more. The electric fireless cooker will increase the farm load, and threshing and plowing will eventually be accomplished by electric power.

If farm lines can be built now which will pay only a very small profit at the present time, the writer's advise is to build them and thus forestall the isolated plant, which will be hard to displace once it is installed.

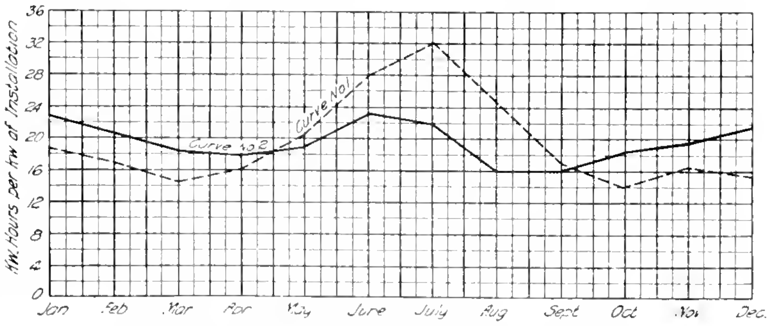


Fig. 10. Curves showing the Difference in Current Consumption of a strictly Pumping Load, as compared with a Load consisting of 62% Pumping and 38% Lighting Curve 1, Pumping only. Curve 2, 38% Lighting, 62% Pumping

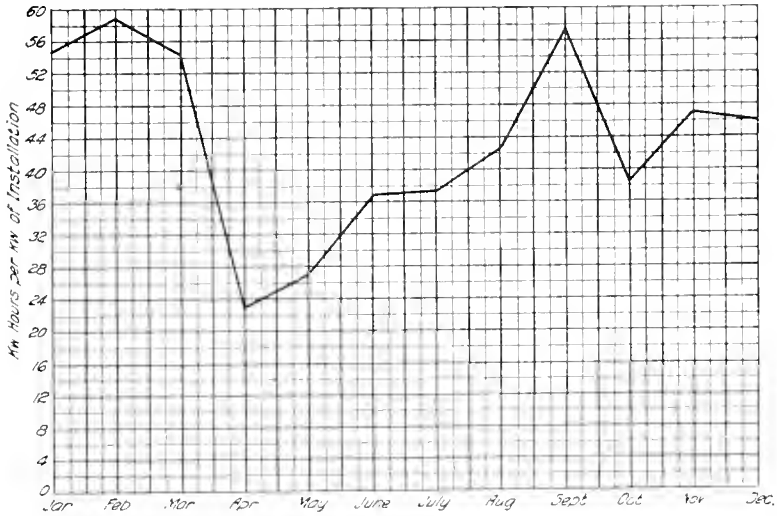


Fig. 11. Dairy Pumping. (3 Installations)

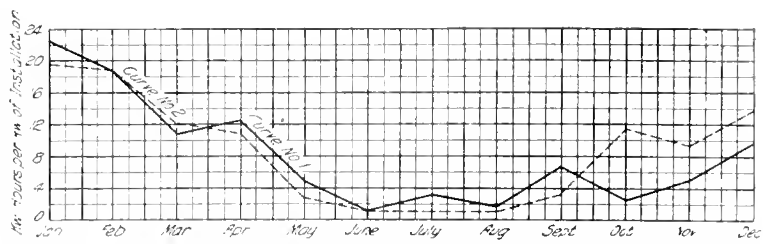


Fig. 12. Curves showing that Huskers and Shredders and Feed Grinders tend to make a Winter Load. Lighting will increase the load to some extent. Curve 1, Huskers and Shredders, and Feed Grinders (68.2 Kw.) Curve 2, Huskers and Shredders, Feed Grinders and Lights. (125 Kw. Power) (8.5 Kw. Lighting)

The farm demand for electric power will steadily increase from year to year—there will be no retrogression.

GROUNDED Y *versus* ISOLATED DELTA FROM THE POINT OF VIEW OF THE SYSTEMS IN THE SOUTHWEST

By Chester W. Rice and S. Thomson

Consulting Engineering Department, General Electric Company

The substance of this paper is to the effect that for extended networks of low power concentration, the advantages, from the standpoint of continuity of service, are virtually all in favor of the dead grounded neutral. Grounding the neutral relieves the system from dangerous potentials to earth resulting from grounds on the line, and as a rule such systems are not subject to the damaging effects of the high frequency disturbances that accompany an arcing ground on an isolated system. Furthermore, a fault is more readily located on a grounded system, while both systems admit of operating the transformers in open delta, or the equivalent, in cases of emergency. For further information on this important subject, we refer the reader to the article by Dr. Steinmetz, "The Grounding of Transmission Lines," published in our June, 1913, number.—Editor.

The question of whether it is desirable to ground the neutral of a transmission system is independent of the transformer connections to be used, namely, Y or delta, for either connection may be grounded or isolated. Generally speaking, the Y connection is used in those cases where the neutral is to be grounded; otherwise, delta connected transformers are usually preferred.

The arguments for and against the operation of a system with or without a grounded neutral will be based upon the importance of the phenomena which are incident to a failure of insulation in their bearing upon the continuity of service. A failure of insulation is most likely to occur at some point on the transmission lines, because of their great extent and the number of supports. Obviously the chances of a point of weak insulation increase with the total length of lines. The transmission systems in the Southwest, both large and small, generally consist of a network or loop of lines; and furthermore, the systems are frequently tied together.

If more than one phase in a three-phase system becomes accidentally grounded, or a short circuit occurs between phases, the resulting phenomena are identical on both the isolated and grounded systems, and a shut down of the damaged line results. If on the other hand one phase only becomes grounded, the phenomena which follow are very different on the two types of systems. Therefore in the following discussion concerning the relative merits of the grounded and isolated systems we may limit ourselves to the case of single-phase grounds.

In the case of a grounded system, the result of a ground is a single-phase short circuit, and a current rush takes place, the severity of which depends upon two factors: first, the connected generator capacity; second, the impedance of the circuit thus formed, which includes the impedance of the line wire, transformers, and ground circuit including connections. The short circuit will burn off the line wire and destroy the insulators if the line is left in circuit; therefore, in most cases, the procedure is to shut down the damaged line and supply the load over some of the other lines of the net work. It is alleged that the synchronous apparatus on the system is infrequently thrown out of step by single-phase short circuits. Thus a short circuit entails only a momentary discontinuity of service, which is considered permissible on the systems here discussed.

A ground on a dead grounded system does not subject the system to abnormal potentials to ground, for under these conditions the ungrounded phases remain at Y potential above ground. This advantage is lost, however, if an appreciable resistance or reactance is inserted between neutral and ground; because in this case the voltage stress from the other two phases to ground, when a ground occurs, is increased by the voltage drop of the short circuit current through the resistance or reactance, and may reach the full line voltage.

Apparatus on the type of grounded systems here discussed is seldom damaged by the electromagnetic forces which result from a short circuit. The destructiveness of the electromagnetic forces depends upon the magnitude of the short circuit current, and, since network systems fed by a large number of relatively small generating stations are inherently of low energy concentration, little trouble may be expected. As the systems increase in power, suitable reactances can be placed in the outgoing line to limit the short circuit current to a safe value. This is probably more desirable than placing a resistance or reactance in the ground circuit.

If the neutral of a large system of this type were isolated, the potential stresses which would result from operating with a dead ground on one phase would be considered undesirable. The increase of potential to ground, namely, from Y to delta, would in such instances be liable to find a weak spot in some one of the thousands of insulators of the other two phases, and result in a phase short circuit. Thus two faults would have to be located and repaired, and where such simultaneous failures occur on the vital arteries of the system, the service will be seriously crippled. It may be added here that there are certain conditions under which an isolated system may become inoperative with a ground on one phase: first, when it is operating near the critical corona voltage, in which case the increase of corona loss and additional charging current which flows may involve a prohibitive voltage drop; second, when the resulting telephone disturbances become objectionable.

The apparatus of a system may be subjected to abnormal electrostatic stresses as the result of changes in the dynamic potential distribution of the system, or as the result of high frequency phenomena which may produce resonant rises of voltage, or from travelling waves of high frequency which impinge upon the end turns of inductive apparatus. The dynamic potential variations are not usually destructive to apparatus, since ample safety factor of insulation is generally present. However, in the case of potential stresses resulting from high frequency, the problem of insulation becomes very difficult. In order to understand this, we will now consider the origin and effects of the high frequency disturbances.

An arcing ground on an isolated system results in a superposition of the oscillatory discharge of the line, which is usually of a comparatively high frequency, upon the dead grounding current of machine frequency. The arc will go out and re-strike in each half cycle, which means that it will be of an oscillatory character, and wave trains of high frequency will be impressed upon the circuit at each discharge of the line, or in every half cycle. A transformer, even of medium size and voltage, cannot be considered merely as a high inductance, and, as such, impervious to high frequency oscillations which result from arcing grounds and other line disturbances, but must be considered as a circuit of distributed constants. As such it will transmit the impressed high frequency, which is very much lower than the natural period of the transformer, in the same way that a transmission line will transmit a 60 cycle wave, which is very much longer than its natural wave length. Thus when we think of a transformer as a circuit having distributed constants we readily see that when a wave train of high frequency strikes the end turns, a definite rise in voltage will take place; and also that the wave will not be entirely reflected, but a part will traverse the transformer windings and be inductively communicated to the low tension circuit, and thence to all the connected apparatus. It should also be kept in mind that the transformer, being a circuit of distributed constants, may oscillate independently at its own natural period. Thus we see that abnormal potentials may occur at the end turns or at random between turns or sections throughout the transformer windings, or in the generator windings, and failures may result. We may, therefore, conclude that in most cases it is inadvisable to operate a line with an arcing ground on one phase, because of the destructive nature of the phenomena incident thereto.

A ground on an isolated system does not usually develop into a short circuit; but the current flowing to ground, in the case of long and therefore high voltage lines, may be comparable in magnitude to the single-phase short circuit current of such a line. The effective grounding current is the result of the superposition of two effects: first, the oscillatory line discharge, the maximum value of which is approximately proportional to the line voltage for all lengths of line; second, the dynamic current which flows from the conductor through the arc to ground in charging the other two phases. This current is of the order of twice the charging current of the conductor when operating under normal conditions and increases directly with the length and voltage of the line. Therefore it is apparent that on long high voltage lines the effect of a ground, in its destructiveness of line wire and insulators, may be comparable in magnitude to that which would result from a single-phase short circuit on the system.

A further difficulty that is often met with in the operation of isolated systems, is that a fault on a line does not generally open the line switches, and is therefore difficult to locate in those cases where several lines are paralleled on the same bus.

Now that we have seen what takes place in an isolated system, let us consider the case of a ground on a grounded system. Here a ground results in a short circuit, and at the first half cycle the line will discharge exactly as in an isolated system; but in this case the arc usually does not go out and restrike at each half cycle, but in most instances will become a steady dynamic short circuiting arc. In the latter case only a single wave train of high frequency is impressed upon the circuit from the line, and the liability of destructive effects is therefore greatly decreased. Furthermore, when a transformer is thus short circuited by the steady dynamic arc, a large amount of its capacity may be regarded as permanently short circuited, and hence its natural period will be very high and the damping influences, which are always present, will be proportionally effective. Another way of looking at this is that in a transformer under short circuit the e.m.f. induced in each turn or unit of length is consumed in that turn, and hence the resulting electrostatic fields of the various capacities which depend upon the potential differences across the dielectrics are small. From these considerations we see that usually only slight high frequency manifestations, if any, may be expected in the case of short circuits on dead grounded systems.

To offset the advantage of operating open delta on isolated systems it is sometimes possible to operate a Y system, grounded at generating and receiving end, in what may be termed "open Y," that is, the damaged line is cut out, and the return current of the remaining two phases flows between the neutrals, using the ground as conductor. It is evident that this method of operation is limited, first, to those instances where the grounds are extremely good, and second, when the telephone disturbances which are liable to result from this connection are not objectionable. Here we should not forget that delta connected transformers may be used on grounded systems in substations, etc., which can be operated open delta at times of emergency.

Another advantage that is sometimes claimed for the grounded system is that it permits the use of single-phase transformers rated for line to ground voltage, which are considerably cheaper than those designed and rated for delta connection. This argument is, however, based on questionable engineering, for by using transformers in such a manner the factor of safety of insulation to ground is reduced from four to approximately two, or in the ratio of two to one. When using this connection, one side of the transformers is connected to the neutral, or is maintained at zero potential; therefore, the total voltage stress to ground comes across one insulation, whereas the transformers are designed to be operated with this stress across two insulations, that is, from line to ground and back to the other line. A certain saving in material can, however, be made when designing transformers for Y connection, which will make them slightly cheaper than those designed for delta connection. This consideration is aside from the instance cited above where transformers designed and rated for single-phase operation are connected in Y on a three-phase system.

SUMMARY

The question as to whether it is desirable to ground the neutral of a transmission system is independent of the transformer connections to be used, namely, Y or delta, for either connection may be grounded or isolated.

The arguments for and against the operation of a system with or without a grounded neutral are here based upon the importance of the phenomena which are incident to a failure of insulation in their bearing upon the continuity of service of extended network systems of low power concentration.

As the phenomena which result from phase short circuits are identical on both the isolated and grounded systems, we may limit our discussion to the case of single-phase grounds.

In the case of grounded systems of the type here discussed a ground entails only a momentary discontinuity of service, which is considered permissible.

A ground on a dead grounded system does not subject the system to abnormal potentials to ground.

Apparatus on the type of grounded systems here considered is seldom damaged by electromagnetic forces resulting from a short circuit.

If the neutral of large systems of this type were isolated, the potential stresses which would result from operating with a dead ground on one phase would be considered undesirable.

An arcing ground on an isolated system usually results in high frequency disturbances which make it inadvisable to continue operation.

A ground on long high voltage isolated systems may be as destructive to line wire and insulators as a single-phase short circuit would be.

A faulty line is, in most instances, more difficult to locate on an isolated than on a grounded system.

A ground on a grounded system does not usually result in high frequency disturbances and consequent apparatus breakdowns.

Isolated and grounded systems may both be operated in open delta or in an equivalent manner to take care of emergencies.

Transformers designed for use on grounded Y systems are not materially cheaper than those designed for use on isolated systems.

When the importance of the various factors are given proper weight in regard to their bearing upon the continuity of service of a system, it may be concluded that extended network systems of low power concentration are best operated with a dead grounded neutral.

FLOW METERS, THEIR APPLICATIONS AND RELATIONS TO INCREASED PRODUCTION AND HIGHER EFFICIENCIES

By James Wilkinson

Flow Meter Department, General Electric Company

The high efficiencies which are required in the handling of energy at the present day demand an intimate knowledge of both the quality and quantity of its medium at all times. To supply the lack of a direct means of measuring the quantity when in a liquid, vaporous, or gaseous state, the flow meter was developed. This article lists the benefits to be derived from the use of the meter, describes its working principles completely, gives directions for the installation of the plugs or orifice tubes by which the main is tapped, shows how the use of a reducer in low-velocity-flow piping increases the accuracy of the meter reading, and furnishes a table in which is given the proper size of reducer to use with various sizes of pipe, these carrying various amounts of flow at different pressures. The article concludes with a discussion of the benefits which are to be obtained in the operation of a battery of boilers if each is equipped with a steam flow meter.—Editor.

The rapid and substantial growth of the use of flow meters, since the time of their inception, may be assigned to the world-wide demand for higher efficiencies. It is particularly fortunate that the thorough development of the flow meter has just preceded this present efficiency-demanding period in the history of industrial progress.

The manager of today is not satisfied with keeping a plant merely in good running order, but is seeking every means to insure the most efficient and effective result for every operation. The new rule presumes that if knowledge is power, more knowledge is more power—for obtaining more efficient results. The demand is that the mere operating engineer become the efficient engineer.

Along with this demand has come a broader recognition of the fact that proper working instruments are the very basis for good efficiency; and without them the work of the ablest engineers, or the most skilled helpers is limited to unstandardized operations, which produce only the crudest results.

To operate a plant at highest efficiency, the proper handling of fluids such as steam, air, and water is imperative, and consequently it has been found that in every instance flow meters are essential. These meters give the operator a complete knowledge of what is going on in the vital parts of his plant. They serve to make visible to him the quantity-rate at which fluids are flowing through pipe lines. This information enables him to directly regulate or adjust all processes whose efficiency, effectiveness, or capacity is dependent upon the flow.

The great utility of the flow meter will be appreciated upon consideration of its function, as made use of by the operator. The following lists the points of valuable service secured by the use of such a meter:

Indications of the instantaneous rate of flow.

Indications of maximum and of minimum flow rates.

Indications of loss of flow due to leakage.

Directions as to the regulation of the rate of flow by throttling.

Directions as to the regulation of the means for producing flow.

Directions as to the regulation of the means for consuming flow.

Directions as to the regulation of flow for maximum production.

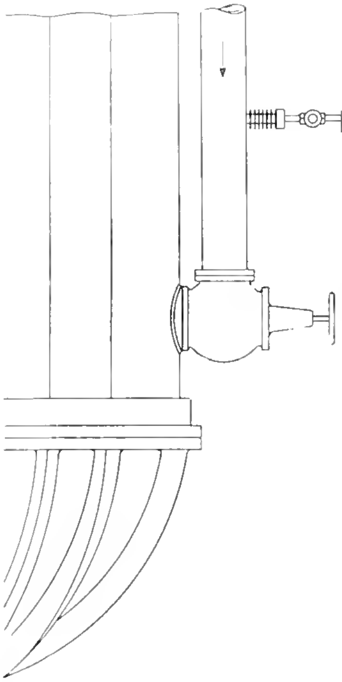


Fig. 1. An Indicating and Recording Steam Flow Meter Attached to the Steam Inlet of a Wood Pulp Digestor

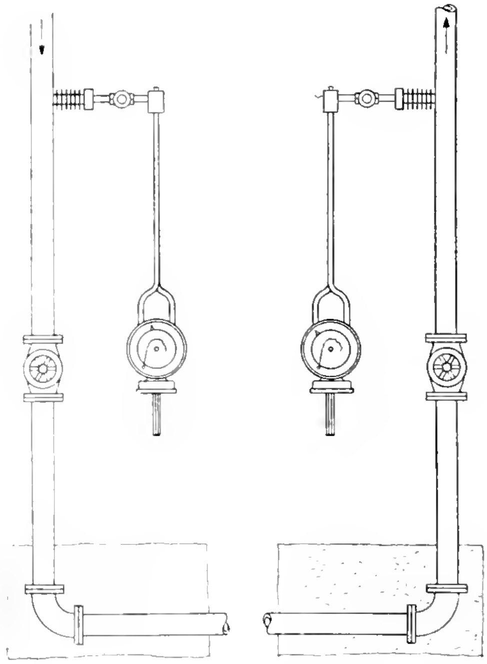


Fig. 3. The Indicating and Recording Flow Meter Measuring Underground Transmission of Steam for Heating and Power Purposes. By the use of two meters Flow Loss can be determined and any leakage discovered

A record of the flow-rate over an interval of time.

An integration of the total quantity of flow during an interval of time.

From the foregoing, it is evident that without the use of flow meters, a considerable range of action of an important element may remain unknown; and, consequently, the method of controlling or handling it left to guess work, with the chances infinity to one against its being done the right way.

The principal value of flow meters is, therefore, in the standardization of working processes. Next in importance is their recording feature, which enables permanent accounting, and insures the maintenance of the best standard.

The following reasons comprise the general argument for the use of the flow meter:

First, it enables the *conservation* of fluid and energy through the detection of leakage, or other waste, such as for example abnormal loss of power in producing the flow.

Second, it permits the accurate *standardization* of rate or quantity of flow, so that the best results may be obtained in any given process.

Third, the meter serves as a continuous working *guide*

Fig. 2. Indicating and Recording Water Flow Meter Measuring Discharge from a Pump

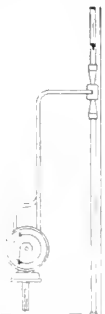


Fig. 4. Steam Flow Meter for Indicating and Recording the Steam Used for Cooking and Canning

for maintaining the standard that has thus been found to be the most efficient.

Records in general show that there are hundreds of plants where the cost of production has been materially reduced through the use of flow meters for gauging the work according to the best standard. Specific references would cover practically the whole field of industry. Figs. 1, 2, 3, 4, 5, and 6 illustrate a few of their applications which have been found to produce very beneficial results.

A feature of no small importance is the saving reported to have been made through detecting and stopping invisible leaks; and in some instances the saving has amounted to thousands of dollars annually.

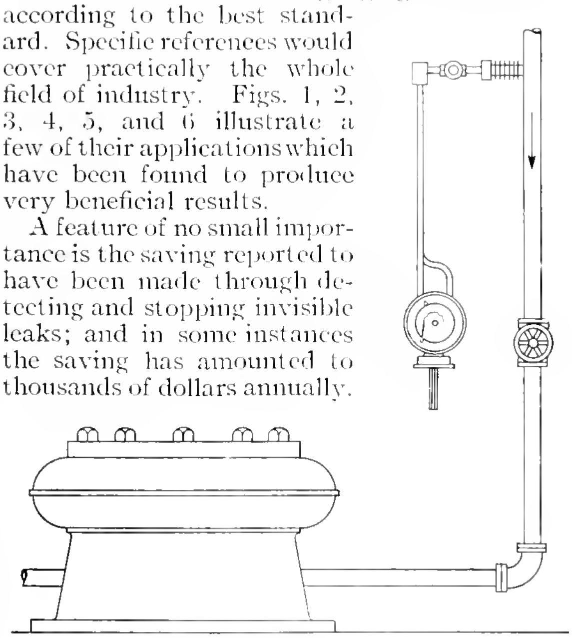


Fig. 5. Application of Steam Flow Meter to Rubber Vulcanizer

While a variety of meter types have been provided for the purpose of meeting the specific requirements of different conditions, it has been found that the most generally useful type of meter is that one which indicates the rate of flow so that an operator can use it as a gauge by which to work, and which at the same time records or integrates the total flow so that a corresponding accounting can be made and the results preserved for reference.

A new embodiment of this type of meter is illustrated in Fig. 7. The indicator scale is calibrated for the particular combination of pipe diameter, pressure, quality, and flow-range of fluid under which the meter is to operate. The indicator needle will accordingly point out at all times the exact flow-rate. The flow-rate can also be read at any point of time on the curve chart by the aid of a multiplying constant derived for the combination. The constant is also used to multiply the planimeter reading when obtaining the total flow for an interval of time from the curve.

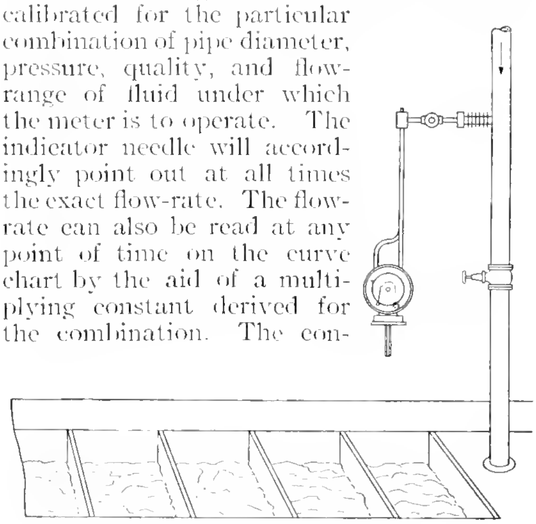


Fig. 6. Steam Flow Meter for Regulating the Process of Tanning Leather

TABLE I—PIPE REDUCERS COMPLETE WITH NOZZLE PLUGS

QUALITY OF STEAM 51 DEG. F. TO 150 DEG. F. SUPERHEAT

Steam Pressure 25 Lb. Gauge Range of Flow in Lb. per Hour from 0 to	Steam Pressure 50 Lb. Gauge Range of Flow in Lb. per Hour from 0 to	Steam Pressure 75 Lb. Gauge Range of Flow in Lb. per Hour from 0 to	Steam Pressure 100 Lb. Gauge Range of Flow in Lb. per Hour from 0 to	Steam Pressure 125 Lb. Gauge Range of Flow in Lb. per Hour from 0 to	Steam Pressure 150 Lb. Gauge Range of Flow in Lb. per Hour from 0 to	Steam Pressure 175 Lb. Gauge Range of Flow in Lb. per Hour from 0 to	Steam Pressure 200 Lb. Gauge Range of Flow in Lb. per Hour from 0 to	Diameter of Pipe in Inches in Which the Reducer will be Installed	Diameter in Inches of the Outlet of the Reducer Inside of Pipe
1790	2260	2650	3010	3310	3590	3850	4090		2
2410	3040	3570	4060	4450	4830	5180	5520	4	$2\frac{1}{4}$
3850	4760	5700	6470	7100	7710	8250	8800		$2\frac{3}{4}$
3020	3800	4470	5070	5570	6050	6470	6880		$2\frac{1}{2}$
4620	5820	6850	7770	8520	9250	9900	10550	5	3
6350	8000	9400	10650	11700	12700	13600	14450		$3\frac{1}{2}$
4620	5820	6856	77[illegible]	8520	9250	9900	10550		3
6350	8000	9400	10650	11700	12700	13600	14450	6	$3\frac{1}{2}$
8300	10470	12300	13940	15280	16600	17770	18900		4

Wherever it is desirable to obtain the total quantity without the use of the planimeter, an integrating device, as shown in Fig. 9, can be applied. Multiplying the integrator reading by the constant for the combination gives the total flow registered.

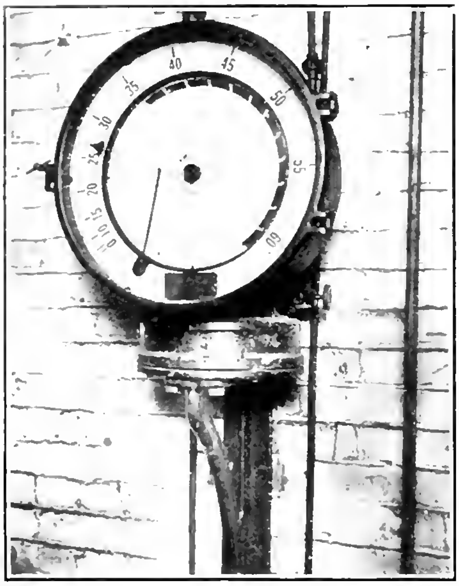


Fig. 7. Latest Type of Indicating and Recording Flow Meter

The meter operates upon the principle of a mercury **U**-tube, see Fig. 8. The tube is connected in parallel with the main pipe. The connection for pipes 2 in. and larger in diameter is made with a nozzle plug, which is illustrated in Fig. 10. The plug can be inserted directly into the pipe line without disturbing the latter. For smaller size pipes an orifice tube is used, see Fig. 11. This tube is incorporated in the pipe line.

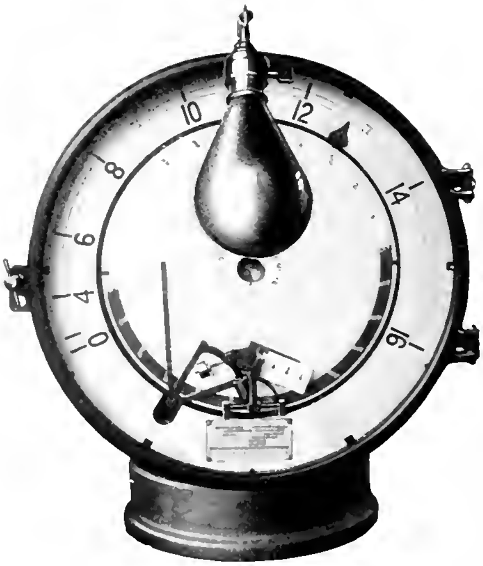


Fig. 9. A Flow Meter Similar to that Shown in Fig. 1 Except for the Addition of an Automatic Integrating Device

The meter, upon being properly loaded with mercury and having all cavities and piping above the mercury primed with water, will indicate and record with high accuracy the flow through the pipe, or orifice tube as the case may be.

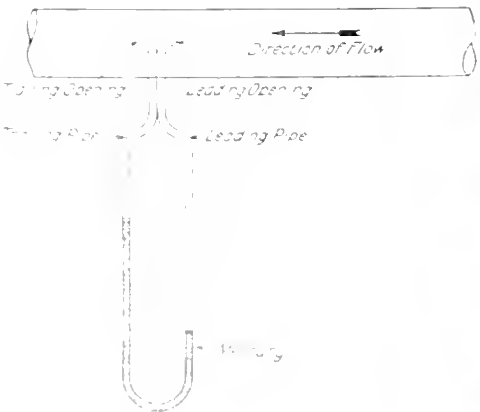


Fig. 8 Elementary Diagram of a Pitot Tube and Meter

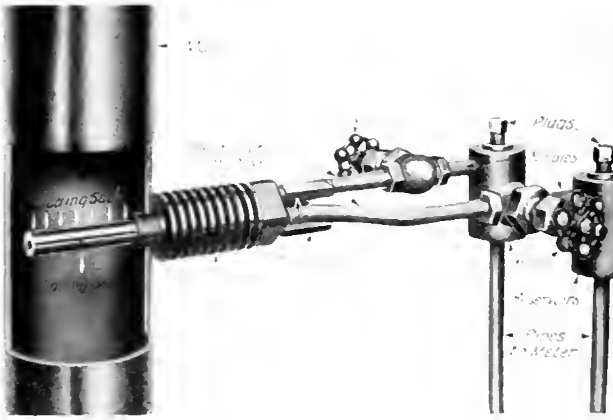


Fig. 10. Nozzle Plug and Connections Used in Installing a Flow Meter in the Larger Sizes of Piping

The mechanism of the meter is illustrated in Fig. 12. The few parts are shown so clearly as to not need detailed description. In action the flow causes a difference in pressure in the connection for the two meter pipes, resulting in what is virtually a drop in pressure across

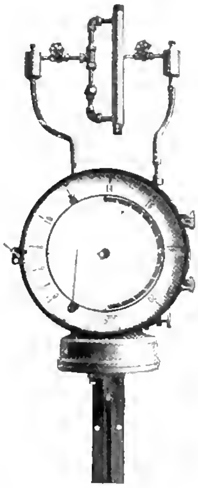


Fig. 11. The Orifice Tube Type of Connection which is Used When Tapping a Small Pipe for a Flow Meter

the meter, the drop varying in intensity according to the rate of flow. This differential pressure elevates the mercury and the float in the float tube inside the meter. The float has a vertical rack extension which meshes with a pinion fastened upon the shaft of the interior half of a permanent magnet clutch.

The exterior or outside half of the clutch is mounted on the outside of the meter in the dial case; and the outer half of the clutch is geared through pinion and quadrant to the indicator needle and recording pen. By use of the permanent magnet clutch, the motion is transmitted to the outside of the meter without the use of a through shaft, which would have to be packed. Both the interior and exterior shafts are mounted on end pivots to reduce friction to a minimum. The parts of the internal mechanism are made of special steel containing an alloy for preventing corrosion.

The only adjustment of the meter to be made is the zero setting. This is done, after the meter is primed with mercury, either by turning the interior magnet on its shaft or moving the dial and pen arm so that the needle and pen read zero.

The float mechanism has sufficient range to provide for the highest accuracy. In this matter of accuracy, however, the whole result does not lie entirely with the meter itself, for to secure highly accurate results involves taking all of the conditions into careful consideration. This is a matter, however, with which it is easy to comply. To know that the meter reading is an accurate translation of the main flow, the exact diameter of the stream must be used. This is obtained by measuring the exact internal circular diameter of the main pipe at the point where the meter plug is inserted. To insure that the stream is of standard form, so that the part which is shunted for the meter represents a true sample, the main pipe should contain no obstruction near the nozzle plug on the up stream side which would interrupt a uniform flow. With these conditions perfect, standard results will be obtained with the meter. The degree of error for the whole apparatus is then dependent only upon the velocity of flow, and the precision with which the meter is read. The

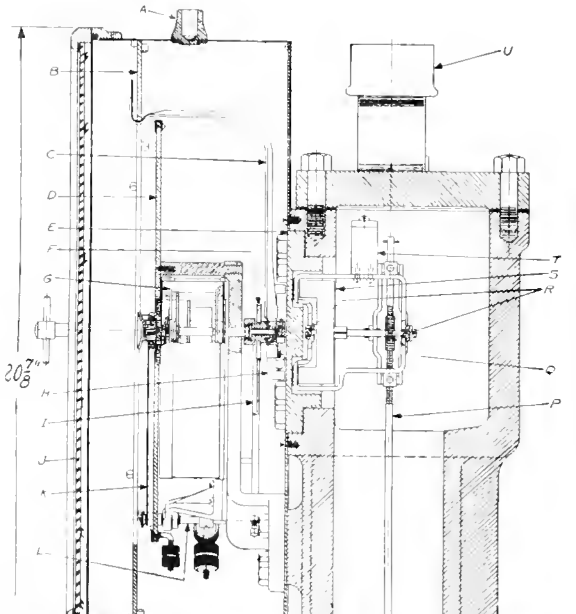


Fig. 12. A Cross-Sectional View of a Flow Meter Showing Its Internal Mechanism

lower the flow velocity, the less will be the range of movement of the meter parts. This not only makes probable a multiplication of the slight residual error of the whole metering apparatus, but also serves to increase the slight error of reading.

In many pipe installations, it is found that the velocity of flow is quite low. Velocities

Fig. 13. Reducer to Increase the Velocity in a Pipe Having a Low Rate of Flow

ranging as low as 3 to 6 feet per second for water and 10 to 30 feet per second for steam appear to be the rule rather than the exception. Velocities three to five times as high are found in the more modern plants. With the lower velocities, the error of the equipment may range around 5 per cent, whereas with the higher and entirely practical rates of flow, the error would range around 1 percent.

For the purpose of easily bringing low-flow piping up to the high accuracy standard, a simple form of pipe reducer is introduced as a part of the meter equipment for such installations.

Such a reducer is illustrated in Fig. 13. It can be inserted at almost any flanged joint in the pipe to be metered, in the manner shown in Fig. 14. The reducer serves to increase the velocity of flow at the meter plug, which is inserted in the reducer as shown. No appreciable drop in pressure is produced by the insertion of the pipe reducer, because the velocity of flow through the reducer is not raised above a value considered good operating practice, even in a pipe line.

Table 1 is part of a compilation arranged to cover all diameters of orifice tubes, reducers, and pipes ranging from 1¼ in. to 60 in. for steam, air, and water service.

Fig. 14. Phantom View of the Installation of a Reducer, as Shown in Fig. 13, in a Low-Rate-of-Flow Piping System

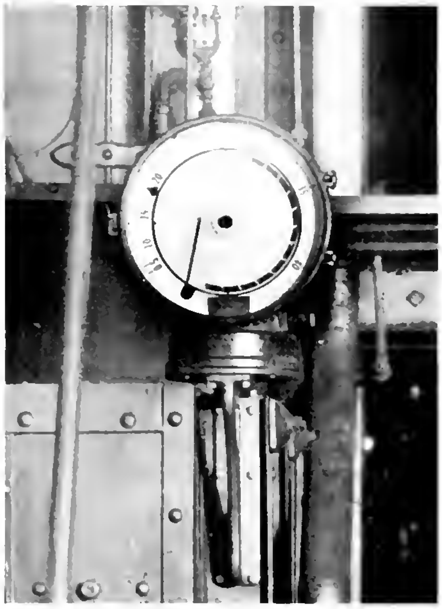


Fig. 15. The Steam Flow Meter as Mounted on the Front of Each Boiler of a Battery

The application of the meter in steam service is particularly valuable. Steam is a relatively high priced fluid, and is subject to a rapid decrease in value through radiation of heat.

The division of operating cost of a steam plant is illustrated graphically in Fig. 16. The diagram shows that two-thirds of the total expense is for fuel. No stronger argument is needed to illustrate the necessity for the steam flow meter. It is the only instrument that will show in figures just what this item of expense is chargeable to, how much of it to losses in generating and distributing, and how much to consumption by actual work done.

Flow meters are finding one of their most extensive fields of application in boiler room practice. Probably no part of the average plant consumes more money, receives more superficial attention and less real thought than the boiler room. With a meter attached to the steam outlet of each boiler, the firemen can see the degree of load under which the boilers are operating, and can adjust each boiler to carry its share of the load. When the boilers are thus balanced the battery operates at a higher efficiency than when the boilers are steaming unequally.

The meters are mounted on the boiler fronts where their indicators can be seen by the firemen. A view of one of the meters, of such an installation, is shown in Fig. 15. By comparing the several record charts, which have been made simultaneously on the various boilers, the degree of accuracy with which the firemen have maintained adjustment of the battery can be determined.

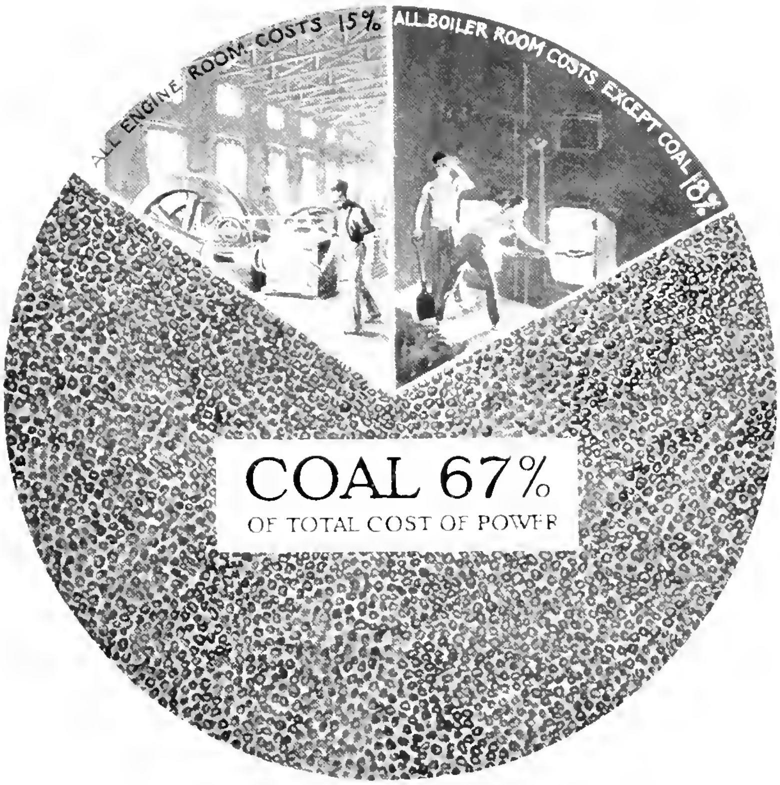


Fig. 16. Diagram Showing the Proportionate Division of the Operating Cost of a Steam Plant

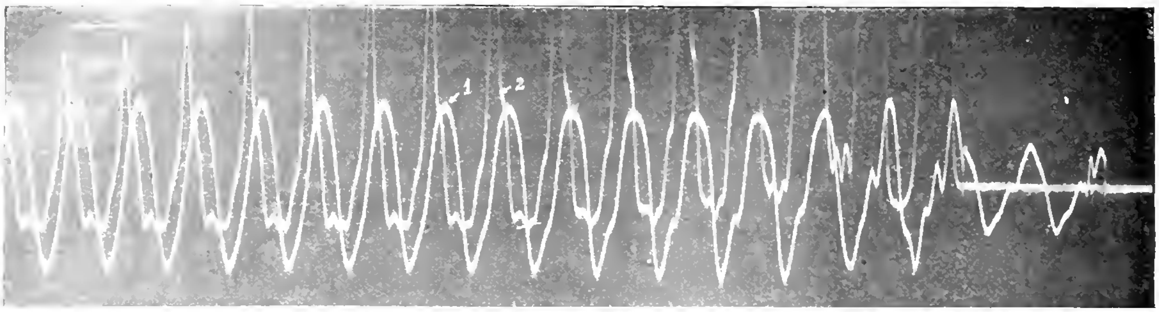


Fig. 1 Switching Transformer on End of Line by High-Tension Switch. Waves of Low-Tension Voltage and High-Tension Current

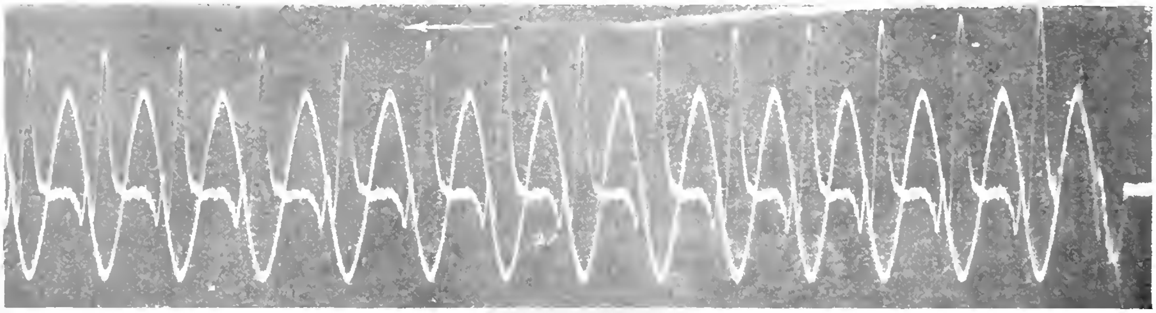


Fig. 2. Switching Transformer and Line onto Generator by Low-Tension Switch. Waves of High-Tension Voltage and Low-Tension Current

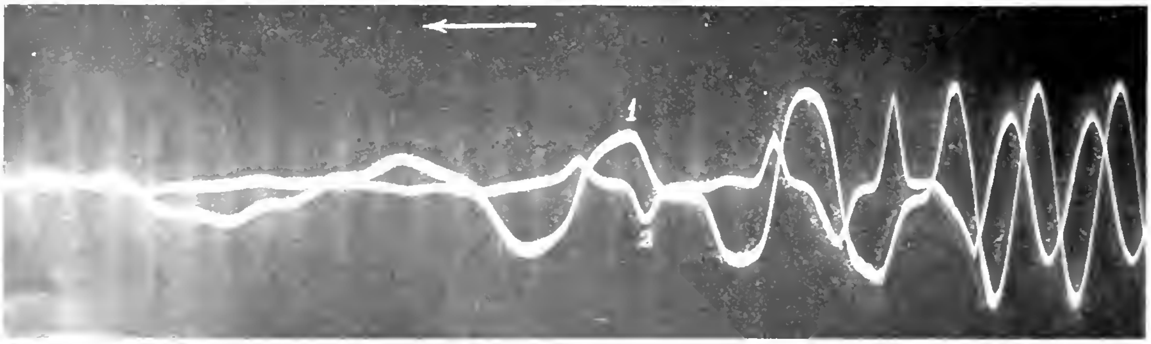


Fig. 3. Switching Transformer and Line off Generator by Low-Tension Switch. Waves of Low Tension Voltage and High-Tension Current

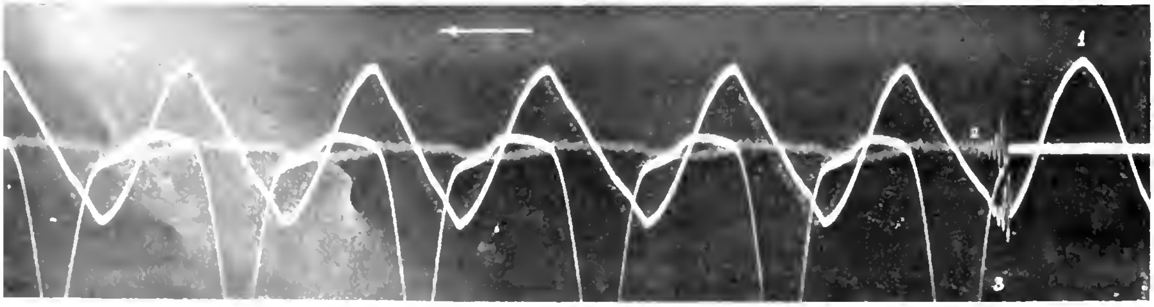


Fig. 4. Switching Transformer onto Generator by Low-Tension Switch. 1 Wave of Low Tension Voltage, 2 Wave of Capacity Current in Middle of High Tension Winding, 3 Wave of Exciting Current

SWITCHING OPERATIONS ON LOW AND HIGH-TENSION SYSTEMS, WITH SPECIAL REFERENCE TO THE SAFEST METHODS

By W. W. Lewis

Transformer Engineering Department, General Electric Company

This article summarizes the results of many investigations of the phenomena occurring when high or low-voltage switching is performed with various interconnections of generator, transformer, and line. Wiring diagrams accompanied profusely with oscillographic records cover each of the general classes of switching that occur in practice, and enable the fundamental principles thus established to be applied to the more complicated cases of switching. The conclusion of the article furnishes valuable detailed recommendations, which are advanced from the conclusions of these and other investigations, as to the safest methods to be employed in switching.—Editor.

Much consideration has been given in the past few years to the subject of switching on high-tension lines. The phenomena involved have been discussed at various times by Dr. Steinmetz, P. H. Thomas and others, and perhaps most recently in a paper by G. Faccioli, on "Electric Line Oscillations."* Partly as a result of the conclusions of that paper, the tendency has been toward the simplification of switching arrangements, the elimination of high-tension switches, and the operation of transformer banks at both ends of a line as part of the line.

The most approved circuit connections from the standpoint of switching, safety, and continuity of service have been fully discussed in recent articles in the General Electric Review,† as have also the approved methods of switching in certain cases. The present article will therefore merely summarize briefly what takes place in a few general cases of switching, in order to give an idea of the reasons for the crystallization of opinion on certain approved methods.

Oil-break switches are almost universally used for switching high-voltage lines under tension, although air-break switches have been used in emergency cases. The use of the latter has been considered bad from a theoretical standpoint, and in practice the large amount of clearance required for the spectacular and dangerous-looking arcs necessitates an outdoor construction, which has its disadvantages.

However, the demand for an inexpensive switch to connect small isolated substations to and disconnect them from the main transmission lines may lead to the more extended use of the air-break switch, and to the gathering of experimental data, which is yet too meagre to warrant definite conclusions as to the effect of operating this type of switch.

There are two general classes of switching, viz., low-tension and high-tension. The electrical disturbances during switching operations differ on account of the difference in voltage and on account of the difference in energy involved.

Low-Voltage Switching

On closing a switch, arcs may strike between the points of the switch, the severity and frequency of which depend upon the difference of potential between the points, and the speed of the switch. In low-voltage switching, the potential across the switch is comparatively small and the arcing negligible. The resulting oscillation depends upon what point of the e.m.f. wave the switch closes, and the constants of the circuit.

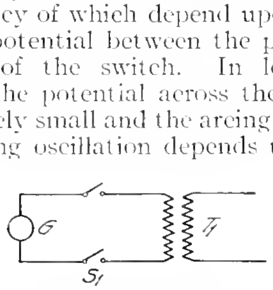


Fig. 5. Diagram of Connections showing a Dead Transformer about to be Switched onto a Live Generator

(a) Thus, in Fig. 5, a step-up transformer T_1 is switched onto a live generator G by the switch S_1. A rush of magnetizing current results. If the switch closes when the e.m.f. wave is at its maximum, the rush of magnetizing current is a minimum, that is, the current at the instant of maximum e.m.f. would normally be zero (assuming the transformer to be a pure inductance). On the other hand, if the switch happens to close at the zero point of the e.m.f. wave, the rush of magnetizing current is a maximum. This is true because at that instant the magnetizing current would normally be a maximum.

* "Electric Line Oscillations," by G. Faccioli, Transactions A.I.E.E., Vol. XXX, 1911.

† "Circuit Connections in High-Voltage Systems," by R. E. Argersinger, General Electric Review, June, 1913.

Hence, in attempting to assume its normal value instantaneously, it overshoots the mark and oscillates. Most cases of switching lie between these two extremes. (See Records 4 and 9.)

However, as the magnetizing current is normally only about 5 per cent of the full-load current of the transformer, a rush of 20 times normal magnetizing current may occur without exceeding full-load current. Hence there is very little danger in this class of switching.

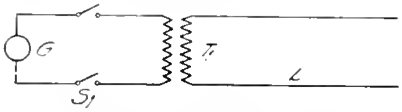


Fig. 6. Diagram of Connections as illustrated in Fig. 1 except that here the Transmission Line is connected to the Transformer

(b) Fig. 6 differs from Fig. 5 in that the line L has been connected to the transformer T_1. The switching phenomena are modified by the fact that the line, acting as a condenser, shunts the transformer. The current demanded by this condenser leads the e.m.f., and, as it may be much larger than the transformer exciting current, the latter will appear only as a superposition on the former. However, the oscillation resulting from this class of switching is also mild. (See Records 2 and 10.)

In charging the systems of Figs. 5 and 6, energy is stored—electromagnetically in Fig. 5, electromagnetically and electrostatically in Fig. 6. When the system of Fig. 5 is switched off, most of the stored energy is dissipated in the arc of the switch, a small part of it being lost in an exchange between the inductance and capacity of the transformer itself. In the system of Fig. 6 part of the energy is dissipated in the switch, and part is lost in an exchange between transformer and line after the switch is open. Records 3 and 11 illustrate these cases. The mildness of the oscillations is apparent.

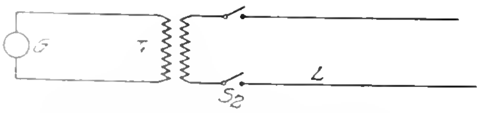


Fig. 7. Diagram showing the Switches placed between the Line and Transformer, which latter is connected to the Generator

High Voltage Switching

Suppose now that we have the system of Fig. 7, that is, a generator G closed on a step-up transformer T_1, which is separated from the line by a high-voltage switch S_2. Assume also that the transformer is excited. Now close the switch. The line capacity is shunted across the transformer, and charged through the line resistance and inductance. The severity of the oscillation again depends upon the point of the e.m.f. wave at which the switch is closed. If the wave is at its maximum, full voltage is applied to the condenser and the maximum disturbance results. Owing to the high voltage, long arcs may strike across the blades as they approach each other, thus complicating the disturbance. (See Record 12.)

When the high-tension switches are opened, the energy may be dissipated by means of one oscillation of short duration. (See Record 13.) On the other hand, the generating system continues its attempt to feed energy to the line, through the arcs in the switch. These may die out as the voltage wave passes through zero, and be re-established as the voltage builds up,—oscillations occurring and recurring with a severity that increases as the blades of the switch get farther apart and the arcs consequently longer. This action continues until limited by dissipation of the power or breakdown of the apparatus. Record 14 illustrates this case.

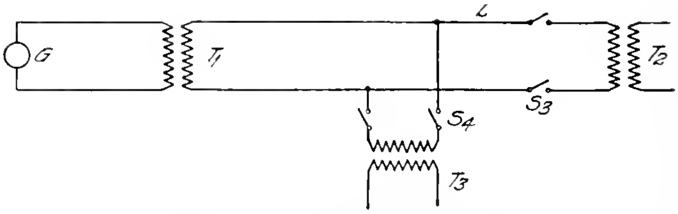


Fig. 8. Diagram of Generator, Step-Up Transformer, Line, and Two Step-Down Transformers Separated from the Line by High-Tension Switches

If a transformer is to be switched on at the end of or along the line (see Fig. 8), high-tension switches must necessarily be used; and if the voltage is normal at the power house, it may be 10 or 20 per cent above normal at the end of the line. Full-voltage or over-voltage suddenly applied to the transformer on the high side causes a rush of magnetizing current and an exchange of stored energy between the line and transformer, with results that are apt to be quite severe. Switching off is accompanied by the usual oscillations produced by arcing in the switch. Records 1, 15, 16, and 17 illustrate this class of switching.

High Frequencies Produced by Switching

A study of many oscillograph records made during various switching operations does not disclose any dangerous over-tensions due to switching—probably 60 or 70 per cent over-voltage is the maximum. The records do

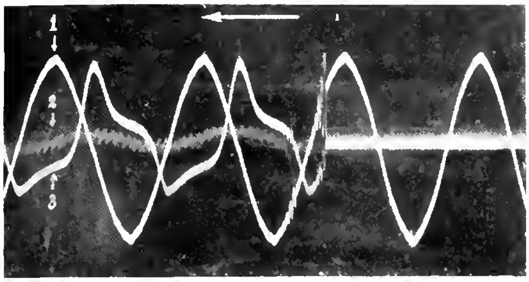


Fig. 9. Switching Transformer onto Generator by Low-Tension Switch. (1) Wave of Low Tension Voltage, (2) Wave of Capacity Current at Middle of High-Tension Winding, (3) Wave of Exciting Current

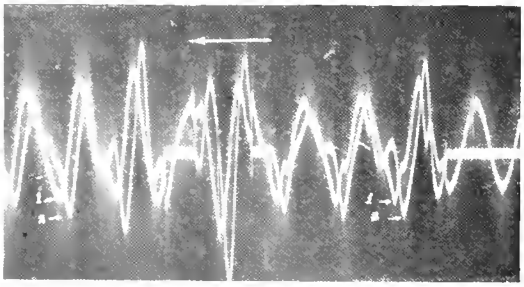


Fig. 12. Switching Line onto Transformer by High-Tension Switch. Waves of Generator Voltage and High-Tension Current

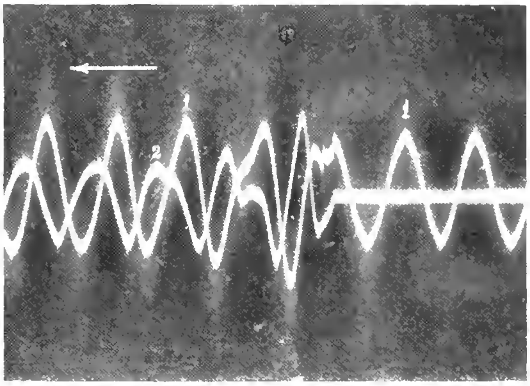


Fig. 10. Switching Transformer and Line onto Generator by Low-Tension Switch. Waves of Generator Voltage and High-Tension Current

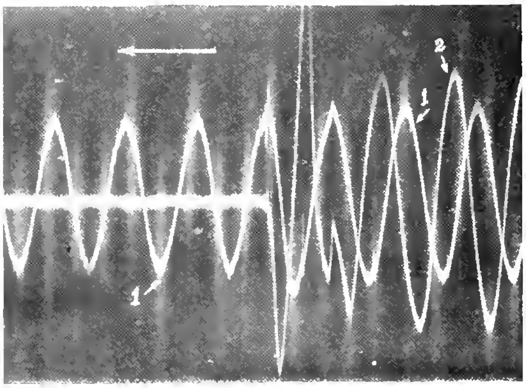


Fig. 13. Switching Line off Transformer by High-Tension Switch. Waves of Generator Voltage and High-Tension Current

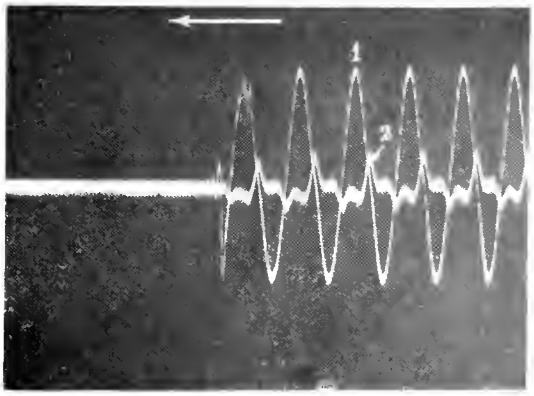


Fig. 11. Switching Transformer and Line off Generator by Low-Tension Switch. Waves of Low-Tension Voltage and Exciting Current

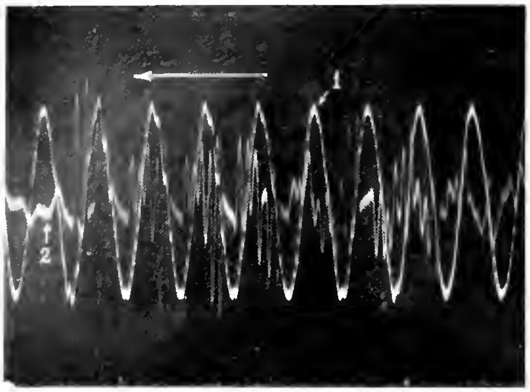


Fig. 14. Switching Line off Transformer by High-Tension Switch. Waves of Low-Tension Voltage and Current

show, however, that the disturbances produced are of high frequency, and in this source lies possible danger. At the high-tension terminals of the transformer are produced local impulses of very steep wave front. This has been determined experimentally by placing in the line a small choke coil or air reactance, shunted by a needle spark-gap. The sparking distances were measured for the different switching operations, as shown in Table I. Thus it will be seen that the most severe operations, from this standpoint, are switching off the line by high-tension switches (see Fig. 7 and Record 13) and switching on the transformer at the end of line by high-tension switches (see Fig. 8 and Record 15).

The sparking distances are a measure of the steepness of the wave front. An equivalent effect would be produced by a very high frequency wave impressed on the choke coil. The frequency of such an equivalent wave may be calculated from the constants of the line, the inductance of the choke coil, and the change in voltage produced across the transformer by the switching operation.* Thus in the case of Record 13, the equivalent frequency is about 735,000 cycles per second and in the case of Record 15, the equivalent frequency is about 880,000 cycles per second.

The steep wave fronts are local, as may be inferred by the sparking at the end of the line in connection with Records 13 and 15. The danger to the transformer from these disturbances lies in the fact that they may pile up high voltages on the end turns, and thereby endanger the insulation of the transformer; or they may cause local oscillations within the transformer. Each switching operation may cause a slight injury to which successive operations add, until breakdown finally results. While it is not possible to trace any large number of failures directly to this cause, still it is better to avoid any danger of such failures.

*"Electric Discharges, Waves and Impulses," by Dr. C. P. Steinmetz.

Safest Method of Switching

The above examples include in general all the various classes of no-load switching. Specific cases are combinations or complications of these simple examples. It is only possible to cover the large number of probable combinations by a few general rules. Nothing will be said here about switching under load, which differs from no-load switching in the amount of current and energy involved, etc.

TABLE I

SPARKING DISTANCES MEASURED IN CONNECTION WITH VARIOUS SWITCHING OPERATIONS

Record	Fig. No.	Low Tension or High Tension	On or Off	Sparking Distance	Location of Gap
3	2	L.T.	On	Less than 1/8 in.	Switching-point
6	2	L.T.	Off	Less than 1/8 in.	Switching-point
7	3	H.T.	On	1/4 in.	Switching-point
8	3	H.T.	Off	1 3/8 in.	Switching-point
				Less than 1/8 in.	End of line
9	3	H.T.	Off	3/4 in.	Switching-point
10	4	H.T.	On	1 1/4 in.	Switching-point
				Less than 1/8 in.	Generating station
12	4	H.T.	Off	1/2 in.	Switching-point
				Less than 1/8 in.	Generating station

In a simple system, such as that of Fig. 8, consisting of one or more generators and transformers and a single line, it is often possible to close all switches while dead and build up the voltage on the whole system by means of the generator field, and likewise to de-energize the system by reducing the generator voltage. This is obviously an ideal arrangement, as no disturbances whatever are caused to the apparatus.

Frequently it is not possible to do this, as for instance when a line is to be energized from live, low-voltage busses. If the line has its own transformer to be connected to the busses, then low-tension switching may be done with a small amount of disturbance. However, if a line is to be switched onto live, high-voltage busses, there is nothing to do but

ERRATA

Insert this note in your file copy of the October, 1913, REVIEW.

Article on "Switching Operations on Low and High-Tension Systems, with Special Reference to the Safest Methods," by W. W. Lewis, page 734.

The first two columns of Table 1 should read:

Record	Diagram
Fig. 10	Fig. 6
3	6
12	7
14	7
13	7
15	8
16	8

Also, wherever "Record 13" appears in the left-hand column, page 734, (three times) it should read "Record 14."

the low side. They may then be connected

ing stations, the two systems being of different potential, the transformer should be con-

.ca-

Steinmetz.

high-voltage busses, there is nothing

use high-tension switches. If other lines are already connected to the busses, their electrostatic capacity will assist in absorbing the displaced energy.

Likewise, if transformers are to be switched onto a live line along its course or at its end,

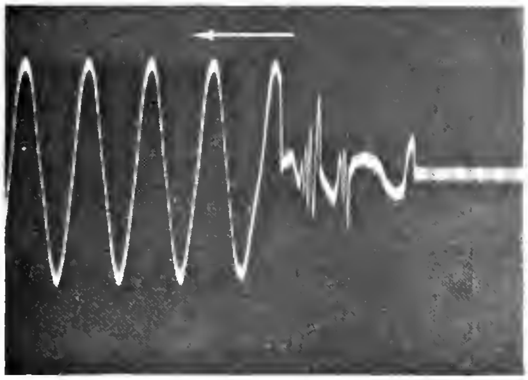


Fig. 15 Switching Transformer onto End of Line by High-Tension Switch. Wave of Low-Tension Voltage

high-tension switches must be used. Sometimes it is possible, however, to switch on the transformer when the line is dead. This is desirable from the standpoint of eliminating the danger to the transformer, and also because apparatus possessing considerable inductance

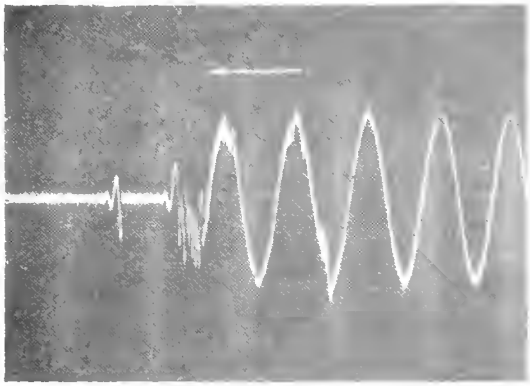


Fig. 16. Switching Transformer off End of Line by High-Tension Switch. Wave of Low-Tension Voltage

along the line reduces the rise in potential that occurs when the open line is charged.

When additional transformers are to be paralleled in a station with transformers already alive, they should first be excited on the low side. They may then be connected on the high side without disturbance. When disconnecting, the high-voltage switches should first be opened and then the low-voltage switches.

Two systems, *A* and *B*, are sometimes synchronized at the generating station of

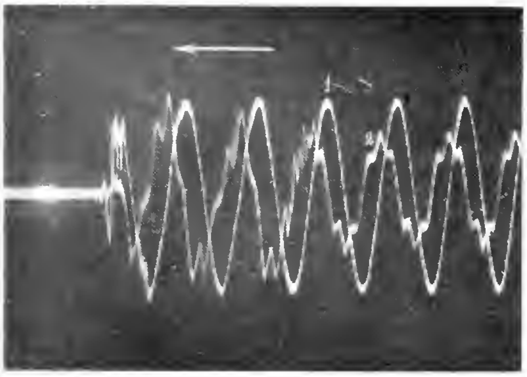


Fig. 17. Switching off Transformer at End of Line by High-Tension Switch. Waves of Low-Tension Voltage and High-Tension Current

system *A*. The preferable way to do this is to connect the high-side of the transformer at *A* onto the dead line, then energize the line and transformer from *B*; and lastly, synchronize on the low side at *A*. Even by this method considerable disturbance may be

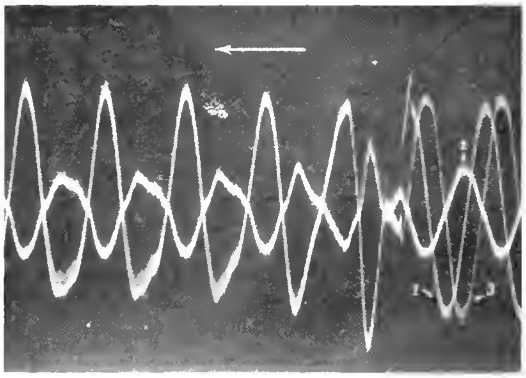


Fig. 18. Synchronizing Systems *A* and *B* at Generating Station *A*. Transformer Connected to End of Line Excited from *B*, Synchronizing on Low Side of Transformer at *A* (1) Generator Voltage, (2) Induced Potential on Parallel Line Conductor to Ground, (3) Voltage on Low-Tension of Transformer

caused if the synchronizing is poorly done, as illustrated by Record 18.

If synchronizing is to be done at a substation intermediate between the two generating stations, the two systems being of different potential, the transformer should be connected to the line on the high side before the line is energized, after which both lines should be energized and the synchronizing done on the low side; or, if both lines have been necessarily previously energized, the transformers should be excited on the low side and then synchronized on the high side, if this is not prohibited by the location of the synchronizing apparatus. The simple and inexpensive static synchronizer assists greatly in this class of work.

To sum up, the least possible switching should be done under tension. When switching under tension is necessary, it should preferably be done on the low side, both when starting up and shutting down.

A number of auxiliary devices for switches have been suggested, and in some cases tried in practice; for instance, a mechanism for inserting a series resistance when the switch begins to close and short-circuiting the resistance when the switch is fully closed; shunting the line with resistance before closing the switch and automatically disconnecting the resistance when the switch is closed, etc. These devices are intended to limit current rushes and moderate other surges. A switch with a number of poles in series has also been suggested. This would be especially valuable in disconnecting with high-tension switches, as such a large gap would be introduced when the switch is opened that there would be no tendency for arcs to form between the blades, and this source of disturbance would be eliminated.

THE OPERATION OF LARGE TRANSFORMERS OUT-OF-DOORS

By F. C. Green

Transformer Engineering Department, General Electric Company

In station design at the present day the tendency is to install a large part of the high tension apparatus, i.e. lightning arresters, transformers, disconnecting switches, and sometimes remote-control oil switches, outside of the station building. This article covers the outdoor use of transformers. It describes the general construction of suitable water-cooled, self-cooled, and air-blast transformers, and presents the special features which must be embodied to prevent moisture entering (or condensing if it is already within the case), and those whose function it is to maintain the temperature of the transformer, whether in operation or idle, above the freezing point of the oil or cooling water. It enumerates and defines the best location of the various pieces of auxiliary apparatus, such as the low-voltage transformer for energizing the heating coils, the filter press, and the drying-out equipment, which are necessary for the successful operation of transformers out-of-doors.—Editor.

Several years of operation of large transformers out-of-doors have demonstrated that there are no obstacles in outdoor operation that can not be easily overcome. The mistake should not be made, however, of neglecting various detail features, any one of which, while not difficult to be taken care of, may lead, if neglected, to serious inconvenience and possibly to unexpected losses.

Temperature is the one variable factor that must be considered in adapting transformers to outdoor service in the various climates. Moisture and the direct heat rays of the sun are universally encountered, but their undesirable effects may be prevented without difficulty and at small cost. The extent to which it is necessary to consider cold, heat and moisture depends upon the type of transformer used.

Moisture must be excluded from all types. Water-cooled transformers must be guarded against the freezing of the water. In the case of self-cooled transformers, there is no question of the freezing of water, but it is preferable to prevent the freezing of the oil, although this is not absolutely necessary. Transformers of the air-blast type are not affected by freezing, nor by direct radiation of heat from the sun, and therefore it is necessary only that they shall be rain-tight, and that provision be made for preventing the absorption of moisture when they are idle.

Construction of the Transformer

The outdoor transformer differs from the indoor only in those details involved in making the casing and leads water-proof. For the oil-insulated transformer only the cover and leads differ from the cover and leads of the indoor transformer, the tank and base remaining the same. A gasket is placed between the cover and the tank, which are firmly bolted together. All surfaces are made to shed water, so that at no point water is allowed to stand on any gasket used in the cover. All parts of the lead are similarly made to shed water, and to prevent its standing on gaskets in the lead.

There is the usual manhole, with its cover, for obtaining access to the terminal boards underneath the oil. In the smaller sizes of transformers, there is either a handhole, or the high-tension lead is so designed that it may be lifted out of the cover without disconnecting from the transformer winding, i. e., the conductor passes out through a tube in the center of the lead. This construction facilitates the use of the lead-hole as a hand-hole for gaining access in changing tap connections. Where cooling-coil terminals pass through the cover or tank, water-proof stuffing-boxes are used.

Self-cooled transformers may be painted a light color for reflecting the heat from the sun. The water-cooled transformer needs no protection from this heat for there is, in the top of the transformer, a weather-protected passage for the free exchange of air. The passage consists merely of piping attached to the cover terminating in a small chamber which is thoroughly screened but which does not offer any impediment to the free exchange of air. Inside of the transformer and suspended from the cover is a small electric heating coil which is used to prevent condensation of moisture. The capacity of this coil ranges from 100 watts to 400 watts, depending upon the size of the transformer. In larger sizes, two or more units making up the desired capacity may be used for giving a distributed heat. Terminals from the heating coils are brought to the outside through small piping.

The thermometer attached to the transformer cover should have a scale indicating as low as −15 deg. C., this being approximately the temperature at which oil begins to freeze. Air-blast transformers need only to have the casing rain-proof, as there is nothing about them that is affected by freezing temperatures.

Features Involved in Station Layout

While there may be a wide range in the elaborateness of the station layout, the essential features are approximately the same for any given latitude, and it is necessary that they be provided, regardless of the capacity of the station or of the crudeness of the layout.

In large outdoor installations, it is economical to have substantial facilities for taking care of the various features involved. Preferably, the transformer should be placed upon a concrete foundation with rails for the receiving truck attached to the transformer. Unless other provisions are made for supplying heat to idle transformers, a space should be left underneath each transformer of ample dimensions for the accommodation of electric heaters. A track leads from the transformer to the repair house, where there should be facilities and room for the dismantling and the building up of a transformer. For moving transformers on the track, suitable stationary motor-driven equipments, with the necessary cable, may be used. The arrangement should be such as to allow the transformer to be drawn back and forth between its location in the installation and the repair house.

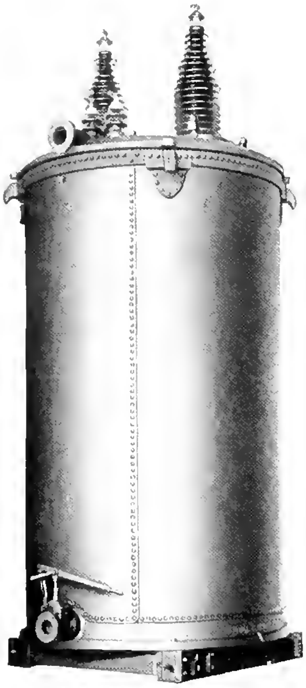


Fig. 1. A 3333 Kw., 110000 11000-Volt Water-Cooled Transformer For Outdoor Use

Tanks for storing oil, and the necessary piping arrangement with pump, should be provided. In cold climates these tanks should be thoroughly jacketed, and some heat-insulating space left under them for electric heating coils, which must be employed in cold weather to prevent freezing of the oil.

In order to prevent freezing of the water where it is used for cooling, the piping should be so laid that it is thoroughly protected from the coldest weather experienced in the locality. Where the water piping is exposed to the atmosphere it should be heavily lagged. Permanent equipment consisting of a high-pressure air-pump and air-heater should be installed for the purpose of blowing out the water, and at the same time drying the cooling coils of transformers that are under repair.

Wiring and switches should be permanently installed for supplying current to the heating coils in the top of transformers, and to such other heaters as may be used for preventing freezing.

THE OPERATION OF TRANSFORMERS OUT-OF-DOOR

Water-Cooled Transformers

Under normal load conditions or under only full-voltage excitation without load, sufficient heat is generated in the water-cooled transformer to prevent freezing of the water or of the oil in the coldest climates within the temperate zones. If at some point in the water-piping system there is danger of freezing of the water, it may be allowed to circulate through the cooling coil at a sufficient rate of flow to prevent freezing at the exposed points. The circulation of the water not only keeps the water itself from freezing, but tends to prevent the lowering of the temperature of the oil below the freezing point of water. Thus circulation also tends to prevent the freezing of the oil, it being understood that oil begins to freeze at about −15 deg. C.

In putting into practice the plan outlined above, there may occur the question of condensation of moisture in the top of the transformer. In the first place, however, extremely cold weather is assumed, as for example, when the outside air temperature is in the neighborhood of −40 deg. C. Thus not only is the oil at −15 deg. C. considerably warmer than the air, but also the heating-coil provided in the top of the transformer further increases the temperature of the air inside above the temperature of the air outside, thereby positively preventing condensation.

Except in the coldest weather, it is probable that the transformer while in service will radiate sufficient heat to its cover to melt snow and sleet, and thereby prevent their

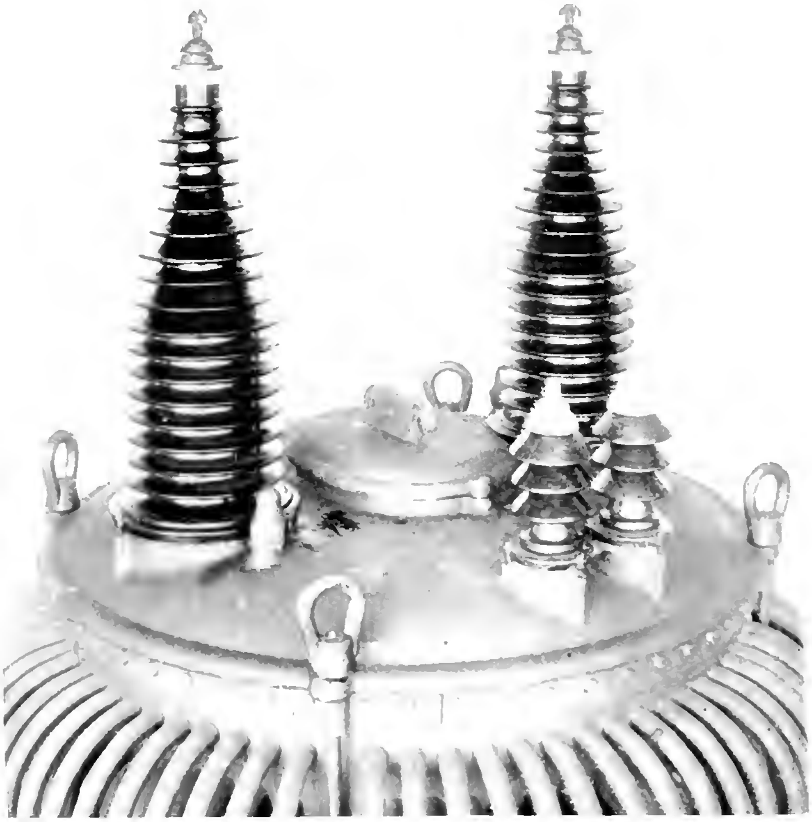


Fig. 2. A Top View of a 1000 Kw. 55000 110000-11000 22000-Volt Self-Cooled Transformer, Showing Water-proof Leads, Manhole, and Cover

accumulation; but if they should accumulate, compressed air applied by means of a hose, or a wire brush with a long handle, may be used for removing the accumulation.

The simplest and most convenient arrangement for maintaining the desired temperature in an idle transformer when under very cold weather conditions is to excite it at normal voltage on the low tension side. A second method of maintaining the temperature is to short-circuit one winding and impress sufficient voltage on the other to give the needed current. A third is the use of grid heaters underneath the transformer. The first method is the simplest, because only a switch with the necessary wiring is required for impressing the normal low-tension voltage upon the transformer. The second method requires the use of extra transformers for obtaining the desired voltage. The third requires not only extra transformer capacity for obtaining the current, but also the grid heaters and the expense involved in heat-insulating the space underneath the transformer.

When it is necessary to repair a water-cooled transformer, the water should be blown out of the cooling coil and hot air forced through to thoroughly dry it out. This necessity is emphasized for the reason that a very small amount of water in freezing may cause a cooling coil to burst. After the water is blown out and the coil is thoroughly dry, caps should be screwed on the ends to prevent entrance of moisture or rain.

During the period of idleness of a transformer in warm weather, only the heating coils in the top are necessary to be energized in order to prevent the condensation of moisture. It is not necessary to heat the oil in the idle transformer except when there is danger of freezing either the water or the oil. There is no danger from condensation of moisture so long as the air in the top of the transformer is a few degrees warmer than the air outside.

Self-Cooled Transformers

In self-cooled transformers, the prevention of the condensation of moisture and of the freezing of the oil is accomplished in the same manner as in the water-cooled. It is not certain that the injury resulting from the freezing of the oil is appreciable. It is certain that its puncture strength is not sufficiently lowered in the various stages of freezing to make it undesirable to impress the full voltage on the transformer with its oil frozen. Where the oil is frozen, it is desirable to impress voltage without load for a sufficient period to allow the oil to liquify. In putting the transformer under full-load with the oil frozen, there is the danger that the heat from the coils will not be carried away fast enough to prevent damaging the coils from excessive temperature.

The features enumerated above are elaborated upon for the reason that the self-cooled

Fig. 3. A Small Self-Cooled Single-Phase Transformer For Outdoor Use. Rating 60 Cycles, 100 Kw. 60000 2500 Volts

transformer has a temperature rise of only approximately 20 deg. C. under normal voltage without load, while the water-cooled transformer normally excited and without water has a temperature rise of 50 to 60 deg. C. Under any of the methods suggested for preventing freezing of oil, therefore, the oil of a self-cooled transformer would certainly become colder than that of a water-cooled transformer. For use in oil-filled leads there is available a grade of oil that does not freeze at −40 deg. C.; and, where very low temperatures occur, it is advisable to use this oil, although there is apparently no risk in the freezing of the ordinary transformer oil used in high-tension leads.

Light-colored paint when used on the tank is sufficient provision against absorption of direct heat from the sun, and no screen is necessary. Large self-cooled transformers in outdoor sunshine, even if painted black, will run cooler because of the abundance of fresh air than will the same transformers indoors, unless the building is ventilated by means of fans.

Air-Blast Transformers

While little thought has been given to the installation of air-blast transformers out-of-doors, they are nevertheless better adapted in their nature to outdoor operation than either the self-cooled or water-cooled type. There is no question of freezing of water or oil, nor of absorption of heat radiated from the sun.

As long as they are in service, there is no danger whatever from the absorption of moisture. Only when they are idle is it necessary to give any thought to the excluding of moisture; and this can be done in a very simple manner either by energizing the transformer in some way or by placing small heaters underneath in the air pit.

INSTALLATION OF TRANSFORMERS OUT-OF-DOORS

The hot-air method used for drying can be applied with the transformer out-of-doors, if the blower intake is protected from rain. The transformer may either be in or it may be out of its tank and protected with temporary covering. When it is in the tank, the passage of the air from the cover will have to be protected from the entrance of rain. There is a prevailing notion that air drawn out of rain should not be used for drying; but this idea has no foundation either in theory or practice, provided the air is heated to 80 to 90 deg. C.

The Filter Press

The filter press for drying the oil should preferably be installed in the repair house. It must, at least, be thoroughly protected from rain, especially when the filter paper is being placed in position.

Storage of Transformers

Occasionally it is desirable to store transformers for a considerable period before placing them in service. Before they are stored they should be thoroughly dried and filled with oil. The electric heaters in the top should then be kept continuously energized in order to prevent condensation of moisture. Where no energy is available for giving heat in the top of the transformers, breathers should be attached and allowed to perform their function. Breathers without the heaters will lessen but not prevent condensation.

SOME OUTDOOR TRANSFORMERS BUILT OR UNDER CONSTRUCTION

Location of Installation	Number of Transformers	Type	Kv-a.	Voltage
New York	6	Self-cooled	1500	46700Y
New York	3	Self-cooled	2000	15600
California	6	Water-cooled	4165	60000Y
North Carolina	3	Water-cooled	1000	100000
North Carolina	3	Water-cooled	800	60000
North Carolina	3	Self-cooled	750	60000
South Carolina	3	Self-cooled	3000	101200
Massachusetts	3	Water-cooled	1500	24200
Massachusetts	1	Water-cooled, three-phase	3000	69000Y
Massachusetts	4	Self-cooled	1500	66000
Utah	3	Water-cooled	2000	46500
Utah	14	Water-cooled	4000	130000
Utah	3	Water-cooled	1000	45000
Utah	9	Self-cooled	150	45000
Alabama	7	Water-cooled	2100	110000
Pennsylvania	5	Water-cooled, three-phase, quarter-phase	2100	2300
Oregon	4	Water-cooled	1000	66000
Oregon	3	Water-cooled	1500	66000Y
Washington, D. C.	1	Water-cooled, three-phase	3600	13560
Washington, D. C.	1	Water-cooled, three-phase	1500	12400Y
Georgia	3	Self-cooled	500	110000
New York	2	Self-cooled	125	2200
Alabama	3	Self-cooled	1000	110000
Texas	3	Water-cooled	2000	62400

SOME NOTES ON SWITCHBOARD DESIGN

By Emil Bern

Switchboard Engineering Department, General Electric Company

The author has assumed in this article that all the instruments and apparatus to be placed on the switchboard have been selected, and therefore no attention need be given to them except insofar as they affect the design of the board. A short description suffices to cover the familiar vertical switchboard, since at the present day it has reached the point of thorough standardization. The major portion of the article is devoted to a review of the requirements which have caused the development of the bench type of board and to a description of the elementary bench-board, this being followed by a further description of the construction and layout of the several modifications that have been designed for special conditions, and a presentation of the advantages of each.—Editor.

The object of this article is to discuss briefly the structural design of a few types of switchboards for modern power plants of large capacity. In order to limit the scope of these notes to *structural* design it must be assumed that the electrical connections, the number of instruments, and the switching equipment have been settled, at least tentatively.

If certain types of switches have been selected for mounting directly on the switchboard, there is not much choice in the design of the board except in the arrangement of instruments and switches. The vertical board, usually built of slate or marble panels supported on a frame work of gas pipes or structural steel, was long ago standardized in units for various requirements to easily permit changes and extensions of the installation. On account of neatness and simplicity in construction, pipe frame work is nowadays almost universally used, except for panels with heavy equipment, where occasionally angle irons or even channel irons are required. When frequent extensions and changes are not contemplated, artistic taste sometimes calls for ornamental cornices and frames of various materials around the board; but these are as a rule not required for larger installations where utility must be considered primarily.

Fig. 1 shows standard switchboard frames with wooden sills, the method of bracing the board to wall, and the arrangement of bushings or slabs in the floor for bringing cables to the switchboard. Similar construction may be used for instrument and control leads where these enter the switchboard from below, but the usual and best practice is to run them through conduits laid in the floor, terminating as near the switchboard sill as convenient. Frequently the ends of the conduits are bent to point upwards and cut to extend just a short distance above the finished floor. This often necessitates a number of visible crossing, of the leads, where the conduits cannot be run to the desired point. To obtain a neater construction a pull-box with cover is usually provided in the floor along the back of the board, and the conduits arranged so as to terminate in the walls of the box. Provision is made for bringing the leads from this box to the desired point at the bottom of the board, the necessary splices and crossings being made in the box.

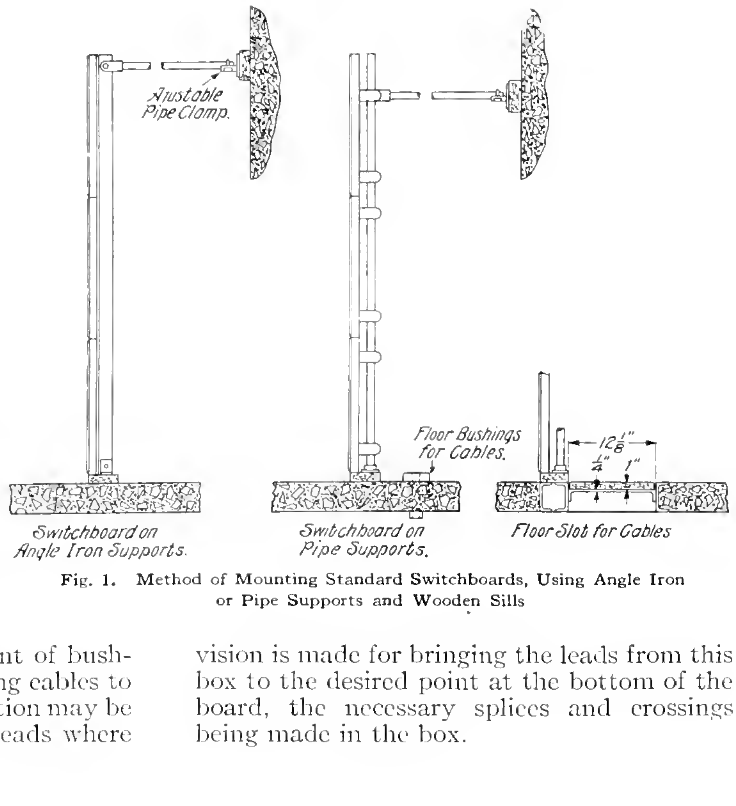


Fig. 1. Method of Mounting Standard Switchboards, Using Angle Iron or Pipe Supports and Wooden Sills

It is often found in a large and complex installation that, if all the instruments and apparatus were located on a vertical switchboard its dimensions would be too great for

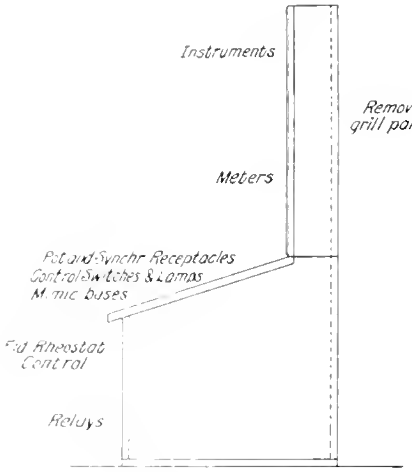


Fig. 2. A Simple Type of Combination Control Board and Instrument Board Showing the Locations Best Suited for the Various Pieces of Apparatus

convenient operation; and many appliances such as control switches, synchronizing and potential receptacles could not all be accommodated in a position most convenient for the operator. To overcome these difficulties, at least to some extent, the type of bench-board shown in Fig. 2 may be introduced. It will be seen that, for the same height of board, the useful surface has been increased by an amount almost equal to the top of the bench, the latter offering an excellent position for the control apparatus, bringing it within convenient reach and distinct view of the operator. Another advantage is also incidentally obtained by reason of the greater distance between the instruments and the operator, which enables him to observe a greater number of instruments from any point while manipulating the control apparatus. A further advantage may be taken of this condition by increasing the height of the instrument section, if desirable, in order to allow room for more instruments, which may be read without difficulty. While the bench-board offers many advantages for complicated instrument and control equipments, it must not be forgotten that the vertical switchboard is still the most feasible arrangement for many installations. Fig. 2 also shows the relative location of the different pieces of apparatus on this bench-board, from which it will be found that the connections should enter the board at the bottom of the sub-base, passing under the bench, and up back of the instrument section to the meters and instruments. The removable grill panels on the back serve to enclose the instrument resistances and wiring, and to provide access to them when necessary. To complete the enclosure, and for esthetic reasons, end panels of the same material as the board are usually provided.

A switchboard project often calls for testing links and switches for relays and instruments, and a multiplicity of meters which could not be accommodated on a board of the design shown in Fig. 2 without a more than desirable extension in length. The construction shown in Fig. 3, consisting of a combination of an independent bench and a vertical instrument board, offers certain advantages in space and design. The view of the instruments is even better than in the previous design, and the space between the instrument board and the bench permits the reading of meters and calibration of relays and instruments without disturbing the switchboard operator. This design also permits a better distribution of the numerous connections, in that the conduits for the instrument leads terminate under the instrument board and those for the control leads under the bench.

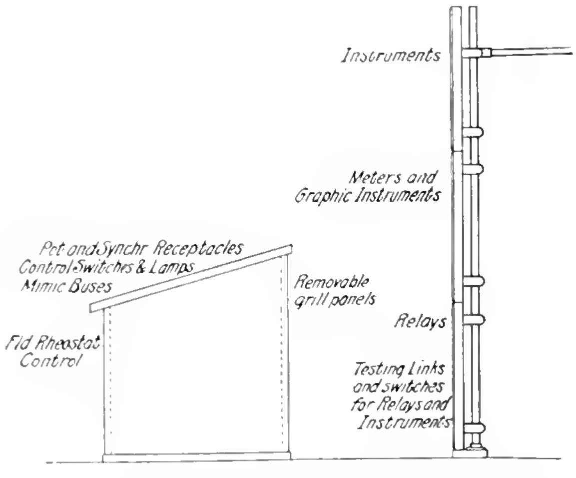


Fig. 3. Control Board with Independent Instrument Board. This arrangement offers more useful surface than does that of Fig. 2

Conduits are, of course, necessary in the floor for carrying the potential leads from the instrument board to the potential and synchronizing receptacles on the bench. Removable grill panels on the back side of the bench give access to the wiring, operating busses, control switches, and lamps. Sometimes the instrument board is also provided with end panels and grill work; and when installed near the wall the grill work usually encloses the space between the board and the wall, and is provided with a door at each end of the board.

In case of further complicated equipment, or the desire or perhaps the necessity of reducing the length of the board, the design of Fig. 4 may be suggested. This is really a modification of the design of Fig. 2, with all apparatus not requiring the constant observation of the operator removed to a vertical board located back to back with the bench-board. On this vertical board may also be mounted the charging equipment for the control battery, and the low tension switches for station lighting and auxiliary power. The leads from the instrument transformers should enter through the pull box at the bottom of the vertical board, and the control leads through the pull box under the bench. It will, of course, be necessary to carry the instrument leads overhead from the top of the vertical board to the instrument section of the bench-board, and the leads for the potential and synchronizing receptacles down to the bench. The space between the two boards is usually enclosed by grill work, with a door at each end. If

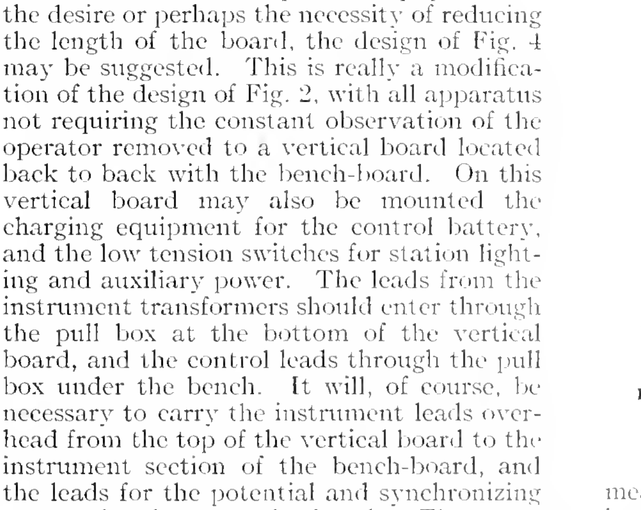


Fig. 4. An Enlargement on the Arrangement Shown in Fig. 2 which meets the demand of greater working surface by the addition of rear panels

the rear board serves also as a switchboard for station light and power, with busses and connections on the back, it becomes necessary to increase the distance between the two boards to give ample space for working on the different parts without danger.

In a power plant with prime movers it is almost always necessary to provide some

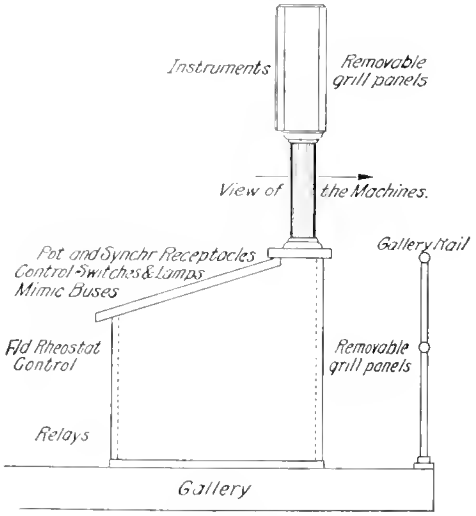


Fig. 5. A Gallery Type of Bench-board which Permits the Operator Viewing the Machines Through the Board

means of communication between the switchboard operator and the machine attendant, and different systems of push buttons or dials with lamps, bells or whistles are used, mounted if possible on the bench, or sometimes on the instrument section as shown in Fig. 4. It is important that this apparatus should be located in a position most convenient to the operator, so as to save time and avoid possible errors at critical moments. With the types of boards just described, direct visual signals between these two persons are practically impossible, without a moving or turning by the switchboard operator from his position before the instruments and control apparatus. This should not be expected of him, as it would mean relocating himself with reference to the switchboard equipment for every signal received or sent.

With this condition in mind, the bench-board design of Fig. 5 is often used where the board can be located on a gallery overlooking the machines. This usually gives the operator a good view of the station between the columns supporting the instrument section, these columns generally being placed where the different panels or vertical sections of the board are joined together and at the ends of the board. With the arrangement of apparatus indicated in Fig. 5 all connections should enter at the bottom of the sub-base, under the

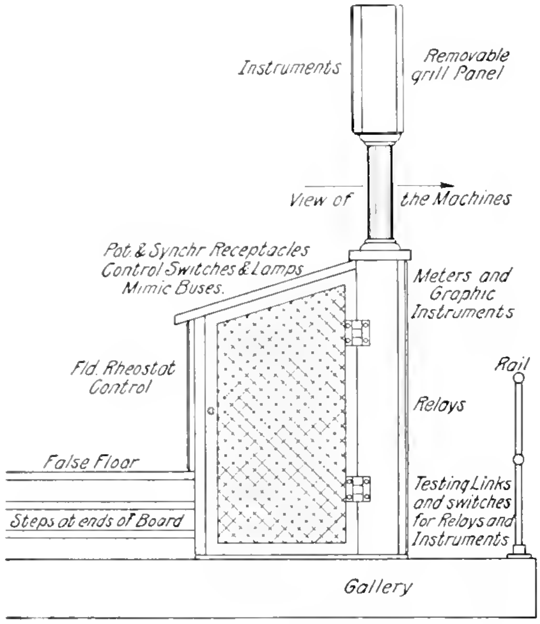


Fig. 6. An Elevated Board of the Same Type as Shown in Fig. 2. Operating floor raised the same amount

bench. The instrument leads are then carried through the hollow columns from the bench to the instrument section, and there brought out again through openings in the walls of the columns. The backs of the instrument section and the bench are covered by grill panels as in previously mentioned designs.

While the design of Fig. 5 facilitates communication between the switchboard and the machines and thereby eliminates, at least in part, the signal equipment, it is obvious that it does not compare favorably with Figs. 2, 3 and 4 for complex equipments, except in extension in length; therefore the grill panels on the back side of the bench are sometimes replaced by solid sections mounting meters and other equipment. With this arrangement dissipation of heat should be considered, especially if there are a great number of lamps and resistances under the bench. Access to the interior of the bench must also be provided, usually by means of doors at the ends of the bench; but on account of the limited height it is necessary to depress the floor inside, or remove it entirely and arrange a platform a short distance below the proper height for working on any part of the equipment under the bench.

To provide somewhat more useful surface and avoid the necessity of depressing or cutting through the floor under the bench, the design of Fig. 6 may be recommended. The height of the bench has been raised considerably to provide easy access to the interior, and to give more space on the back side of the bench for meters, graphic instruments, and testing links. It is preferable to mount even the relays on this side of the bench for convenience in testing, so that all leads from the instrument transformers may be brought up from the floor on this side, and thence up through the columns to the instruments, leaving the other side for the control leads. On account of the increased height of the bench, it becomes necessary to raise the floor in front of it. This arrangement gives the advantage of more space for conduits near the switchboard, where they are usually too concentrated for a thin gallery floor.

Even a gallery type of bench-board may easily be combined with a vertical board in order to gain more space for equipment. While they cannot be located back to back, as in Fig. 4, they may be arranged to face each other. This, of course, necessitates running a number of conduits between the two boards for the instrument transformer leads.

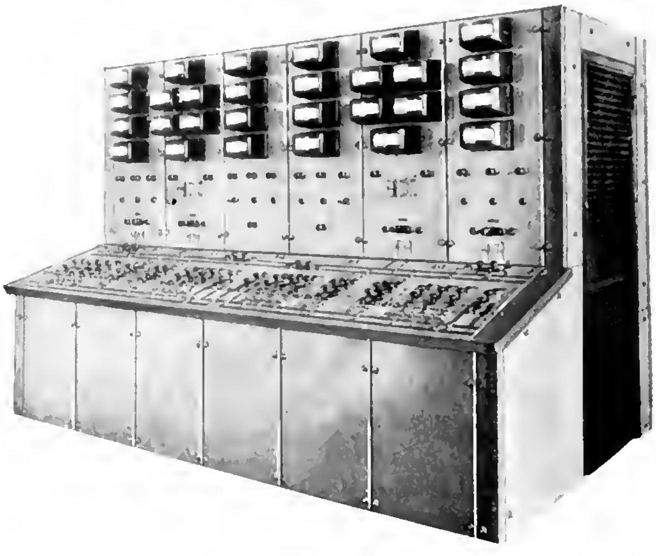


Fig. 7. A Typical Bench-board with Mimic Busses and Connections

It is often found that a bench-board of a certain design will give the best result for controlling the machines, while a vertical control board will be more feasible for the feeders. The difference may be prominent enough to warrant the separation of the equipment on two distinct boards. In this connection the number of operators should also be considered. Separation of the equipments further sacrifices the advantage of a complete mimic connection system, often used for great convenience on the face of the control board to represent all main connections, their relative locations, and the positions of the switches.

THE REQUIREMENTS OF THEATER LIGHTING

By S. L. E. Rose and H. E. Mahan

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In the following article the authors present a description of the purpose and means of lighting a modern theater under subdivisions, viz., stage, auditorium, and building exterior. After identifying and locating each light source from which the illumination is furnished, the functions performed by each of them are discussed. The merits and demerits of the various methods of locating the clear and colored bulbs in the reflectors of the footlights and border-lights are pointed out, and photometric curves are furnished of the candle-power distribution given by them. The importance of very careful consideration being given to the lighting of the auditorium is made apparent, and the necessary requirements which it must meet are named. The two general types of exterior illumination, viz., glaring and artistic, are referred to and recommendations made thereon. In a forthcoming number we are publishing a complementary article which will describe in great detail the construction and installation of the electrical equipment.—Editor.

General

The modern theater depends largely upon lighting for its scenic and ocular effects. How successfully electric light meets the demand is evident to anyone witnessing a modern theatrical production. There one may see the reproduction of the various stages of daylight from the rising to the setting of the sun, the cold light of the moon and the stars, the vivid flashes of the lightning accompanying a storm, the ravaging fire, and many other wonderful and realistic imitations. Marvelous as these effects may seem their development has been largely the result of "cut and try" and "rule of thumb" methods. It is only in comparatively recent times that the problems involved in theater lighting have received scientific attention; and it may be safely predicted that the illumination of the theater a quarter of a century hence will make the present-day play appear very crude.

Light is a form of radiant energy transmitted by means of wave motion in the ether. Light itself is invisible except when intercepted by some object, the reflected rays from which impinge upon the delicate retina of the eye and produce the sensation of sight. In the consideration of light, therefore, it is evident that for a complete understanding we must investigate it from both a physical and physiological standpoint. When we leave the field of physics and enter the realm of physiology we find it difficult to make experimental determinations, and consequently our knowledge is more limited. While we do not know positively the actions that take place in the eye upon receiving the sensation of light, we do know from experience the most advantageous way of applying light for maximum acuity. In solving a problem in the application of light, the following points should be considered:

(1) The use, (2) the intensity, (3) the distribution and diffusion, and (4) the quality. From a consideration of these factors we can decide upon the type of illuminant required, the quantity of light it must emit, the type of reflector to be used, the location of the lighting units, the effect of the light upon the human eye, the emotions, etc.

In this article we have divided the lighting of a theater into three divisions, viz., stage, auditorium, and building exterior. While the first mentioned is chiefly spectacular, the second utilitarian, and the third ornamental, the principles mentioned must be applied in attaining the desired results in any case.

Stage Lighting

In the lighting of the stage the chief aim is to reproduce as nearly as possible the conditions as they actually exist, and at the same time enable the audience to see clearly the actors and scenery. To accomplish this result it becomes necessary to have available light from several different directions, and facilities for directing beams of light in any desired direction to meet special conditions. Perhaps the most important adjunct to the lighting equipment of the stage is the footlight. The function of the footlight is to direct upon the actors a strong light from below. This directed light intensifies the facial expressions and features, and assists to a great extent in holding the attention of the audience. It is essential, however, that no sharp shadows be cast upon the stage setting or actors, hence we must introduce light that will assist in reducing by gradation the sharp contrasts in a vertical plane. This is accomplished by means of proscenium-lights (Fig. 1), assisted at times by strip-lights (Fig. 2), open box and bunch-lamps. The former are located on the side of the proscenium arch; the latter suspended at points along the sides of the stage, usually at the entrances. The light from above is provided by means of border-lights (Fig. 3), which are suspended at adjustable heights from the gridiron structure.

Fig. 1 Lamps and Reflectors Which are Placed Along the Sides of the Proscenium Arch

Fig. 2. A Six-Lamp Section Strip-Light with Reflector

The stage lighting, so far discussed, may be considered as general or permanent as distinct from local or portable lighting. When it is desired to draw the attention of the audience to one individual performer or group of performers, the usual method is to illuminate them with a high intensity of light relative to their surroundings. This is done by means of the lens-lamp (Fig. 4), which directs a strong concentrated beam whose size is adjustable at the will of the operator. The bunch-lamp consists of a group of incandescent lamps backed by a reflecting surface, and is used for directing a soft, warm light over a restricted but somewhat larger area than is covered by the lens-lamp.

It is desirable in accomplishing certain scenic or psychological effects to illuminate the stage with colored light. For this reason footlights, border-lights, etc., are made up with white, red, blue, and amber colored bulbs connected in separate circuits. There are two general methods or arrangements of lamps, first, where the clear and colored bulbs are alternated or intermingled, and, second, where the clear bulbs are all placed in one row and the colored bulbs in another row. Curves showing the distribution of candle-power in a plane at right angles to the axis of the footlight, and to the border-light, are given in Figs. 5 to 9 inclusive. The curves are plotted from readings taken at

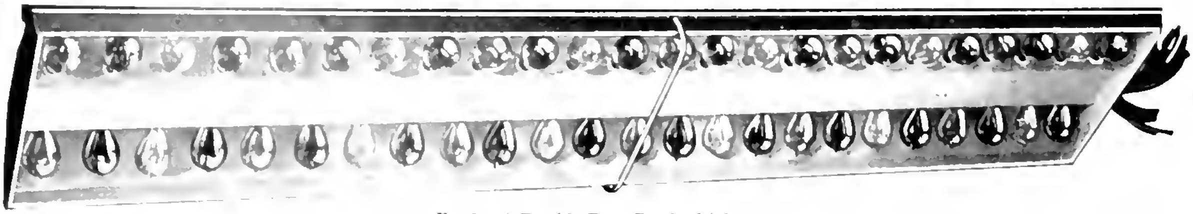

Fig 3. A Double-Row Border Light

25-foot radius, and the lamps are located according to Figs. 5-A to 9-A respectively, being spaced three per foot and backed with a white enamel reflecting surface.

It can be seen that a better distribution and a higher intensity are obtained from footlights when all the clear bulbs are placed in one row. This is an important factor for when the clear lamps are wanted intensity is of prime importance, while when colored effects are desired intensity is usually of secondary consideration. Another feature to be considered is the fact that when the clear bulbs are placed in a single row the quality of the light from them is not discolored by passing through the colored bulbs, as is the case when clear and colored bulbs are intermingled. The operator obtains color effects from the flood, lens, and bunch-lamps by passing the light through color screens. This permits light of any color, or combination of colors, to be thrown upon the stage.

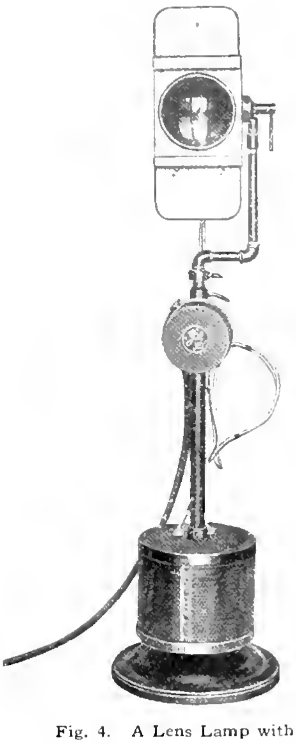

Fig. 4. A Lens Lamp with Offset Supporting Frame

Furthermore, for the reproduction of such effects as, for example, sunset or sunrise, it is necessary to be able to vary the intensity of the light. This is best done by inserting in series with the lamp circuits adjustable resistances called dimmers which cause the lamps to burn at varying degrees of brightness.

Fig. 10 illustrates a distribution of light intensity along the center line of the stage,

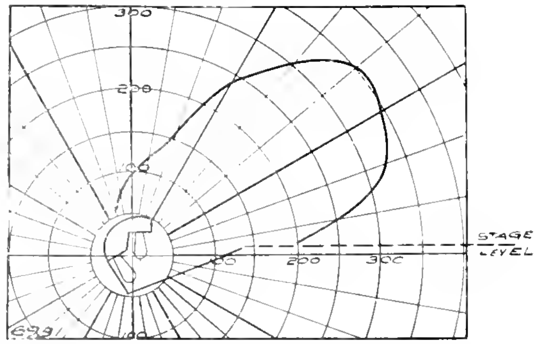

Fig. 5. Curve Showing the Average Apparent Candle-Power in a Vertical Plane of a Footlight in Which Every Third Lamp in Both Rows is Clear, the Others Colored.

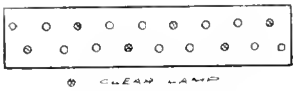

Fig. 5 A. Diagram Showing the Location of the Lamps in Fig. 5

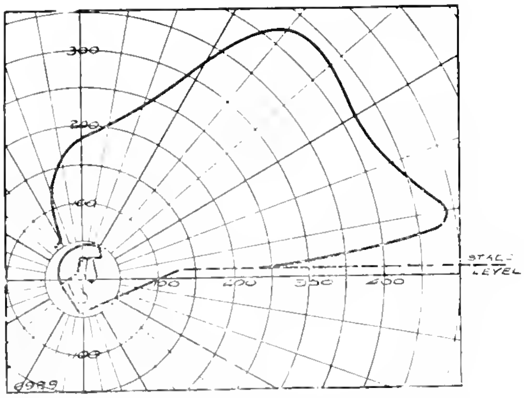

Fig. 6. Curve Showing the Average Apparent Candle-Power in a Vertical Plane of a Footlight in Which All the Clear Lamps are in the Front Row and All the Colored Lamps in the Back Row

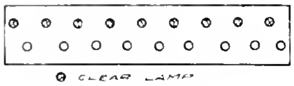

Fig. 6-A. Diagram Showing the Location of the Lamps in Fig. 6

from front to back, suitable for the average theater. It has been selected after careful consideration of photometric tests taken on the stages of theaters in various sections of the country. There has been noticed a tendency on some stages to increase the general intensity far beyond that required. Usually, however, a high intensity is not necessary except for short periods of time.

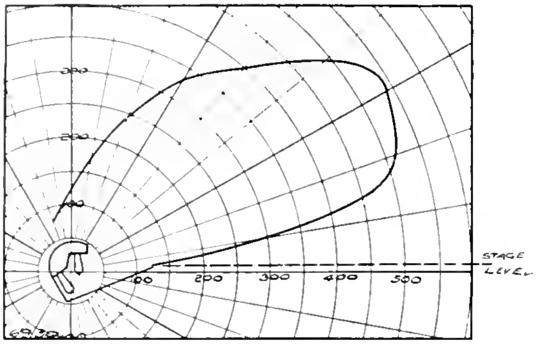

Fig. 7. Curve Showing the Average Apparent Candle-Power in a Vertical Plane of a Footlight in Which the Lamps in Both Rows are Alternately Clear and Colored

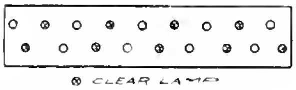

Fig. 7-A. Diagram Showing the Location of the Lamps in Fig. 7

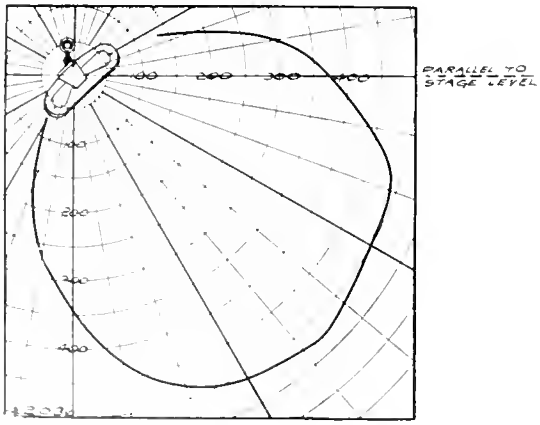

Fig. 8. Curve Showing the Apparent Candle-Power in a Vertical Plane of a Border Light in Which the Clear Lamps are in the Lower Row and the Colored Lamps in the Upper Row

Fig. 8-A. Diagram Showing the Location of the Lamps in Fig. 8

and can best be taken care of by the auxiliary lamps (box, lens, bunch, etc.). An extremely high intensity, when used at all times, is very injurious to the eyes of the performers, and may cause discomfort to the audience if reflected from any large white surface or other reflector in the stage setting.

Auditorium Lighting

A patron of a theatrical performance is there to be entertained. Regardless of how clever the production may be, unless the environment is pleasing to the senses the entertainment is incomplete. That auditorium, therefore, which fulfills its purpose must afford comfort, convenience, and attractiveness. Let us consider the relation that light bears to these features.

We associate with the word comfort, physical and mental ease. How far light improperly applied may remove us from this condition is evident to all who have ever had to sit in an auditorium where a highly brilliant light source is in the line of sight. The presence of unscreened light sources of high intrinsic brilliancy within the angle of vision causes "glare," which is a source of ocular discomfort and probable injury. There are two general methods of reducing glare. First, we may increase the light emitting surface of the source and decrease its intrinsic brilliancy (candle-power per square inch of surface), by surrounding the light with a

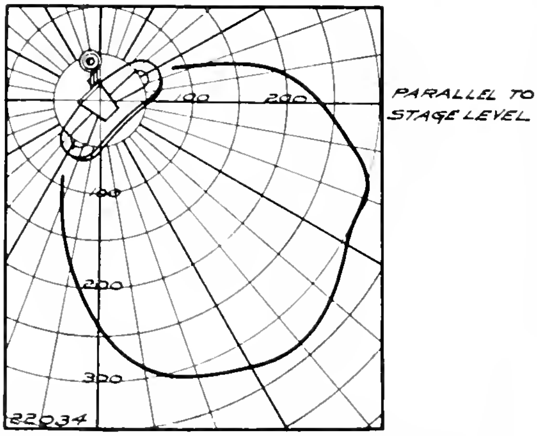

Fig. 9. Curve showing the Average Apparent Candle-Power in a Vertical Plane of a Border Light in Which Every Third Lamp is Clear, the Others Colored

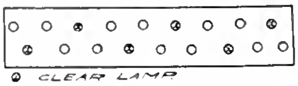

Fig. 9-A. Diagram Showing the Location of the Lamps in Fig. 9

diffusing glass globe. Second, we may conceal the light source from view and utilize its light after redirection from the ceiling or some provided reflecting or diffusing surface.

The first system is known as direct lighting, the second as indirect lighting, and a system combining both characteristics as semi-indirect lighting.

The convenience afforded by the lighting system of a theater auditorium is measured by the degree which it facilitates the reading of programs and tickets, the easy access to and from seats, and the ability to distinguish persons, etc. There must then be provided a light of sufficient intensity to allow of ease in doing these things, but at the same time one which fulfills the rule previously stated regarding the physiological effects.

The architect in the design of the interior of the building has embodied certain ideas which depend for their realization upon the proper relation of light, color, and shadow. The effect of the design depends entirely upon the proper relation of these factors, it being possible by the improper direction or diffusion of light to destroy any relief ornamentation. It is, therefore, essential that attention be given to the direction of the artificial light, as upon it depends the architectural effect.

The ideal arrangement of lighting units, then, is the result of a compromise between the above factors and the cost of installation and maintenance. We cannot adequately express the energy-efficiency of a system of lighting of this kind in physical units, as the personal factor enters very largely in deciding its merits. The artistic effect is the important consideration.

It is required by law, and advisable for the safety of patrons, to provide lights indicating

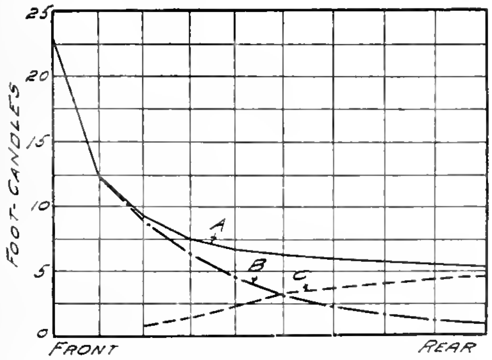

Fig. 10. A Suitable Distribution of Light Intensity Along the Center Line of Stage, from Front to Back

the exits. These lamps should in addition to marking the exit, provide sufficient illumination to allow of convenient egress when the auditorium is in darkness. The most desirable distribution of light is illustrated in Fig. 11, in which it will be noted that light is thrown upon the steps and cut off from the auditorium.

Fig. 11. The Most Suitable Distribution of Light at an Emergency Exit

Exterior Lighting

In illuminating the exterior of the building the manager hopes to attract attention to his house and production. He may do this in one of two ways. First, he may attract the eye of the passerby by a brilliant glare of light from electric signs and exposed lamps; second, he may illuminate the building, making use of concealed light sources to bring out the architectural features. This latter scheme of emphasizing the architecture of the building, in relief against the dark surroundings, is dignified and attractive, and to be preferred to the dazzling and showy methods largely in vogue today. A modest electric sign may be judiciously placed so as to add to rather than detract from the general appearance. Problems of this kind should be treated individually, and receive the cooperative attention of architect and illuminating engineer.

THE RELUCTIVITY OF SILICON STEEL AS A LINEAR FUNCTION OF THE MAGNETIZING FORCE

By J. D. Ball

Consulting Engineering Dept., General Electric Company

The curves usually drawn to represent the magnetic properties of a material are of such a nature that they are not easily determined throughout from the observed data, do not show simple mathematical relationship, do not detect small errors or show reliability of test, do not permit of satisfactory extrapolation, and cause considerable difficulty in determining from them the magnetizing force for high inductions. This article deals with the reluctivity, or reciprocal of the permeability, which over a wide range is a linear function of the magnetizing force, a fact often neglected. Accordingly, curves may be drawn which are most satisfactory from all standpoints, and from which costs may be derived. Sample curves, tables, and equations for silicon steels are given, including the average values obtained for 2.5 per cent and 3.5 per cent silicon content; these materials being widely employed at present.—Editor.

At the meeting of the American Institute of Electrical Engineers in New York City, Oct. 27th, 1891, Dr. A. E. Kennelly read a paper on "Magnetic Reluctance," in which he showed that if the reluctivities of various magnetic materials were plotted against the magnetizing forces the curves so obtained

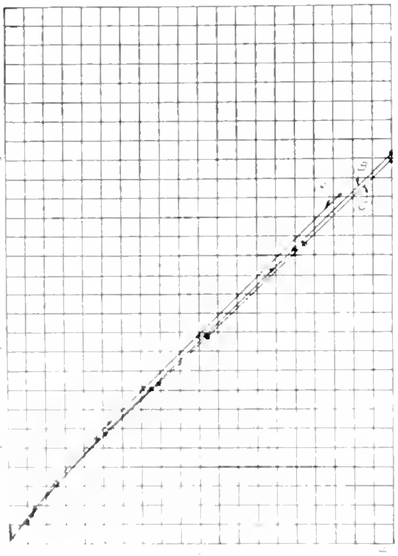

Fig. 1 Reluctivity Curves of Three Samples of 3.5 Per Cent Silicon Steel

A [illegible] 10 kg [illegible] ring sample punched from 0.014 [illegible]

B [illegible] 0.454 kg.) solid ring sample machined [illegible]

C [illegible] kg [illegible] ring sample punched from 0.014 [illegible]

would exhibit a greater degree of simplicity than those usually developed, viz.

$H-\beta$ or curves of magnetizing force and flux density;

$H-\mu$ or curves of magnetizing force and permeability;

$\beta-\mu$ or curves of flux density and permeability.

The $H-\rho$ curve suggested by Dr. Kennelly is the curve of magnetizing force and reluctivity, or the reciprocal of the permeability curve. It consists of two nearly straight lines united by a rounded elbow, expressing the fact that over a wide range the reluctivity of the material investigated is nearly a linear function of the magnetizing stress brought to bear upon it (see Trans. A.I.E.E., Vol. VIII, page 485). This has

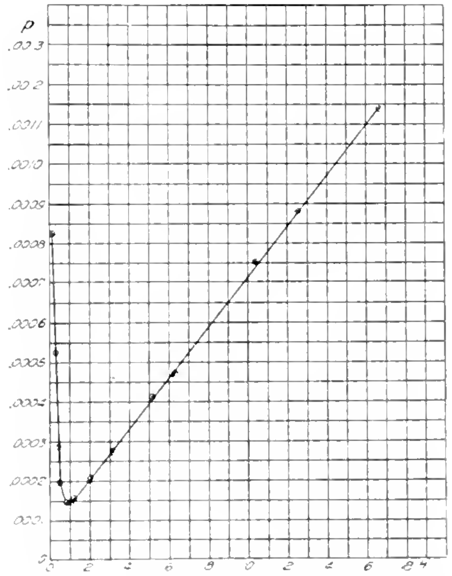

Fig. 2. Reluctivity Curve of Sample A, taken at Low Magnetizing Forces

been shown to be true for a variety of irons and steels under different conditions of annealing, under various mechanical stresses, and at various temperatures. It was also shown to be true for nickel and cobalt in the original observations taken by Rowland, Ewing, and Kennelly. Ewing and Low's observations confirmed this relation for wrought iron as high as $H=24{,}500$. This fact does not seem to have received the attention it deserves, in view of the fact that the curve lends itself more readily to mathematical treatment than do the magnetization curves commonly used.

Since the previously mentioned paper was presented, the transformer steel situation has been materially changed by the introduction of alloyed or silicon steels, the properties of which are very different from standard or carbon iron, by reason of their having about four times the resistivity and much lower eddy current and hysteresis losses, as well as being about four per cent lower in specific gravity.

The permeability curves of silicon steel usually differ from those of standard iron by having slightly higher permeability at low densities, but lower permeability at higher densities. The saturation curves of silicon steel show a more definite and sharper bend at the knee of the curve than is met with in the case of standard iron; further than that, silicon samples vary more among themselves and are varied more by heat treatments than is common iron.

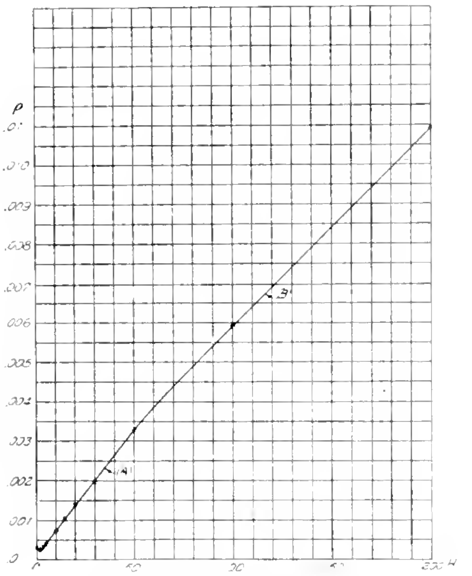

Fig. 3. Reluctivity Curve of the Average of 12 Samples of 2.5 Per Cent Silicon Steel
(A) $\rho = 0.000099 + 0.0000624H$
(B) $\rho = 0.00094 + 0.0000498H$

It is the object of the present article to give some results of tests made in the Standardizing Laboratory of the General Electric Company to determine whether the reluctivity of silicon steel is also sufficiently near a linear function of the magnetizing force that the advantage of this relation may be utilized to facilitate calculations in the various branches of electrical engineering.

Fig. 1 is the plotted results of three samples of steel, each containing about 3.5 per cent silicon. Curve "A" is for a 22 lb. (10 kg.)

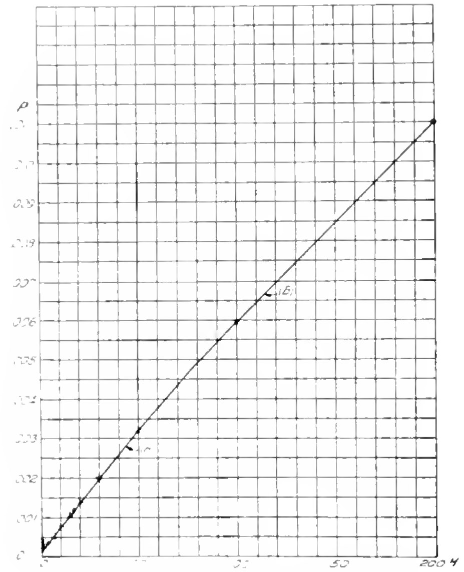

Fig. 4. Reluctivity Curve of the Average of 17 Samples of 3.5 Per Cent Silicon Steel
(A) $\rho = 0.000133 + 0.0000623H$
(B) $\rho = 0.00092 + 0.0000504H$

ring sample punched from 0.014 in. sheets. Curve "B" is of a 1 lb. (0.454 kg.) solid ring sample machined from an ingot, and Curve "C" is for a 1 lb. (0.454 kg.) ring sample punched from 0.014 in. sheets. In order to obtain variety in the product, each of the three samples was obtained from a different country, viz., Germany, England, and the United States.

Fig. 2 is an enlarged portion of the lower part of Curve "A."

Fig. 3 represents an average curve determined from twelve ring samples of $2\frac{1}{2}$ per cent silicon steel punched from 0.014 in. sheets, and Fig. 4 is the average of seventeen ring samples of $3\frac{1}{2}$ per cent silicon steel also punched from 0.014 in. sheets. All samples were annealed. Tabulated results are given in Tables I to V.

It will be noted that the elbows of these curves come lower than for most magnetic steels. It is also noticeable in each case that the curvature beyond the elbow is more pronounced up to $H = 100$ (approx.) than from $H = 100$ up to $H = 400$, which is as high as the observations were made. The rather decided bend, which in this case is in the neighborhood of $H = 100$, is a characteristic of all common magnetic material; and is doubtless due to a change of flux paths on account of the saturation in some parts occurring earlier than in others, or, in other words, to the fact that the material due to heat treatment, cooling, or other causes, is not magnetically homogeneous. It seems true of common iron and cobalt at about $H = 70$, and for nickel* at about $H = 30$. It

* Since preparing this paper I have had the pleasure of examining the results of tests made by the Allgemeine Elektricitats Gesellschaft upon a solid ring of nearly pure nickel. The analysis was Ni 98.91, Cu 0.33, Fe 0.31, Mn 0.21, Si 0.07, Co 0.15. The plotted reluctivity curve showed no evidence of this bend, but gave a straight line from approximately $H = 9$ (β = 3600) to $H = 377$ (β = 6350), the limit of the test. The equation of this line proved to be $\rho = 0.0015 + 0.00175\ H$. This is an evidence of pure, homogeneous material.—AUTHOR.

TABLE I
SAMPLE A
22 LB. RING SAMPLE 0.014 IN. SHEETS

β	H	$\beta_0 = \beta - H$	$\rho_0 = \frac{H}{\beta_0}$
19,580	348.0	19,230	0.0181
19,500	276.0	19,220	0.0143
18,750	200.0	18,550	0.0108
17,700	142.0	17,560	0.00808
16,950	106.0	16,850	0.00629
15,950	50.1	15,900	0.00314
15,050	25.1	15,025	0.00167
13,850	10.45	13,840	0.000754
12,650	5.22	12,650	0.000412
11,400	3.11	11,400	0.000273
10,100	2.11	10,100	0.000209
8,025	1.265	8,025	0.000158
7,100	1.055	7,100	0.000149
5,780	0.838	5,780	0.000145
2,900	0.561	2,900	0.000193
1,490	0.418	1,490	0.000281
537	0.281	537	0.000523
170	0.140	170	0.000823

TABLE II
SAMPLE B
1 LB. RING SAMPLE FROM INGOT

β	H	$\beta_0 = \beta - H$	$\rho_0 = \frac{H}{\beta_0}$
20,030	100.5	19,630	0.0205
19,450	293.3	19,150	0.0153
19,150	204.8	18,950	0.0108
17,680	95.9	17,580	0.00545
16,570	50.4	16,520	0.00305
15,660	25.2	15,630	0.00161
14,810	12.52	14,800	0.000845
13,920	7.56	13,910	0.000543
12,760	5.01	12,760	0.000395
10,300	3.02	10,300	0.000293
8,220	2.10	8,220	0.000255
5,620	1.26	5,620	0.000224
4,480	1.008	4,480	0.000225
3,130	0.756	3,130	0.000242
1.565	0.504	1,565	0.000322
845	0.378	845	0.000448
304	0.252	304	0.000829
87	0.126	87	0.00145

TABLE III
SAMPLE C
1 LB. RING SAMPLE 0.014 IN. SHEETS

β	H	$\beta_0 = \beta - H$	$\rho_0 = \frac{H}{\beta_0}$
20,420	400.0	20,020	0.0199
20,060	308.0	19,750	0.0156
19,200	207.0	19,000	0.0109
17,420	101.0	17,320	0.00584
16,210	50.9	16,160	0.00314
15,180	25.4	15,150	0.00168
13,580	10.17	13,570	0.000751
12,680	7.65	12,670	0.000602
11,500	5.09	11,500	0.000443
9,680	3.05	9,680	0.000315
8,120	2.03	8,120	0.000250
6,140	1.27	6,140	0.000207
5,230	1.017	5,230	0.000194
3,660	0.763	3,660	0.000209
1,465	0.509	1,465	0.000347
823	0.381	823	0.000463
505	0.254	505	0.000503
126	0.127	126	0.00101

TABLE IV
12 SAMPLES 2.5% SILICON STEEL
AVERAGE OF 12 RINGS FROM 0.014 IN. SHEETS

β	H	$\beta_0 = \beta - H$	$\rho_0 = \frac{H}{\beta_0}$
18,600	200.0	18,400	0.0109
17,000	100.0	16,900	0.00592
15,860	50.0	15,810	0.00317
15,180	30.0	15,150	0.00198
14,640	20.0	14,620	0.00137
14,260	15.0	14,250	0.00105
13,660	10.0	13,650	0.000733
12,200	5.0	12,200	0.000409
10,610	3.0	10,610	0.000283
9,100	2.0	9,100	0.000220
7,770	1.5	7,770	0.000193
6,000	1.09	6,000	0.000180
5,700	1.0	5,700	0.000176
4,000	0.819	4,000	0.000105
2,410	0.500	2,410	0.000207

TABLE V
17 SAMPLES OF 3.5% SILICON STEEL
AVERAGE OF 17 RINGS FROM 0.014 IN. SHEETS

β	H	$\beta_0 = \beta - H$	$\rho_0 = \frac{H}{\beta_0}$
18,600	200.0	18,400	0.0109
17,000	100.0	16,900	0.00592
15,860	50.0	15,810	0.00317
15,180	30.0	15,150	0.00198
14,640	20.0	14,620	0.00137
14,260	15.0	14,250	0.00105
13,660	10.0	13,650	0.000733
12,200	5.0	12,220	0.000409
10,610	3.0	10,610	0.000283
9,100	2.0	9,100	0.000220
7,770	1.5	7,770	0.000193
6,000	1.09	6,000	0.000180
5,700	1.00	5,700	0.000176
4,000	0.819	4,000	0.000105
2,410	0.500	2,410	0.000207

is especially noticeable in the case of a cast cobalt ring tested by Rowland at 230 degrees Centigrade. (See Fig. 8, Trans. A.I.E.E., Vol. VIII, page 497.)

A further point in connection with this theory of the change of flux paths is the fact that there are experimental results indicating that there is likewise at the point of deflection of the reluctivity curve an apparent increase of hysteresis loss above that given by the Steinmetz equation, $h=\eta\beta^{1.6}$. Several authors have stated that the exponent 1.6 is too low in the case of high inductions. While this may be true, it should not be overlooked that the hysteresis increase may be due not to the change of exponent, but to the saturation of the softer materials causing flux to enter the harder ones having a higher value of η.

There are several advantages of plotting magnetization curves in this manner. One of considerable importance is seen when it is desired to find, at a point above saturation, the magnetizing force necessary to give a required induction. This is difficult to determine accurately by test or to read from the $\beta-H$ curve, but a value may be obtained by extrapolation of the $\rho-H$ curve or from its equation. A further advantage is found when it is desired to study magnetic properties of materials from a scientific or experimental standpoint, as a change due to any physical cause or to an error in the test is easily discovered by a deviation from a straight line, which would not appear as a deviation from any other form of curve.

Beyond the elbow we may write as a general equation $\rho=a+\sigma H$, where a is a constant representing the distance from the X-axis to the intercept of the $\rho-H$ curve if continued along the straight line, and σ is a constant representing the slope of the line. H is the magnetizing force, and ρ the reluctivity. From a we also have a criterion of the magnetic hardness of the material, as soft materials give lower values of a.

If $\beta=$ the magnetic induction, $\rho=\frac{H}{\beta}$.

$\beta=\frac{H}{\rho}=\frac{H}{a+\sigma H}$, which may be readily handled, having once determined a and σ for the material in question. This relation has been expressed by Lamont and Frolich* as $I=\frac{a\,H}{1+\beta H}$, where $I=$ induction, a and β are constants for a given specimen, and $\frac{a}{\beta}$ is the saturation value of I. It is not stated that this is a straight line but it is obvious, especially after dividing by a and putting into the form $I=\frac{H}{\frac{1}{a}+\frac{\beta}{a}H}$. β and H may be expressed in any form of units by using proper values for the constants. In this discussion β is given as the apparent density in gausses per sq. cm., and H as the field strength in gausses per cm. equal to $\frac{4\pi\,A\,t}{10L}$, where L is the length in centimeters, A the current in amperes, and t the turns.

Using the above units, the curve, although as close an approximation to a straight line as would be required for practical purposes, has undoubtedly a slight downward bend which is prevalent throughout. This confirms the facts, well established by Ewing and others, that the reluctivity curves of metal and of air are asymptotic. Should the reluctivity curve continue straight, it would cross the air curve at a value of unity and indicate that at densities above this point the metal is diamagnetic. For this reason, and for some investigations, it is better to consider the metallic rather than the apparent density. Writing β_0 as the metallic density, $\beta_0=\beta-H$ and $\rho_0=\frac{H}{\beta_0}=\frac{H}{\beta-H}$ etc. At infinite H, this curve would show infinite rather than unit reluctance, true permeability rather than its permeability superimposed upon the unity permeability of air, and the true saturation value of the metal. The curves in this paper are so given, but as will be seen from the tables, there is no appreciable discrepancy at the highest density examined, and the slight difference soon disappears.

From the preceding, we conclude that in the case of silicon steels the reluctivity may be considered as a linear function of the magnetizing force, over a wide range. This relation may be used to advantage for determining the reliability of test results, and in calculations the equation will, in most cases, obviate the necessity of reading β and H values from curves. It may be used to determine values beyond the limits of the ordinary tests.

*"Magnetic Induction in Iron and Other Metals" Ewing—3rd Ed. p. 332.

FROM THE CONSULTING ENGINEERING DEPARTMENT OF THE GENERAL ELECTRIC COMPANY

WIRE CONSTANTS

The B.&S. wire gauge is arranged in geometrical progression, that is, successive sizes always differ from each other by the same percentage. Therefore, if the constants of one size of wire are remembered, those of all others can readily be derived therefrom without tables, usually within one per cent.

The section of wire, and therefore all constants depending on the section, as weight, resistance, etc., halves (or doubles) for every three sizes, and decreases (or increases) 10 fold for every 10 sizes. Approximately, each size is 80 per cent of the next size. Thus, with one size known, any other size can be calculated by approaching it first by tens, and then by threes.

Size No. 10 is most convenient to remember, as it has a diameter of 1/10 inch, that is, 100 mils, a section of 10,000 circular mils, and a resistance of 1 ohm per 1000 feet, at 25 deg. C. Its weight is 31 lb. per 1000 feet.

Suppose the constants of wire No. 4 are wanted: No. 4 is 2×3 sizes larger than No. 10. Since for every three sizes the section doubles, No. 4 is 2×2, or 4 times the section of No. 10; that is, 40,000 circular mils. It has 4 times the weight, or 124 pounds per 1000 feet, and $\frac{1}{4}$ the resistance, or 0.25 ohms per 1000 feet.

Or for instance suppose wire No. 35 is required:

From 10 to 35 are 25 sizes, or $(2 \times 10) + (2 \times 3) - 1$. From No. 10 to No. 30 are 2×10 sizes. Hence, twice 10-fold gives $\frac{1}{100} \times 10{,}000 = 100$ circular mils, 0.31 lb. and 100 ohms resistance per 1000 feet. From No. 30 by threes gives No. 36 as the next to No. 35. From 30 to 36 is 2×3, hence, the size 36 is 2×2 smaller than No. 30, or $\frac{1}{4} \times 100 = 25$ circular mils, $\frac{1}{4} \times 0.31 = 0.0775$ lb., and $4 \times 100 = 400$ ohms per 1000 feet. No. 35 is 80 per cent of No. 36 or $0.8 \times 400 = 320$ ohms per 1000 feet, $\frac{25}{0.8} = 31.2$ circular mils, and $\frac{0.0775}{0.8} = 0.097$ lb. per 1000 feet.

The diameters are the square roots of the sections, in circular mils; thus, No. 35 has the diameter $\sqrt{31.2} = 5.6$ mils. Therefore, all that has to be remembered is that, with increasing number, the section, weight and diameter decreases, while the resistance increases.

The reactance of the wire does not vary proportionally with the section, but logarithmically. Therefore the reactance changes by the same amount for every size. At 60 cycles, and 24 in. between conductor and return conductor, the reactance of wire No. 10 is 0.15 ohms, and changes by 0.0025 ohms for every size. Hence, wire No. 4, being six sizes from 10, has the reactance $0.15 - (6 \times 0.0025) = 0.135$ ohms; wire No. 35, being 25 sizes distant from No. 10, has the reactance $0.15 + (25 \times 0.0025) = 0.2125$ ohms per 1000 feet.

For a distance of 60 in. between the conductors, the reactance is 0.02 ohms higher; hence, for wire No. 4, it is $0.15 + 0.02 = 0.17$ ohms per 1000 feet of wire at 60 cycles.

At 25 cycles, the reactance is $\frac{25}{60}$ as large.

The current carrying capacity of wires in wiring, etc., where the wires are not massed together but each wire radiates separately, depends upon the resistance and the surface; and therefore, at constant watts per square inch radiation, the current carrying capacity doubles every four sizes, and hence increases approximately 20 per cent for every size, 40 per cent for every two sizes.

At 0.1 watt per square inch radiating surface, wire No. 10 carries 20 amperes. Hence wire No. 6 would carry, with the same watts per square inch radiation, $2 \times 20 = 40$ amperes, and wire No. 4, $1.4 \times 40 = 50$ amperes.

Wire No. 35, being $25 = (6 \times 4) + 1$ sizes smaller than No. 01, would carry $\frac{20}{2 \times 2 \times 2 \times 2 \times 2 \times 2 \times 1.2} = 0.27$ amperes.

C.P.S.

LAWS OF CORONA

There were four interesting papers on corona this year at the A.I.E.E. Annual Convention at Cooperstown.

Dr. Whitehead's paper covered the subject of visual corona over a wide range of air density. As usual he gave very complete and explicit data, thus making the paper of great value. In his conclusions he stated that the results are in substantial agreement with the law connecting electric intensity, pressure, and temperature, as given by Peek.* The visual corona law is now very well confirmed.

Mr. Strong's paper dealt mostly with the use of corona in electrical precipitation.

Prof. Benett's paper gave a very interesting and valuable set of oscillograms. Power losses calculated from these were found to follow the "quadratic law" given by Peek.† The constants differed, however, as the tests were made on small wires in a cylinder.

In the paper by Peek, tests were given confirming former conclusions on the "rupturing energy." New data were also given showing that when the free rupturing-energy distance was limited the apparent strength of air is very greatly increased. A very interesting discussion followed. Among the questions asked which elicited general discussion was: "Why does the loss vary as the frequency, if there is considerable loss by continuous voltage?" Mr. Peek stated that while over the commercial range the loss varies approximately as the frequency, at very low frequencies there is a small constant loss. The greater part of the loss, however, is a per-cycle loss. This may be expressed mathematically as:

$$p = K(f + a)\ (e - e_0)^2$$

Then the small loss at zero frequency is

$$p = K\ (a)\ (e - e_0)^2$$

This zero frequency loss, however, should not correspond to the direct current loss, but must be smaller.

C.P.S.

*A.I.E.E., June, 1912. G. E. Review, Dec., 1912.
†A.I.E.E., June, 1911.

QUESTION AND ANSWER SECTION

The Q. and A. Section has been started with the sole object of increasing the practical usefulness of the REVIEW; and in order that it may be made of real value, we invite correspondence from any of our readers who are looking for information on any technical matter in the field covered by this magazine, and which they think we can furnish.

Where possible the answers to such inquiries will be the work of this office; where desirable we shall obtain our authority from that engineering or commercial person in the General Electric Company's organization best fitted for handling the particular subject. We hope our readers will not hesitate to avail themselves of the expert engineering opinion which should be made available through this section of the REVIEW. Information on matters of general importance and interest will be published here; questions of interest solely to the querist will be handled by mail.

Sketches should accompany questions in all cases where this is necessary to give us complete and accurate information on the point at issue. Scale drafts will be made up here from correspondent's rough pencil sketches. Questions must be accompanied with the name and address of the sender, although these will not necessarily be for publication, and should be addressed to the Editor, Q. and A. Section, GENERAL ELECTRIC REVIEW, Schenectady, N. Y.

CURRENT LEAKAGE OVER INSULATORS

(59) When testing high-tension insulators it has been noticed that a current leakage takes place over the glazed surface of the insulator long before the flash-over voltage is reached. Kindly state why such leakage should take place over an apparently perfect insulating surface. What is the nature of such leakage?

It is not generally realized that in the line insulator there are two insulations in series—air and porcelain. Air breaks down when the dielectric flux density at any point exceeds a given definite value. A much higher flux density, however, is required to break down porcelain than air. When the potential applied to an insulator is increased the dielectric flux increases. Finally a voltage is reached which causes a flux density somewhat in excess of the breakdown density of air. The air ruptures at this point and glows, but the porcelain does not as yet break down because it requires a still higher density. Thus the so-called leakage on clean dry insulators is generally due to the local rupture of air by local over-flux densities or over-voltage gradient. The voltage gradient and flux density in any given material are proportional.

In the design of insulators care should be taken to so shape and proportion the solid insulation that it does not cause an increase of flux density in the air and thus weaken the combination. Corona on an insulator is an indication of weakness; it means the air part of the insulator is being punctured.

F.W.P.

LOCATING BRUSH POSITION

(60) What are the methods for determining the correct position of the brushes on a direct-current machine.

The answer will be presented in sections in order that it may be more clearly followed.

Before any adjustments are attempted the first step is to see that the brush studs are equally spaced around the commutator. They should not be located by spacing them apart a distance equal to the total number of commutator bars divided by the number of studs, since this method is liable to inaccuracy. The best means is to lay a ribbon or narrow band of paper tightly around the commutator, marking one complete circumference on the paper, and then to unwrap the band and mark it into as many equal divisions as there are studs. On replacing the paper band on the commutator, the brush studs will be spaced correctly if the brushes on each stud are set to meet their respective division marks.

Non-Commutating Pole Machines

Generators and Motors. Although with these machines it is impossible to hold the position of the electrical neutral constant with a change of load, its travel will be small in a well designed machine. A compromise position, therefore, can be found which will satisfy all requirements.

First set the brushes on the mechanical neutral point. To find this position, one armature conductor should be selected and placed midway between two field poles, and the brushes of one stud set on the commutator bar to which this conductor is joined. Even if the binding wire covers part of the armature surface, this point can usually be found with sufficient accuracy. Run the machine at no-load in its normal direction at normal speed, using normal field current. Then shift the brushes forward (i.e., in the direction of rotation) from the mechanical neutral point if the machine is a generator, backward if it is a motor, until they begin to spark. Apply full-load and locate the brushes for the best commutating position under this condition. This full-load neutral will be farther away from the mechanical neutral than was the no-load neutral. In making a selection for a permanent brush position, which will be between these two neutrals, it is well to choose a point closer to that one which comes nearer to the average load under which the machine will operate.

Commutating Pole Machines

Generators. There are several methods whereby the location of the running neutral on a generator of this type may be found. It is especially important on commutating pole machines that the brush studs be spaced accurately, as heretofore described, and that a good fit of the brushes to the commutator be obtained.

The First Method consists of finding one of the points of zero potential on the commutator by exploring a section of its arc with a pilot brush made of some insulating material, usually fiber, and which is of the same size as the ordinary brush used on the machine. This brush should have two holes drilled in it radially, the two being displaced circumferentially by a distance equal to the width of one commutator bar or less. In each of these holes is placed a copper wire, or preferably a graphite pencil point, which bears on the commutator surface and which leads to a low-reading voltmeter, or millivoltmeter. With no-load on the generator, which is running in its normal direction, the brush-holder yoke should be shifted until the reading of this meter falls to a minimum. This position should be noted with reference to some index mark selected on the stationary frame, in order that the yoke may at any future time be returned to the same position in case it has been displaced. With the brushes set in this position and with proper adjustment of commutating field, the generator will usually carry full-load with satisfactory commutation. Should it be found impossible to secure satisfactory commutation with brushes located by the above method under no-load conditions, readings should be taken with the fiber brush at full-load, which may result in a slightly different brush position.

Shunt Adjustment: If satisfactory commutation is secured with full strength commutating field, no shunts are required. On many machines, especially those of the larger sizes, it is difficult to design the commutating field with the exact strength required, consequently, it sometimes becomes necessary to shunt part of the current from this field in order to obtain satisfactory commutation under load. The first trials should be made with a shunt of high resistance, which should gradually be reduced until good commutation is obtained. Another method of determining when the dimensions of the best commutating field shunt have been arrived at consists in measuring the voltage drop from the pig-tail of a brush to various points on the commutator under the brush, with the brush set on the neutral as described under the third method. Reduce the resistance of the shunt until the voltage drop from the pig-tail to the toe of the brush is the same as that from the pig-tail to the heel.

In the Second Method the generator is run as a motor in both directions of rotation at no-load, under which conditions the brushes are set on the neutral point, found as described in the following section on *Motors.* It is now perfectly safe to assume that the brushes are located on the equi-voltage, or neutral point, when the machine is operating as a generator. This method gives very satisfactory results on the smaller machines.

The Third Method is much simpler than those described and on machines of recent manufacture has been found to be preferable. The armatures of these machines have the conductors of one of their coils, and the ends of the commutator bars connected to them, marked in some distinctive manner (e.g., painted or stamped) whereby the brushes may immediately be placed on the running neutral with sufficient accuracy for commercial purposes. In the case of a full-pitch winding (i.e., one in which the two conductors span a distance around the armature circumference equal to the distance between two main or two commutating poles), the armature [illegible] rotated so that these marked conductors come [illegible] under the centers of adjacent commutating [illegible]. With the armature in this position the [illegible] adjacent stud are placed directly over [illegible] commutator bars. If, however, [illegible] of a fractional pitch (i.e., one in which [illegible] conductors do not span a distance equal to [illegible] two main or two commutating poles), [illegible] to set the armature so that each [illegible] is equi-distant from the center [illegible] commutating poles, or, stated [illegible] they are equi-distant from the [illegible] main pole, and to then set the [illegible] adjacent stud over a marked commutator [illegible]. In case the armature is not marked it will be [illegible] to use one of the two methods given previously, unless the armature conductors can easily be traced from the slot to the commutator bars. If the commutating field is of the proper strength satisfactory adjustment will be obtained at all loads with the brushes set as above. If a shunt is required in the commutating field it should be adjusted as directed under "Shunt Adjustment" but with the brushes always on the neutral found as described in this third method.

Motors. A commutating pole motor has its brushes set on the running neutral if it will run at the same speed in either direction when under the same conditions of applied voltage, field current, and load. The following method for locating the brush position, which is the most satisfactory one, will be greatly facilitated if reversing switches have been placed in both the series and shunt-field circuits.

Before starting up, the brushes should first be set as initially noted under "Non-Commutating Pole Machines." This position can usually be determined with sufficient accuracy by sight and in most cases is directly opposite the center line of a main pole. As a matter of precaution against the possibility of a runaway under full-load, the setting of the brushes should at first be approximately located at no-load by taking speed readings with the motor running in each direction of rotation, holding the same applied voltage and field current, and shifting the brushes to that point which gives approximately the same speed in each direction. In two-speed motors of this type the neutral should be obtained at the high speed. Care should be taken when shifting the brushes to avoid a dangerous rise of speed. The brushes having been placed approximately on the no-load neutral, the machine may be loaded and a permanent brush position accurately located by careful speed readings at full-load, shifting the brushes slightly until the same speed is obtained in each direction under the same conditions of voltage, field current, and load. After an apparent satisfactory adjustment has been obtained, two speed curves should be plotted (one for each direction of rotation) from readings of speed and load taken at such points as no-load, full-load, and whatever over-load is required. If a falling or constant speed is obtained with an increasing load no further adjustments are necessary. Poor commutation, or a rising speed characteristic, should be corrected by the insertion of a commutating field shunt. Readings of speed, etc., should be repeated as above for each change in the shunt, as it will be found that the speed under full-load will usually decrease with a reduction of the resistance of the commutating field shunt. In the case of two-speed motors the speed curves should be taken at both speeds.

General Instructions

Compound-wound generators should, during the above adjustments, have a shunt across the series field giving approximately the compounding required and should then be finally compounded after the brush position has been found.

Compound-wound motors are usually run with full series field, but if a special speed characteristic is required, necessitating a shunt across the series field, this shunt should be set approximately during the adjustment for brush position and then finally adjusted afterward.

In all cases in which a shunt is required across a field winding care should be taken to see that the shunt contains sufficient material to carry the shunted current continuously without overheating, otherwise the rise in resistance of the shunt under continuous operation may nullify all adjustments.

J. D. H., E. M. & F. L. K.

GENERAL ELECTRIC REVIEW

A Special Number

on

Electric Railways

GENERAL ELECTRIC REVIEW

A MONTHLY MAGAZINE FOR ENGINEERS

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Subscription Rates: United States and Mexico, $2.00 per year; Canada, $2.25 per year; Foreign, $2.50 a year, payable in advance. Remit by post-office or express money orders, bank checks or drafts, made payable to the *General Electric Review*, Schenectady, N. Y.

Entered as second-class matter, March 26, 1912, at the post office at Schenectady, N. Y., under the Act of March 3, 1879.

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NOVEMBER, 1913

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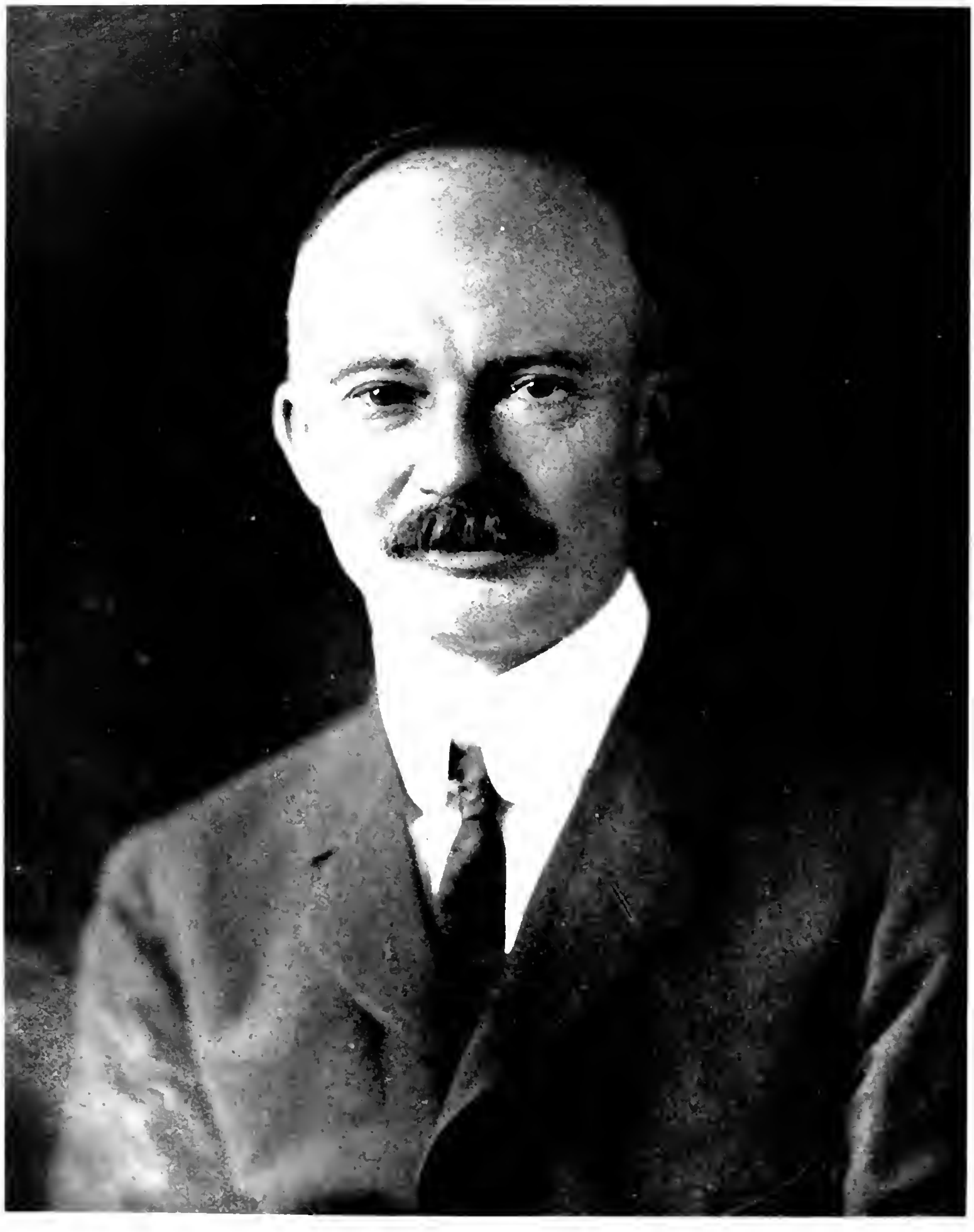
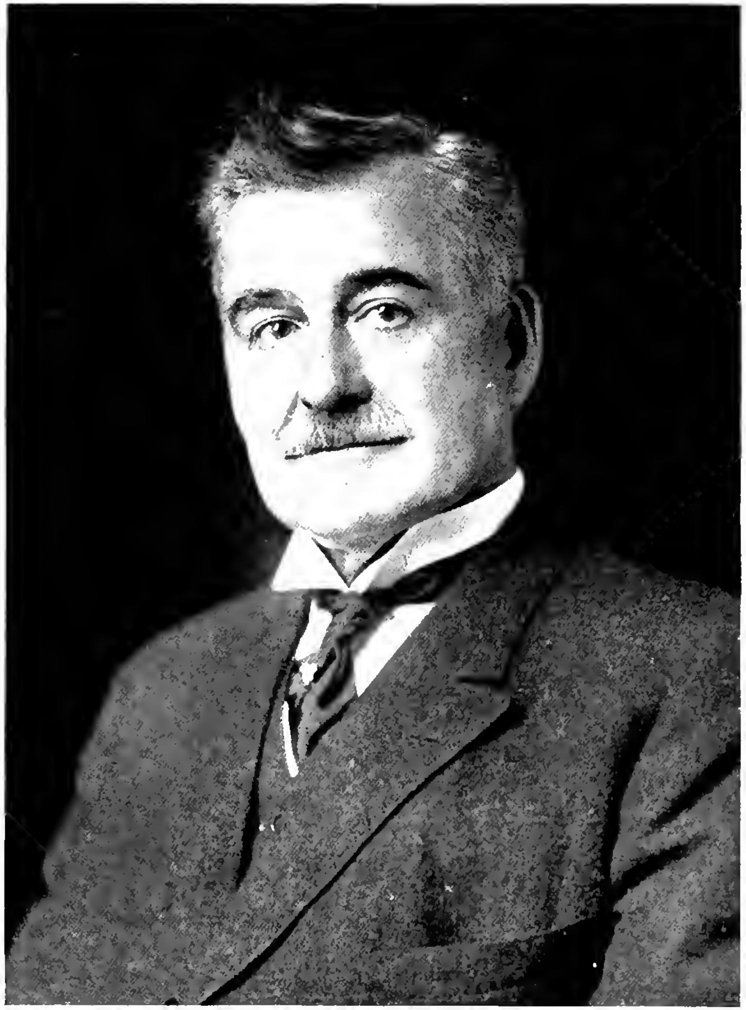


W. B. Potter

A Contributor to this Issue



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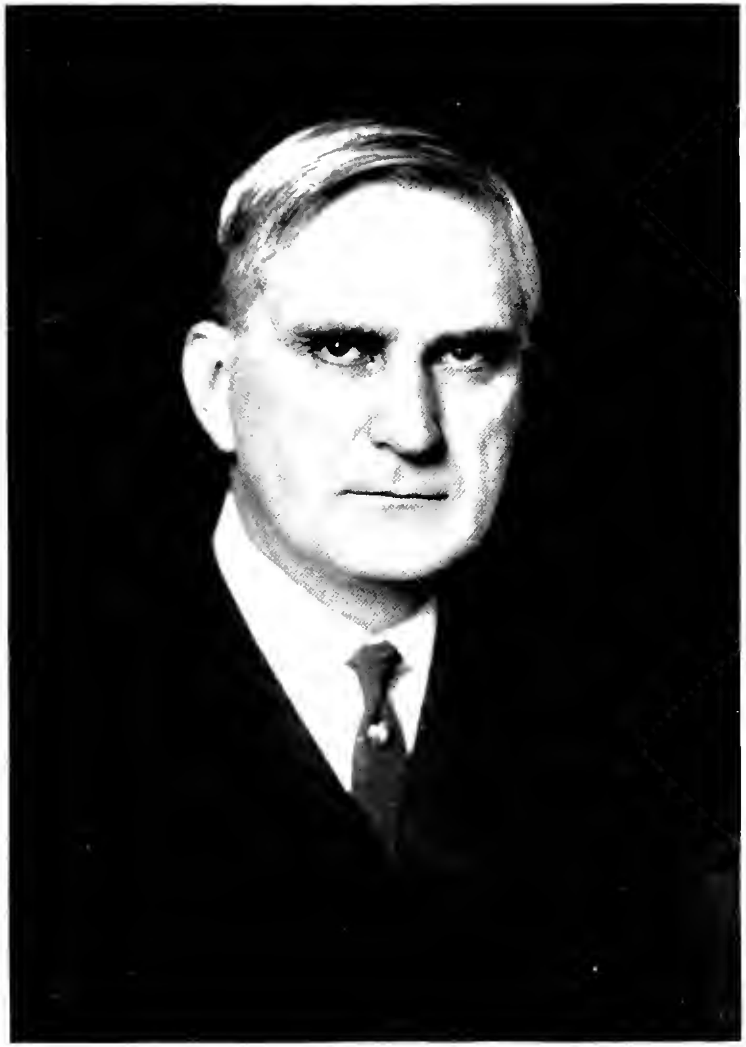

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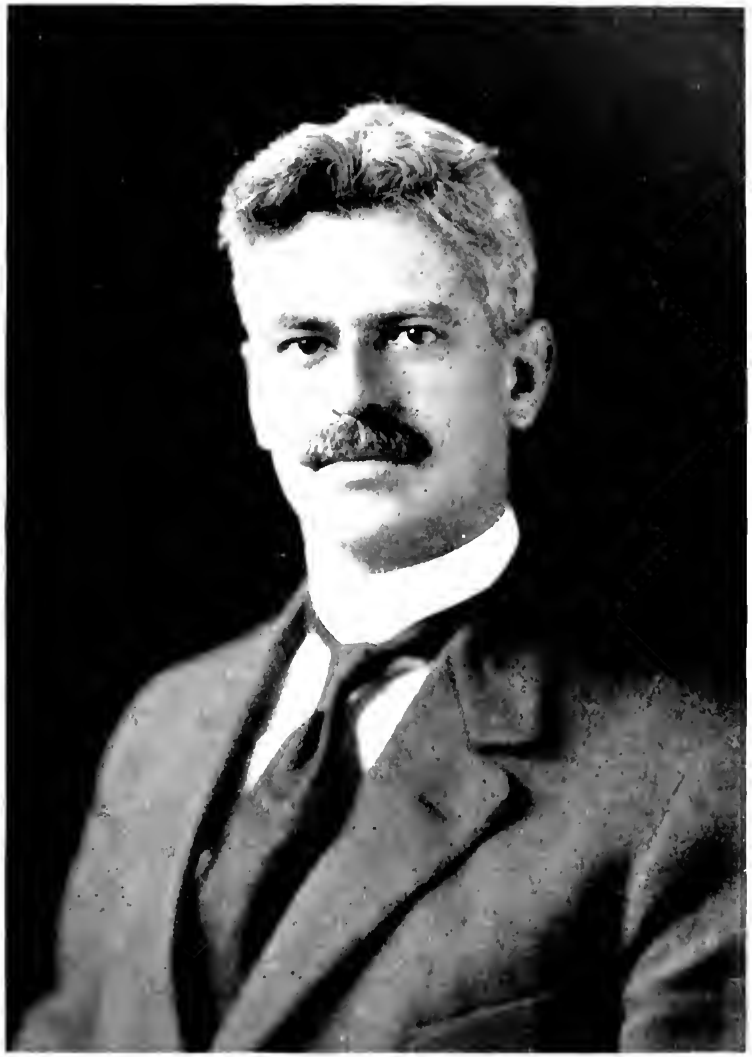

C. E. Eveleth

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GENERAL ELECTRIC REVIEW

THE PATHS OF PROGRESS

Our railways are such an important factor in our present stage of civilization that it is difficult to imagine where we should be without them. Modern modes of living would be quite impossible without modern modes of transportation, as by a gradual process of evolution such enormous populations have been concentrated into comparatively small areas in our cities, that the lives of millions of human beings are entirely dependent upon railway transportation for food and supplies of all kinds. It is not a comforting thought to contemplate what would happen to these communities if railway communication with the outer world were, for some reason or other, suddenly to cease. Indeed, the whole fabric of modern society is so based upon production in one place and consumption in another that efficient railway communication is, today, an absolutely essential part of our complicated social system.

The greatest transportation needs of the nation are at present provided by the large steam railroad systems, but it is interesting to note that, as one of the writers in this issue states, the interurban railroads are today playing as important a part to the particular communities they serve as are the steam railroads.

The interurban electric railway is peculiarly the child of American soil. The total area throughout the Union that owes its development to electric interurban roads is enormous. Such roads have not only played their part in opening up new sections of the country, but have played a most useful role as feeders to the great systems of steam railroads.

Our city and suburban railways have perhaps been the greatest benefactors to the human race in relieving the over-congestion in our cities, towns and manufacturing centers. The cheap transportation that they provide has encouraged the extension of suburbs and the growth of other communities beyond the congested areas. Of all inventions and developments there is perhaps not one that has tended to improve the conditions of life to the same extent as have our city and suburban roads.

Of the sum total of all the benefits conferred by the development of electric railways, whether they be city, suburban or interurban in character, those who have financed and constructed the roads have received but a small share. It would be difficult, if not impossible, to estimate the increase in real estate values that has been brought about by the construction of electric railways. Such roads have certainly given more to the public than they have received from the public. The standards of living, and the very character of the homes of multitudes of people, have been vastly improved owing to the transportation facilities provided by these roads, and anything which affects the permanent status of electric railways in America affects the growth and development of the nation as a whole.

The scope of new work undertaken in recent years is shown by Mr. Clark in this issue; it would seem that there are, or have been, certain factors working to limit the extension of electric roads, but fortunately the future seems bright for more extensive developments. As the progress and development of the country as a whole is so dependent upon transportation facilities, it is to be hoped that electric railway activities will be resumed with renewed efforts in all sections of the country. It is reassuring to realize that splendid work is being done in the development of the many details which must be perfected to put electric railways on a sound economic basis.

In the growth of electric railways, as in most great evolutions that have been brought about by human effort, the development has been dependent upon the ingenuity, resourcefulness, energy and perseverence of the engineer.

The economies in construction, operation and maintenance of electric railways, apparatus and equipment have been given the closest attention during the last decade, and there are many articles in this issue which will testify to the gratifying results secured in this direction. The adoption of higher direct current potentials seems to stand out most prominently among recent developments; over nineteen hundred miles of road are now operated by higher direct current voltages. Some of these systems, using higher direct current potential equipments, have now been in operation for a sufficiently long time to show in a definite manner the economies that can be secured by this mode of operation. It seems that there is no exception to the gratifying results secured.

One of the most prominent and, at the same time, most vital questions that has been before the railway world for the last decade has been the selection of the most suitable system for any particular undertaking. It would seem that opinions, tempered by experience, are better defined on this subject now than a few years ago. This phase of the railway question is dealt with in an interesting and instructive article by Mr. Potter in this issue, entitled "Systems of Electrification."

Efficiency in operating methods has been given a great deal of attention during the last few years and is fast being reduced to a science. Electric and other railways are in reality manufacturing concerns, although it is not usual to regard them as such. They are manufacturing "passenger seat miles" and "ton miles" and the closer they can keep the ratio of "goods" manufactured to "goods" sold, the better their financial returns will be. The arrangement of schedules to avoid as far as possible the manufacture of unused, or waste, passenger seat miles constitutes an important part in railway management. It would seem that this general principle is becoming better recognized in another way and that there is an insistent demand for a reduction of the ton miles of work that have to be expended in producing passenger seat miles. This has led to the design of many new types of cars and equipments of lighter weight than the older standards.

There have been some notable developments in car construction recently, and many of the new types of cars being put into service today have been designed expressly to increase the efficiency of handling passenger traffic. The pay-as-you-enter car, center-entrance car, near-side car, and double-deck car are all witnesses to the efforts being made in this direction.

The evolution of economic transportation facilities has entailed a vast amount of detail work. In fact, many items which are details of a railway system have only been developed to their present stage of perfection after years of work and experimentation and by the expenditure of enormous sums of money. The development of the modern direct current railway motor is dealt with in this issue by Mr. Priest, and the development of the multiple unit control by Mr. Case. Both of these items serve as examples of the many evolutions that are being made. The recent developments in the railway motor, such as the adoption of commutating poles and of an improved method of internal ventilation have all played their part in enhancing the economic status of electric railways. The simplification of the Type M control has been influential in extending the use of this particular type of control to city service and in producing a lighter equipment. The more general adoption of air brakes on city cars has added a factor of safety to city service. All these and the many other developments that are taking place serve to show that the construction, operation and management of electric railways in general, and the design and construction of their equipments are constantly progressing in a direction that leads to greater efficiency.

It will be noted that very little mention has been made in this issue of the Review of the developments in heavy electric traction and in the electrification of steam railroads, the reason for this being that we hope in the future to issue a special number of the Review to show the steps taken in this direction along the paths of progress.

SYSTEMS OF ELECTRIFICATION

By W. B. Potter

Chief Engineer, Railway and Traction Department, General Electric Company

The selection of the most suitable system of electrification for any particular installation is the most vital problem in electric railroading today. A false step made in the beginning can not be corrected later, without involving an enormous additional outlay of capital. For this reason, Mr. Potter's article will be welcomed by all railway men as a most valuable addition to electric railway literature. No one is more competent to speak with authority on this subject than the author.—Editor.

The development of the electric railway is practically covered by the short period of 25 years since the days when Sprague, Van Depoele, Daft and Bentley-Knight, among other pioneers, inaugurated a new era in transportation by substituting the electric motor, in place of the horse and cable, for street railway service. Many and radical improvements have been made in methods of generating and transmitting electric power and in the details of the motors and car equipment, but fundamentally the street railway trolley system of today in its general characteristics and in the use of direct current is similar to the original electrifications. During this period the standard trolley voltage has increased from 500 to 600, a change that has occurred gradually so far as the average voltage of the trolley line is concerned.

Until within the past few years there has been no general consideration of higher trolley voltages. This has been due in part to the additional expense of equipment wound and insulated for higher voltage, as within the limitations of speed imposed by the urban railway a potential of 600 volts is about the limit of economic design for non-commutating pole motors. Since the number of cars per mile of track is a maximum in this class of service, the cost of car equipments is an important factor. The same is true with respect to the voltage as affecting design of the generating apparatus, although to a less extent.

The more general extension of interurban lines introduced a new condition in which the cost of rolling stock became of relatively less, and that of the feeder and conductor system of relatively greater, importance.

Improvements in the electrical design of the railway motor, particularly with respect to commutation, made it possible to use single-phase alternating current and also permitted a more economic design for higher voltage direct current.

Under the requirements of interurban service there have been a number of installations of single-phase alternating current and high voltage direct current equipments, and, as the result of several years' experience with both of these systems, direct current may be accepted as the standard for this class of work.

Single-phase equipments in this service have proved unsatisfactory by reason of their cost, excessive maintenance and the troubles incident thereto.

A potential of 1200 volts direct current has become a recognized standard for interurban lines because of being conveniently interchangeable in operation at the same speed on 600 and 1200 volt lines. The motors commonly used have 600 volt windings which may be connected two in series or two in parallel, as required.

The use of 1500 volts is more in the nature of a special voltage for those cases where the saving in copper offers sufficient advantage, and where the ratio of speeds is acceptable under interchangeable operation.

It seems reasonable to anticipate a more general use of 1200 volts for suburban and even urban service, since existing 600 volt equipments, both on cars and in substations, can be utilized in many cases by series connection with new apparatus insulated for the higher potential.

The use of motor cars operating in trains with multiple unit control is recognized as the best method of meeting the service requirements of railway terminals and interurban lines handling large passenger traffic, and direct current is generally regarded as also the standard for this class of work. Direct current at 600, 1200 and 1500 volts is in common use, and an interurban railway is now under construction which will use direct current at 2400 volts, both for locomotives and multiple unit operation.

There are several railways operating multiple unit trains equipped with single-phase apparatus, but it is unlikely that there will be any new installations of this character.

The electrification of main lines of steam railroads or similar heavy service is often over long distances, with train units each requiring considerable power and operating under infrequent headway and irregular schedule. The feeder and conductor system under these conditions is therefore a more important factor in determining cost of electrification than in the classes of service before mentioned.

The question of interchangeable operation with existing low voltage direct current lines is usually of little or no importance, and the type of equipment used can therefore be considered wholly with respect to the local conditions and requirements.

At present there are in operation in this class of service three general systems, each of which has proven successful in the handling of traffic. In brief these systems are direct current at 2400 volts and the voltages before mentioned, three-phase alternating current with induction motors, and single-phase alternating current with commutating motors.

There is in process of development another system in which polyphase induction motors, having the characteristics of the three-phase system, will operate with single-phase alternating current from a single conductor instead of from two conductors as with the three-phase. A phase converter to furnish the additional phase for the motors is a feature of the locomotive equipment, and for the sake of distinction as between the others this has been called the split phase system.

The characteristic features of constant speed and power regeneration are common to both the three-phase and split phase systems, and as the split phase requires only a single conductor instead of two, it seems probable that the split phase will be generally used where the three-phase would formerly have been considered.

The single-phase system permits a high voltage conductor, but the motors are of lower voltage and have larger commutators than usual with direct current motors, and the characteristics of the single-phase commutator motor with respect to commutation and capacity seem to possess inherent limitations. New applications of the single-phase system to main line service do not seem probable.

The mercury arc rectifier in small sizes has proven so successful a device for converting alternating into direct current, that with further development it is probable the capacity of the rectifier will be increased and made suitable to meet railway requirements. The principal field of usefulness for the rectifier will doubtless be in substations where under favoring conditions it would replace the rotary converter or motor-generator set. There is also the possibility of rectifiers being used in connection with direct current motor equipments on locomotives supplied with single-phase alternating current.

The alternating current in an overhead conductor, both in the single-phase and split phase systems, and to a somewhat less extent with the three-phase system, has an inductive action upon adjoining circuits which does not occur with direct current. To protect telegraph and telephone lines which parallel overhead conductors with grounded return circuit from this inductive effect of alternating current requires protective methods which are an item of expense to be seriously considered, and which may prove of considerable amount under some conditions.

The direct current system introduces fewer uncertain elements than any of the others. Conductive influence of direct current due to differences in potential in the return circuit does not create disturbance in the telephone, and protection for the telegraph is easily provided.

The regeneration of power by the locomotive equipment, which also provides for electric braking, is of value in some cases, and the development of this feature in connection with direct current may reasonably be expected.

The direct current system, which has proven so successful in other classes of service, gives promise of equal performances for steam railway electrification. Practical experience thus far with 2400 volts direct current and experiments at higher voltage indicate that the limitation in voltage will be due to economic reasons rather than in any difficulty in the design of the apparatus.

For steam railroad electrification, with present knowledge of the several systems and their possibilities, the choice seems to lie between the high voltage direct current system and the split phase system, each of which will have its particular field of usefulness, with the probability that in the majority of instances the economic advantage will be in favor of direct current.

A REVIEW OF AMERICAN ELECTRIC RAILWAY COMMERCIAL CONDITIONS

By William J. Clark

Manager, Traction Department General Electric Company

The problem of keeping operating expenses of street and interurban railways below receipts by an amount sufficient to pay a reasonable profit on the investment involved is of direct importance to us all, and not only the railway man. The building of new lines and extension of old, the purchase of up-to-date equipment, and the maintenance of a satisfactory service are all dependent on the earning powers of the road; for it is a difficult matter to induce capitalists to invest in properties that sell their services for cost or less. Under present conditions, however, it is impossible for many roads to earn a fair return on the capital invested, and it is apparent that there is need of constructive geniuses, as well as reformers. Fortunately there are signs of a change for the better in the field of city and interurban railroads, as well as a brilliant future for heavy electric traction. Mr. Clark has made a study of commercial conditions of the electric railways of the United States, and the present contribution is the forerunner of a series of articles on this subject that he has in preparation for the Review.—Editor.

As is well known, the development of electric railways in a sound engineering way to secure highly economical results has been, and is, most remarkable. Mining and other industrial electric railways, upon which over 12,000 locomotives are now operated within the United States alone, are expanding and increasing with great rapidity, and the cost of haulage thereon continues to decrease.

As a result of the practical successes secured by electric traction on steam railroads, their electrification has never been so seriously considered, or so extensively undertaken, as at the present. Still more marked has been the past growth of urban and interurban electric railway systems, yet it must be admitted that in recent years their expansion has been checked and retarded by causes entirely independent of the state of the art, or its universally demonstrated economic advantages, in such class of service.

The "keynote" to the causes which are responsible for this last condition was struck in a report made to the American Electric Railway Association a few months ago, which remarked that, to a considerable extent, urban and interurban electric railways in this country "were selling their goods (transportation) below cost."

It is, of course, obvious, that capital cannot be attracted to investments in urban and interurban electric railways where such conditions exist, and it is axiomatic that, unless additional capital continues to be invested in an industry, it cannot expand. Fortunately the condition stated is not universal; and many instances can be cited where urban and interurban electric railways show a net financial return upon the capital invested therein comparable to, and as favorable as, that secured from the operation of other classes of public utilities. Nevertheless, the average showing of net financial returns made by all the urban and interurban electric railways, plus certain specific showings of like character, for which electric traction *per se* is not responsible, are frequently quoted as a fallacious argument to try to demonstrate that there is something inherently wrong in its basic principles. This is having an unfavorable effect upon the further extensive investment of capital in local transportation systems.

The writer will therefore attempt, in a series of articles which will appear in the General Electric Review, to clearly set forth the causes which in many instances are responsible for such systems being forced to furnish transportation below cost and the other reasons which are similarly responsible for their unfavorable financial returns in certain instances; also to show why such conditions cannot continue permanently and to indicate how such changes can be facilitated. The remainder of the present article, however, will be devoted to a review of urban and interurban electric railway development, and to incidental references only concerning the financial features involved.

In 1880, the United States census returns state the total population as 50,155,783, of which 11,318,547, or 22.5 per cent, was classified as urban. At this time there were approximately 2870 miles of street railway track in this country, upon which about 11,480 cars were operated by various forms of motive power.

No traffic statistics are available for this period; and a goodly portion of what was then classed as urban population had no local railway facilities available at all. There was then but one mile of street railway track for each 3943 of urban population and for each 17,475 of the total population, while one passenger car was in service for each 985 of the urban, and for each 4378 of the total population.

In the decade from 1880 to 1890 a marvelous development of local transportation facilities occurred. This was the great period for cable railway construction; and in 1887 the serious introduction of commercial electric railways began.

In this decade also, for the first time, the greatest proportionate growth of trackage was in the smaller cities, the increase for the entire country having been 182.1 per cent; in cities above 50,000 population the increase was 102.35 per cent, and in cities of less than 50,000 people the increase was 453.19 per cent.

To contrast with the more recent growth of local transportation facilities, it is considered well to state the approximate yearly construction of street railway track in the United States during this period:

Year	Miles of Track Constructed
1881	140
1882	269
1883	230
1884	244
1885	370
1886	465
1887	870
1888	860
1889	1100
1890 (first half year)	690

This tabulation shows that in the later eighties the increases in the construction of American local railway tracks was greater than that subsequently stated from 1907 up to 1912, despite the much greater proportionate demand for increased local transportation facilities existing in the latter period, as evidenced by the statistics of that time cited herein.

The general census of the United States for 1890, the only time when a complete census of street and similar railways was taken in the same year and included in the general census reports, gives the following figures:

The total population was then 62,947,714, of which 22,720,223, or 36.1 per cent, was classified as urban in the general census returns. The street railway census, however, considered the urban population to consist only of residents in towns having 8000 population, or over. The total of these was 18,284,385, or 29 per cent of the total population.

There were then 8123 miles of street railway track in the country, upon which 32,505 passenger cars were operated, the mileage of which is not obtainable; these cars according to the 1890 census report carried a total of 2,023,010,202 passengers, averaging 62,237 per car. The number of transfers then issued cannot be ascertained, but it was not an important traffic factor, as is subsequently illustrated by the receipts per passenger.

Certain other important averages at this date were as follows:

	Total Population	Urban Population	Population in Towns of 8000 Over
Per mile of track	7749	2796	2238
Per passenger car	1936	699	559
Rides per capita	32	89	111

The average annual increase in miles of track from 1880 to 1890 was 525, and the increase of passenger cars, 2103.

On 142 out of a total of the 789 systems then existing, a flat rate of fare above five cents was charged. Nearly all of the other systems charged a flat rate of five cents.

The average fare received per passenger and gross earnings per passenger car mile on all systems were as follows:

System of Operation	Receipts per Passenger (Cents)	Receipts per Car Mile (Cents)
Animal	4.75	21.05
Electric	4.84	14.13
Cable	4.43	21.38
Steam	5.07	26.62
Mixed	4.94	25.02

The census of 1890 does not give the total capitalization of all the street railways, but it does state their costs as reported to the Census Bureau.

These costs, which include equipment, real estate and other physical property, are given below. Incomplete figures would also indicate that the capitalization of the properties was about 20 per cent greater than these figures:

System of Operation	Miles of Track	Total Cost	Average Cost per Mile of Track
All systems	8123	$389,357,289	$47,933
Animal traction	5661	195,121,682	34,468
Electric	1262	35,830,950	25,600
Cable	488	76,346,618	156,447
Steam	711	82,058,039	115,412

Between 1890 and the next census of street and electric railways in 1902, the great majority of such systems had changed ownership at much higher figures than their costs and capitalization reported in 1890; in many instances, from 100 to 200 per cent greater.

During the same period, practically all of the properties existing in 1890 were reconstructed, re-equipped and electrified, if not then so operated; and in a large number of cases a goodly portion of such expensive work was repeated once or more times prior to 1902, all of which necessitated enormous additional capital investment.

From the investors' standpoint, this has not always operated to his benefit, but otherwise the public would have had to wait for years to get adequate local transportation facilities, and the financial and other advantages which it has so long derived therefrom.

That which has just been remarked clearly indicates how what is so frequently termed the "over capitalization" of urban and interurban electric railways was primarily brought about.

The next census of population was taken in 1900, but that of street and electric railways, as already stated, not until 1902. To permit a logical comparison of all local traffic conditions in the latter year with those of 1880 and 1890, the population in 1902 is estimated by adding to the census totals of 1900 one-fifth of the total increase which occurred between that year and 1910, when the next census of population was taken. On this basis, the total population of the country in 1902 was approximately 79,190,113, of which 33,162,525 or 41.9 per cent was urban.

There was then a total trackage of 22,577 miles of street and electric railway upon which 60,290 passenger cars were operated, running a total of 1,120,101,944 car miles in the year and averaging 18,578 miles per car.

These cars carried 4,774,211,904 fare passengers and 1,062,403,392 free and on transfers, or a total of 5,826,615,296 passengers, making the average number of fare passengers carried per car 79,176, and of free and on transfers 17,622—a total of 96,808 passengers per car.

Certain other important averages then were:

	Total Population	Urban Population
Per mile of track	3508	1473
Per passenger car	1313	550
Total rides per capita	73	176
Fare rides per capita	60	141
Free rides and on transfers per capita	13	35

The total trackage was then thus operated:

System of Operation	Miles of Track
Total all systems	22,577
Electric	21,908
Animal	259
Cable	241
Steam	170

The average annual increase in miles of track from 1900 to 1902 was 1204, and of passenger cars 2315.

In 1902, the gross passenger earnings averaged but 4.01 cents upon the total of all passengers carried; and then the operation of interurban systems, which charged a fare graduated according to distances, tended to offset the decrease in that average rate of fare caused by the increased issue of transfers when flat rates of fare were charged.

At this date, the average passenger earnings per car mile had decreased to 20.8 cents.

These two conditions show that in practical effect upon passenger earnings, what was equivalent to about a 20 per cent reduction in rates of fare had come between 1890 and 1902.

The next census of street and electric railways was taken in 1907, but, as in 1902, no official total of population was available for that year, so this is approximated by adding seven-tenths of its growth from 1900 to 1910, to the total of population in 1900.

The total of the country's population in 1907 is thus fixed at 87,178,958, of which 39,082,518, or 44.8 per cent, was urban.

The total trackage of street and electric railways was then 34,404 miles, on which 70,016 cars were operated, running a total of 1,583,831,199 car miles and averaging 22,621 miles per car annually. These transported 7,441,114,508 fare passengers and 2,091,966,258 free and on transfers, making a total of 9,533,080,756; thus the average number of fare passengers carried per car was 106,277; and of free and on transfers 29,887;—a total of 136,154 passengers per car annually.

Certain other important averages then were:

	Total Population	Urban Population
Per mile of track	2534	1135
Per passenger car	1245	552
Total rides per capita	108	243
Fare rides per capita	85	187
Free rides and on transfers, per capita	23	56

The total trackage was then thus operated:

Systems of Operation	Miles of Track
Total of all systems	34,404
Electric	34,060
Animal	136
Cable	62
Steam	105
Gasolene motors	41

The average annual increase in miles of track from 1902 to 1907 was 2365 and of passenger cars 1945.

Between these dates practically no increase occurred in the average capitalization per mile of track, and on the face of the returns a slight improvement had been made in the average gross passenger earnings; the earning per total passengers carried being identical with similar figures of 1902, viz., 4.01 cents, while those per passenger car mile had increased to 24.01 cents, and this despite the great increase in transfers issued.

Both of these averages, however, had been most beneficially affected by the enormous increase between 1902 and 1907 in the mileage of interurban systems which charged a graduated fare. Nevertheless, the general trend in the directions just stated is a favorable indication of the future averages of passenger earnings.

The last census of street and electric railways was taken in 1912, but as its results have not as yet been made public, and as the last population census was taken in 1910, to fairly approximate conditions on both of these features at the end of 1912 necessitates various methods of estimate. The total population, based on government approximations made at the first of that year, is considered to be 97,000,000, and that of the urban population 47,532,600, or 49 per cent of the total.

The miles of street and electric railways and the number of passenger cars are determined from unofficial published figures, adjusted to harmonize with a discrepancy which existed between such statistics in 1907 and those of the street and electric railway census in that year. On this basis, at the first of the present year, there were approximately 38,000 miles of such track in the United States, upon which about 75,300 passenger cars were operated.

Passenger traffic and car mileage have been estimated in the following manner:

From such state commission reports as show the increases on these features from 1907 to 1912 the percentages of increases have been averaged, and the results from applying the same to the totals shown in the census of 1907 have been added thereto.

In accordance with these estimates, on January 1, 1913, the total passengers carried approximated 12,755,460,773; fare passengers 9,889,477,000, and those carried free and on transfers 2,865,983,773.

The passenger car mileage is similarly approximated at 1,979,800,000 or 26,292 miles per car annual, so the total number of passengers carried per car was 169,395, of which 131,334 were fare passengers and 38,061 carried free and on transfers.

Certain other important averages are approximately:

	Total Population	Urban Population
Per mile of track	2553	1251
Per passenger car	1288	631
Total rides per capita	132	268
Fare rides per capita	102	208
Free rides and on transfers, per capita	30	60

It is impossible to approximate for 1912 the proportions of the total trackage thus operated by various forms of motive power, the average rates of passenger fares, earnings per car mile and other interesting features. But on the basis taken, the average annual increase in miles of track from 1907 to 1912 was 719 and of passenger cars 5284.

Even though the miles of track and number of passenger cars in 1912 should perchance have been slightly under-estimated, it is apparent that the period from 1907 to 1912 is the first since 1880 when the increase in local transportation facilities has not been proportionately greater than the growth of the totals of both the urban and the entire population of the country; and that during such period the tide turned in the opposite direction.

As will be described in subsequent articles, this condition cannot fail to be a most important factor in causing a change for the better in the net financial results obtained upon investments in urban and interurban electric railways.

INTERURBAN RAILWAY ECONOMIES

By J. G. Barry

Manager, Railway Department, General Electric Company

The interurban railways of America are as indispensable to the communities they serve as are the other great transportation facilities upon which the prosperity of the country so largely depends. It is pointed out in this article that initial economies are imperative if fixed charges are to be kept within such bounds as will permit the paying of dividends. It is shown that one of the greatest factors which will enable reasonable first costs to be secured with efficient and reliable service is the adoption of higher direct current voltages. —Editor.

The electric interurban railway, having educated the public to its advantages, has become as necessary a factor in the transportation industry as the steam railroad, and the demands for adequate interurban facilities are today as insistent as those of steam railroad traffic. Large sections of the country owe their present state of development to its agency, and millions of people are dependent upon the frequent service and cheap transportation which it affords.

Practically all of the existing interurban track was built during the period of rapid interurban development from 1895 to 1907, and at that time well met the traffic requirements. Since the latter date, little new construction has been undertaken, with the result that interurban transportation facilities have not kept pace with the growth and needs of the population. The cessation of activity in this field was due to a variety of causes, but largely to the attitude of the public toward railroad corporations in general, as evidenced by the restriction of franchise privileges and the opposition to the rate increases warranted by higher costs of operation. Under these conditions the difficulty of interesting capital in such enterprises has effectually prevented any general resumption of interurban construction.

While fundamental conditions may not have materially changed for the better, the growing need of increased transportation facilities, particularly in the West and South, has tended to improve the terms under which franchises can be secured, and improvements in apparatus and systems of operation have materially decreased construction and operating costs. As a result the field for profitable interurban development is much broader today than it was six years ago and increased activity in new construction is being evidenced.

In view of the awakening interest in interurban properties, it is the purpose of this article to emphasize some of the factors affecting the success of new enterprises and to point out the greater possibilities offered by the developments of the past few years.

Three elements having an important bearing upon the financial success of a new interurban railway are:

1st. First cost of construction and equipment.

2nd. Operating expenses.

3rd. Reliability of service.

Considering these in order, economy in construction, without sacrifice of low maintenance and reliability of service, is of particular importance, since to attract capital to such enterprises the fixed charges must be kept at a low figure in order to show a satisfactory margin of safety in the bonds. The higher interest rates prevailing at the present time make doubly important the reduction of construction and equipment costs to a minimum.

A study of present conditions affecting the cost of interurban railroad construction, as compared with those existing in 1906 and 1907, indicates possibilities of economies which are not generally appreciated. The principal of these may be enumerated as follows:

1. Elimination of Power House and Transmission Lines

The general tendency toward the centralization of power generation for distribution over considerable areas has resulted in the construction during the past six years of modern and highly efficient steam generating stations and hydro-electric plants, with distributing high tension transmission lines thoroughly covering the surrounding territory. These stations on account of their size and efficiency are able to furnish power at extremely attractive rates, and with a greater degree of reliability than can be secured from small independent railway power stations. The transmission lines are so widely extended that power can usually be purchased delivered at the railway companies' substations, thereby relieving the railroad of the burden of transmission line investment and maintenance. The saving in construction cost of an interurban road effected by the purchase of power may amount to as much as $2500 to $3500 per mile of track, and ordinarily the cost of purchased current at the substations will not be greater than the cost of power at the switchboard in an independent plant. A further possibility of saving in this connection is found in the fact that it is often possible to locate the conversion apparatus in the distributing substations of the power company, where it can be operated by the regular attendants; and in many instances the investment in substations can be entirely eliminated by purchasing direct current power.

2. Elimination of Terminals and Expensive Station Buildings

The earning power of investments in terminals and expensive buildings is likely to be very small for a newly established road and they can well be dispensed with, without impairing the earnings of the road, until such time as increased earnings warrant their cost.

3. Decreased Costs of Equipment

Owing to the better understanding of transportation problems, and of the design of rolling stock, material reductions have been made in the weight of cars and trucks, which in turn have permitted a reduction in the capacity, size and cost of the car motors. Further reduction in weight has been accomplished by the development of ventilated railway motors, which have a considerably greater service capacity than those of equal rating which were standard six years ago. These savings in weight of rolling stock directly affect the cost of the entire electrical equipment of the road, inasmuch as they effect a proportional reduction in power consumption, feeder copper, substations and power stations.

4. Savings in Distributing Systems by Use of the High Tension D-C. System

The development of equipment for operation on trolley potentials of 1200 and 1500 volts has accomplished a very large possible saving in feeder copper and substations. A large percentage of the interurban roads built during the past four years have taken advantage of the economies of the high tension trolley, and such excellent operating results have been secured that potentials of 1200 and 1500 volts have become the recognized standard for new construction.

As an illustration of the above outlined savings in construction cost now effective as compared with 1907, the items affected are given for a road of 50 miles in length on the basis of operating hourly service:

	CONSTRUCTION COST	
	1907 (600 Volts)	1913 (1200 Volts)
Line construction	$142,000	$110,500
Power house	100,000	None
Transmission line	35,000	None
Substations	40,000	18,500
Cars	63,000	51,000
Total	$380,000	$180,000
Net saving		$200,000
Per mile		4,000
Net saving in fixed charges at 6 per cent		12,000

These savings amount to about 15 per cent of the total cost of the road, and effect a reduction in fixed charges of nearly $250 per mile.

Economies in operating expense are a direct result of the factors enumerated above as affecting construction costs. The purchase of power from central station companies results frequently in the elimination of transmission line maintenance and many items of general expense incident to the operation of an independent power station, without any increase in the cost of power at the substations. Where it is possible to consolidate the railway and power substations, the cost of operators can be materially reduced.

The savings introduced by the use of lighter rolling stock are generally conceded to be from 5 to 7 cents annually per pound of weight eliminated, which is equivalent, under the conditions assumed above, to from $500 to $700 per car per year. The effect of car speed and motor gear ratios is now more generally appreciated, and by an intelligent application of this knowledge to their selection, very considerable economies may be effected in power consumption, cost of equipment and general maintenance.

The use of the 1200 or 1500 volt system results in a large saving in substation operation and maintenance, as well as a reduction in power consumption, due to the higher substation load factor and increased efficiency of power distribution. In the case assumed these savings would amount to approximately $6000 annually.

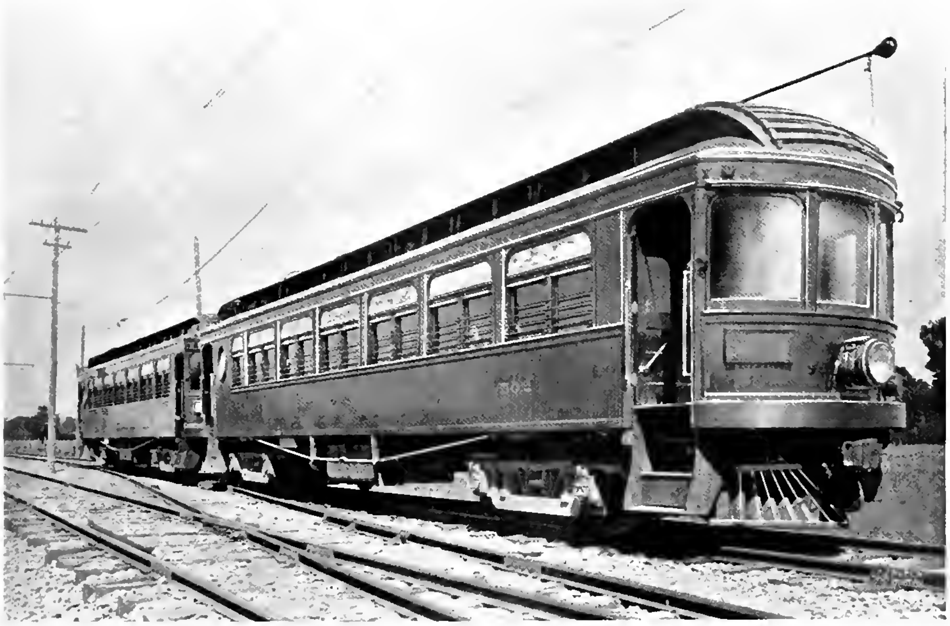
The summation of the possible savings in operation in the service assumed as typical of general conditions would be as follows:

	Annual Saving
Fixed charges	$12,000
Lighter rolling stock	3,000
Substation operation and maintenance	5,000
Power distribution	1,000
Total net saving	$21,000

This is equivalent to $420 per mile of road,—an amount sufficient to pay an additional dividend of $1\frac{1}{2}$ per cent on a total capitalization of $28,000 per mile.

Reliability of service is a necessary condition to the success of interurban operation. A full recognition of this fact must militate against any economies in construction cost accomplished at its expense. New railroads are able to take advantage of the many important improvements which have been made in railway equipment during the past six years. These have uniformly been in line with affording greater reliability of operation, so that today when due care is taken in the proper selection of equipment with regard to construction cost, economy of operation and service reliability, the assurance of profitable interurban operation is materially greater than ever before.

A better appreciation of the conditions affecting electric railway construction and operation, together with the renewed demand for transportation facilities, should greatly stimulate the building of interurban roads, and it is to be expected that the operating results of roads constructed during the past year which have taken full advantage of the economy factors outlined above will cause a renewal of confidence in the profit and safety of investments in this important form of public utility.



THE OPERATION OF THE ELECTRIFIED PORTION OF THE WEST JERSEY AND SEASHORE RAILROAD

By B. F. Wood

Assistant Engineer Pennsylvania Railroad

The West Jersey & Seashore is one of the most noted electric railways in the country and its operation has been watched with keen interest since the change from steam to electric traction was made. Mr. Wood's present article, coupled with a paper read by him before the A.I.E.E. in 1911, gives the complete financial and technical history of the operation of this road. In this article the author gives complete operating statistics for the year 1912, the data being so complete that they can be used as a basis of comparison with other installations, which attaches special importance to the contribution.—Editor.

There was presented before the 28th Annual Convention of the American Institute of Electrical Engineers at Chicago on June 28, 1911, a paper in which data were included pertaining to the operation of the electrified portion of the West Jersey & Seashore Railroad covering the year 1910. It was thought that it would be of value to engineers concerned in the operation of electric railroads to have the operating data for the year 1912. By reference to the A.I.E.E. Proceedings* will be found a description of the electrified section as well as a brief description of the equipment used.

The data given herein are compiled under the following headings:

	TABLE NO.
Passenger Train Statistics, Cost of Operation in Cents per Car Mile	1
Cost of Operation of Westville Power Station	2
Cost of Maintenance of Transmission Systems	3
Cost of Operation and Maintenance of Substations	4
Renewal of Parts of Car Equipment	5
Gear and Pinion Breakages	6
Detentions to Passenger Trains (all causes)	7
Detentions due to Failure of Electric Train Equipment	8
General Power Data	9

Cost of Operation and Maintenance

Table 1 shows the total cost of operation in cents per car mile. The headings of this statement are self-explanatory with the exception of "Other Expenses," which includes cost of maintenance of way and structures, dispatching trains, telephone and telegraph, crossing gatemen, together with traffic expenses and general expenses. This statement differs from those for 1909 and 1910 published as before mentioned, in that an item covering depreciation of electric equipment of cars has been added, and the items under the heading "Electric Power at Car Shoes" include depreciation on power plant, substations and transmission systems, whereas on previous statements this has not been included. Therefore the total expenses per car mile for 1912 are considerably higher than those for 1910, being 22.61 cents and 18.19 cents respectively.

* Transactions of A.I.E.E., Volume XXX, pages 1371-1390.

Table 2 shows the cost of operation and maintenance of the Westville power station. This statement is subdivided under the general headings of "Operation and Maintenance" and under the further subheadings of "Material" and "Labor," and shows the total monthly cost as well as the cost in cents per kw-hr. for each item. The total net output of the station, pounds of coal per kw-hr., and cost of coal per ton are also shown.

Compared with the same items for 1910, the output of the power station in kw-hr. has increased approximately 13.5 per cent; the total cost of operation per kw-hr. has dropped from 5.42 cents to 5.30 cents, and the pounds of coal per kw-hr. has dropped from 3.246 to 3.223.

Table 3 shows the cost of maintenance of the transmission systems, which includes the high-tension transmission, overhead trolley, third rail and track bonding. This statement gives the total maintenance cost and the average cost per mile per month for each of the above items, which slightly exceeds the cost during the year 1910.

The cost of operation and maintenance of the eight substations is given by months in Table 4, as well as the cost per kw-hr. and the direct current output at 700 volts.

Renewal of Parts of Car Equipment

The number of renewals of the various parts of car equipment is given by months in Table 5. Since the car mileage for the year was 4,647,236, the number of car miles per third rail shoe replaced was 5067.

As each car is equipped with four shoes this gives an average life of 20,268 miles per shoe. Likewise the number of car miles per brake shoe replaced was 523, making the average life of each brake shoe 4184 miles.

The number of replacements of the remaining items is governed rather by special occurrences than by mileage, with the exception of the lamps, the average life of which is not readily obtainable. It might be mentioned here that a continuous test was made on the 15 watt, 125 volt tungsten lamp, now used, burning five in series, and the average life exceeded 2000 hours, when the test was discontinued.

Table 6 shows the number of motor gear and pinion breakages by months.

Detentions to Train Service

A detailed statement of the detentions to electric train service occurring during the year is given in Table 8. The column headed "Number of Detentions" means number of trains detained and that headed "Minutes Detention" shows the train minutes of detention for each cause. The column headed "Car Miles per Minute of Detention" shows the total car miles per minute of detention for each cause. It will be noted that, of the total number of train detentions, but 7.478 per cent were caused by motive power failures. Of this percentage 4.057 per cent of the detentions were caused by failure of train equipment, as shown in detail in Table 7. This statement comprises both mechanical and electrical failures of train equipment.

Omitting the failures of train equipment from the total motive power failures, we see that 3.421 per cent of the total number of detentions are caused by interruptions to service due to power plant, substations, and transmission systems, resulting in 5.925 per cent of the total number of train minutes detention. This record attests to the reliability of the electric system, the total number of failures due to this equipment being exceeded by those caused on account of baggage, express and mail, heavy travel, train connections, traffic ahead, held at signal, picking up cars, and signal failures.

Table 9 shows by months certain general power data collected from various other tables. This statement shows the kw-hr. output of the power station; the cost in mils per kw-hr. output, not including depreciation; pounds of coal per kw-hr.; and the efficiency of transmission and conversion from the alternating current bus in the power station to the direct current bus in the substations.

TABLE 1
WEST JERSEY AND SEASHORE RAILROAD COMPANY
ELECTRIC TRAIN SERVICE
PASSENGER TRAIN STATISTICS
COST OF OPERATION IN CENTS PER CAR MILE
YEAR 1912

1912	Repairs Electric Equipment of Cars	Repairs Passenger Cars	Other Maintenance of Equipment Costs	Electric Power at Car Shoes	Yard Service Shifting Costs	Motormen	Trainmen	Train Supplies and Expenses	Total	Depreciation of Electric Equipment	Other Expenses	Total Expenses	Car Miles, Total	Average Cars per Train
January	0.82	1.82	0.40	5.60	0.54	0.93	1.67	1.52	13.30	1.12	11.32	25.74	333,588	3.452
February	2.36	1.98	0.22	4.43	0.54	0.99	1.75	1.27	13.54	1.28	12.51	27.33	292,204	3.293
March	1.46	2.44	0.17	5.45	0.48	0.96	1.71	1.21	13.87	1.47	11.39	26.73	318,750	3.364
April	1.13	1.07	0.06	5.75	0.45	0.86	1.56	1.08	11.96	1.52	8.36	21.84	371,887	3.714
May	0.91	0.62	0.18	5.69	0.47	0.91	1.60	0.74	11.12	1.68	10.65	23.45	357,745	3,635
June	1.21	0.81	0.18	5.12	0.42	0.85	1.50	0.54	10.63	1.58	9.26	21.47	417,891	3.790
July	0.47	0.66	0.14	4.67	0.38	0.86	1.45	0.45	9.08	1.84	6.98	17.90	540,933	3.769
August	0.59	0.59	0.10	4.24	0.33	0.79	1.36	0.41	8.41	1.71	6.56	16.68	593,667	4.069
September	0.49	0.62	0.14	4.58	0.40	0.90	1.58	0.47	9.18	1.62	8.47	19.27	461,557	3.547
October	0.79	0.84	0.17	5.57	0.50	0.96	1.80	0.60	11.23	1.61	12.65	25.49	327,025	3.421
November	0.93	1.13	0.23	5.70	0.52	0.97	1.88	0.93	12.29	1.46	11.38	25.13	310,104	3.347
December	1.16	1.31	0.77	5.66	0.51	0.95	1.81	0.93	13.10	1.69	15.98	30.77	321,285	3.398
Year	0.96	1.07	0.22	5.10	0.43	0.90	1.61	0.79	10.08	1.58	9.95	22.61	4,647,236	3.598

TABLE 2

WEST JERSEY AND SEASHORE RAILROAD

ELECTRIC TRAIN SERVICE

COST OF OPERATION AND MAINTENANCE OF WESTVILLE POWER STATION

YEAR 1912

		Items	January Total	January Cents per Kw-Hr.	February Total	February Cents per Kw-Hr.	March Total	March Cents per Kw-Hr.	April Total	April Cents per Kw-Hr.	May Total	May Cents per Kw-Hr.	June Total	June Cents per Kw-Hr.
Operation	Labor	Boiler Room	128746	0.044	131753	0.050	125114	0.047	123036	0.049	115194	0.050	120858	0.049
		Turbine Room	83681	0.028	83032	0.032	83403	0.031	82574	0.033	83128	0.036	81174	0.033
		Electrical	14621	0.005	14300	0.005	14641	0.006	14765	0.006	14510	0.067	14582	0.006
		Supervision—Janitors and Watchmen	16758	0.006	17610	0.067	17141	0.007	16916	0.006	16770	0.007	17348	0.007
		Total Operating Labor	243806	0.083	246695	0.094	240299	0.091	237291	0.094	229602	0.099	233962	0.095
	Material	Coal	1097783	0.373	925717	0.352	952923	0.361	908182	0.361	846612	0.367	936027	0.382
		Water	4167	0.001	4167	0.002	4167	0.001	4167	0.002	4166	0.002	4166	0.002
		Lubricants	5267	0.002	13730	0.005	8986	0.003	7673	0.003	11132	0.005	417	0.000
		Miscellaneous Material	11495	0.004	12485	0.005	14566	0.006	16315	0.006	10760	0.005	11900	0.005
		Miscellaneous Charges	12961	0.005	17110	0.006	10992	0.004	17955	0.007	12413	0.005	26066	0.011
		Total Operating Material	1131676	0.385	973209	0.370	991634	0.375	954322	0.379	885113	0.384	978576	0.400
		Total Operation	1375482	0.468	1219901	0.464	1231933	0.466	1191613	0.473	1115015	0.483	1212538	0.495
Maintenance	Labor	Building	1219	0.000	1242	0.000	532	0.000	8381	0.003	15758	0.007		
		Boiler Room	10868	0.014	28192	0.011	29990	0.012	13583	0.005	16793	0.007	7954	0.003
		Turbine	7580	0.003			8165	0.003	3893	0.002	9480	0.004	22451	0.009
		Auxiliary Apparatus	3399	0.001	6081	0.002	5563	0.002	5556	0.002	2435	0.001	4767	0.002
		Electrical	48	0.000	475	0.000			765	0.000	1039	0.001	271	0.000
		Piping	3795	0.001	7163	0.003	8989	0.003	11295	0.005	6277	0.003	4510	0.002
		Miscellaneous			3181	0.001			2703	0.001	2772	0.001	3738	0.002
		Total Maintenance Labor	56939	0.019	46337	0.017	53239	0.020	46173	0.018	54554	0.024	43721	0.018
	Material	Building	3740	0.001	8241	0.003	166	0.000	5496	0.002	7763	0.003	1460	0.001
		Boiler Room	58235	0.019	44550	0.017	47314	0.018	37261	0.015	66546	0.028	35228	0.014
		Turbine	717	0.000	27	0.000	14259	0.005	3699	0.001	10733	0.005	101257	0.043
		Auxiliary Apparatus	21380	0.008	497	0.000	1017	0.000	1508	0.001	1564	0.001	5667	0.002
		Electrical	295	0.000	35696	0.014	71	0.000	6222	0.003	119	0.000	75	0.000
		Piping	3942	0.002	14173	0.005	28504	0.011	7348	0.003	1325	0.000	5191	0.002
		Miscellaneous	9268	0.003	2117	0.001	3013	0.001	242	0.000	15574	0.007	996	0.000
		Total Maintenance Material	97577	0.033	105301	0.040	94044	0.036	61976	0.025	103654	0.044	152874	0.062
		Total Maintenance	154516	0.052	151641	0.057	147283	0.056	108149	0.043	158208	0.068	196595	0.080
Summary		Total Labor	300745	0.102	293032	0.111	293538	0.111	283464	0.112	284456	0.123	277683	0.113
		Total Material	1229253	0.418	1078513	0.410	1085678	0.411	1016296	0.404	988767	0.428	1131450	0.462
		Total Labor and Material, Power Station Proper	1529998	0.520	1371545	0.521	1379216	0.522	1299762	0.516	1273223	0.551	1409133	0.575
		Other Items Charged to Power Station Accounts	24524	0.008	27341	0.010	25040	0.010	25178	0.010	21325	0.009	24118	0.010
		Total	1554522	0.528	1398886	0.531	1404256	0.532	1324940	0.526	1294548	0.560	1433251	0.585
		Net Kw-Hr.	2,940,500		2,633,600		2,640,500		2,516,000		2,309,000		2,449,800	
		Pounds Coal per Kw-Hr.	3.289		3.097		3.180		3.180		3.229		3.294	
		Cost of Coal per 2000 Pounds	$2.26		$2.27		$2.27		$2.27		$2.27		$2.32	

TABLE 2 (Continued)

		Items	July Total	July Cents per Kw-Hr.	August Total	August Cents per Kw-Hr.	September Total	September Cents per Kw-Hr.	October Total	October Cents per Kw-Hr.	November Total	November Cents per Kw-Hr.	December Total	December Cents per Kw-Hr.	Year Total	Year Cents per Kw-Hr.
Operation	Labor	Boiler Room	132988	0.044	131239	0.041	126028	0.046	119961	0.051	119490	0.048	126013	0.044	1500720	0.047
		Turbine Room	86990	0.029	86109	0.027	87916	0.032	85185	0.036	83344	0.033	85589	0.030	1012125	0.031
		Electrical	14995	0.005	14549	0.004	14618	0.005	15178	0.007	14630	0.006	14647	0.005	176036	0.005
		Supervision—Janitors and Watchmen	18446	0.006	17164	0.006	18215	0.007	17373	0.008	17791	0.007	18277	0.007	209809	0.007
		Total Operating Labor	253419	0.084	249061	0.078	246777	0.090	237697	0.102	235255	0.094	244526	0.086	2898690	0.690
	Material	Coal	1097388	0.363	1159965	0.365	1010749	0.370	852922	0.364	925229	0.370	1008183	0.351	11721710	0.365
		Water							1746	0.001					26746	0.001
		Lubricants	20343	0.007	4807	0.001	3062	0.001	5984	0.002	232	0.000	7890	0.003	89523	0.003
		Miscellaneous Material	16080	0.005	18626	0.006	18723	0.007	19776	0.008	17593	0.007	24578	0.008	192927	0.006
		Miscellaneous Charges	11786	0.004	12654	0.004	10451	0.004	10924	0.005	10912	0.004	11256	0.004	165483	0.005
		Total Operating Material	1145597	0.379	1196052	0.376	1042985	0.382	891352	0.380	953966	0.381	1051907	0.366	12196389	0.380
		Total Operation	1399016	0.463	1445113	0.454	1289762	0.472	1129049	0.482	1189221	0.475	1296433	0.452	15095079	0.470
Maintenance	Labor	Building	5406	0.002	1629	0.001	1361	0.000	2352	0.001	2728	0.001	9908	0.004	50546	0.002
		Boiler Room	6462	0.002	9704	0.003	6002	0.002	12937	0.005	14437	0.006	17603	0.006	204522	0.007
		Turbine	2696	0.001	2043	0.001			295	0.000	[illegible]	0.000	1318	0.000	58838	0.002
		Auxiliary Apparatus	4065	0.001	1986	0.000	675	0.000	2594	0.001	[illegible]	0.001	3933	0.001	43854	0.001
		Electrical	225	0.000							10474	0.004	146	0.000	13443	0.000
		Piping	3326	0.001	5163	0.002	7378	0.003	6323	0.003	6220	0.003	3216	0.001	73985	0.002
		Miscellaneous	1310	0.001			1530	0.001	1672	0.001	2316	0.001	2227	0.001	21452	0.001
		Total Maintenance Labor	23490	0.008	20825	0.007	16946	0.006	26173	0.011	39892	0.016	38351	0.013	466640	0.015
	Material	Building	2320	0.001	3386	0.001	30310	0.011	1969	0.001	4235	0.002	7577	0.003	76966	0.002
		Boiler Room	10194	0.003	14333	0.005	16342	0.006	18260	0.008	23867	0.010	27819	0.010	399949	0.013
		Turbine	67348	0.022	165	0.000			290	0.000	270	0.000			200365	0.006
		Auxiliary Apparatus	4607	0.002	3946	0.001	4344	0.002	7358	0.003	11109	0.004	1466	0.000	64463	0.002
		Electrical			273	0.000	278	0.000	100025	0.043	17974	0.007	95819	0.033	257077	0.008
		Piping	3392	0.001	4183	0.001	8193	0.003	7619	0.003	5168	0.002	4371	0.002	93469	0.003
		Miscellaneous	6188	0.002	1118	0.001	6910	0.001	6823	0.003	6086	0.002	22153	0.008	77288	0.002
		Total Maintenance Material	94019	0.031	27404	0.009	62377	0.023	142344	0.061	68709	0.027	159205	0.056	1169517	0.036
		Total Maintenance	117539	0.039	48229	0.016	79323	0.029	168517	0.072	108601	0.043	197556	0.069	1636157	0.051
Summary		Total Labor	276909	0.092	269886	0.085	263723	0.096	263870	0.113	275147	0.110	282877	0.100	3365330	0.105
		Total Material	1239646	0.410	1223456	0.385	1105362	0.405	1033696	0.441	1022675	0.408	1211112	0.422	13365906	0.416
		Total Labor and Material, Power Station Proper	1516555	0.502	1493342	0.470	1369085	0.501	1297566	0.554	1297822	0.518	1493989	0.522	16731236	0.521
		Other Items Charged to Power Station Accounts	26495	0.009	25558	0.008	23914	0.008	23155	0.010	21889	0.009	25722	0.008	294259	0.009
		Total	1513050	0.511	1518900	0.478	1392999	0.509	1320721	0.564	1319711	0.526	1519711	0.530	17025495	0.530
		Net Kw-Hr.	3,020,400		3,179,800		2,734,500		2,342,100		2,501,200		2,871,600		32,139,900	
		Pounds Coal per Kw-Hr.	3.159		3.19		3.228		3.181		3.191		3.066		3.223	
		Cost of Coal per 2000 Pounds	$2.30		$2.25		$2.29		$2.29		$2.29		$2.29		$2.26	

TABLE 3
WEST JERSEY AND SEASHORE RAILROAD ELECTRIC TRAIN SERVICE
COST OF MAINTENANCE OF TRANSMISSION SYSTEMS
YEAR 1912

1912	HIGH TENSION		OVERHEAD TROLLEY		THIRD RAIL		RUNNING-TRACK BONDING	
	Total	Per Mile	Total	Per Mile	Total	Per Mile	Total	Per Mile
January	$513.18	$7.40	$283.90	$29.73	$1542.09	$10.88	$1023.65	$6.82
February	308.80	4.46	254.31	26.63	2006.19	14.15	77.48	0.52
March	423.29	6.11	923.07	96.67	1191.80	8.41	241.27	1.60
April	297.29	4.29	602.55	63.10	831.38	5.86	13.62	0.09
May	1014.75	14.64	1590.32	166.80	968.53	6.83	46.91	0.31
June	277.81	4.01	272.81	28.55	1289.65	9.10	617.15	4.11
July	535.66	7.73	390.41	40.88	1270.85	8.97	132.15	0.88
August	582.05	8.40	424.98	44.50	929.01	6.55	122.44	0.81
September	205.34	2.96	318.48	33.35	870.25	6.14	220.02	1.47
October	308.99	4.46	562.95	58.95	1032.83	7.29	22.32	0.15
November	262.50	3.79	241.35	25.27	1373.48	9.69	333.42	2.22
December	331.10	4.78	295.90	30.98	739.67	5.22	464.51	3.09
Total and avg. per mile per month	$5060.76	$7.30	$6161.03	$64.51	$14045.73	$9.91	$3228.84*	$1.79

*Credit by scrap of $86.10.

TABLE 4
WEST JERSEY AND SEASHORE RAILROAD
ELECTRIC TRAIN SERVICE
COST OF OPERATION AND MAINTENANCE OF SUBSTATIONS
YEAR 1912

1912	TOTAL FOR EIGHT SUBSTATIONS				
	Operation	Maintenance	Total	Cost per Kw-Hr.	Substation Output Kw-Hr. 675 Volts Direct Current
January	$1813.94	$227.78	$2041.72	$0.000846	2,348,000
February	1793.49	224.77	2018.26	0.000950	2,065,300
March	1727.91	249.19	1977.10	0.000948	2,026,300
April	1712.95	192.90	1905.85	0.000961	1,929,300
May	1752.04	347.39	2099.43	0.001168	1,745,800
June	1705.59	324.18	2029.77	0.001092	1,859,300
July	1699.99	170.18	1870.17	0.000789	2,321,700
August	1703.30	79.37	1782.67	0.000717	2,433,200
September	1765.03	267.72	2032.75	0.000977	2,029,100
October	1776.44	478.63	2255.07	0.001273	1,714,800
November	1762.66	99.10	1861.76	0.000954	1,894,400
December	1740.58	68.34	1808.92	0.000830	2,113,900
Total for year	$20953.92	$2729.55	$23683.47	$0.000967	24,481,100

TABLE 5
WEST JERSEY AND SEASHORE RAILROAD
ELECTRIC TRAIN SERVICE
RENEWAL OF PARTS OF CAR EQUIPMENT
YEAR 1912

Parts of Equipment	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Third Rail Shoes Replaced	168	75	125	76	66	108	30	105	54	42	35	33	917
Brake Shoes Replaced	404	527	514	538	585	687	873	1149	1085	515	1087	919	8883
Trolley Poles Bent	4	2	7	6	1	1	2	5	3	0	3	4	38
Trolley Poles Broken	0	0	0	0	0	0	1	2	7	0	1	2	13
Trolley Poles Missing or Replaced	2	2	3	2	0	4	1	2	7	0	1	2	26
Trolley Wheels Lost or Replaced	2	22	12	10	33	7	14	22	4	14	21	32	193
Trolley Retriever Dogs Broken	0	0	0	0	0	0	0	0	0	0	0	0	0
Trolley Harps Broken or Replaced	0	0	2	1	3	0	4	5	7	0	2	3	27
800 Ampere Fuses Blown (Shoe)	150	121	87	172	154	193	189	197	179	132	154	161	1889
800 Ampere Bus Fuses Blown	26	5	103	0	0	3	10	6	3	2	6	7	171
800 Ampere Trolley Fuses Blown	20	16	12	25	15	51	25	29	12	14	20	25	264
25 Ampere Controller Fuses Blown	5	0	4	3	3	0	1	0	0	1	0	1	18
20 Ampere No. 2 Heater Fuses Blown	2	5	5	6	2	2	0	0	13	5	38	8	86
10 Ampere No. 1 Heater Fuses Blown and Comp. Fuses Blown	5	8	10	7	1	2	4	3	24	11	27	33	135
5 Ampere Cab Heater Fuses Blown	0	0	0	0	0	0	0	0	0	0	0	0	0
4 Ampere Control Cable Fuses Blown	8	0	0	0	0	2	4	3	0	0	3	1	21
2 Ampere Headlight Fuses Blown	9	5	5	2	0	2	6	8	2	4	1	5	49
1 Ampere Car Light Fuses Blown	8	2	6	2	3	0	2	2	0	3	1	7	36
50 C-P. Headlights Burned Out	12	7	3	3	1	12	16	5	6	14	28	23	140
50 C-P. Headlights Missing	7	1	2	4	0	1	0	3	4	1	6	0	29
16 C-P. Lamps Burned Out	135	188	159	135	93	120	57	78	68	52	25	65	1175
16 C-P. Lamps Missing	44	28	91	39	75	23	2	8	6	0	3	0	319
Gauge Lamps Replaced	4	8	5	3	1	8	19	9	1	4	5	7	74
16 C-P. Lamps Broken	5	0	1	3	2	1	2	0	0	0	0	0	14
36 Watt Lamps Replaced						9	49	35	17	129	19	48	306
15 Watt Lamps Replaced						1	24	17	40	102	153	277	614

TABLE 6
WEST JERSEY AND SEASHORE RAILROAD
ELECTRIC TRAIN SERVICE
GEAR AND PINION BREAKAGES
YEAR 1912

1912	Number
January	2
February	2
March	0
April	2
May	0
June	1
July	0
August	1
September	2
October	1
November	1
December	0
Total	12

TABLE 7

WEST JERSEY AND SEASHORE RAILROAD

ELECTRIC TRAIN SERVICE

REPORT OF DETENTIONS TO PASSENGER TRAINS DUE TO FAILURES OF TRAIN EQUIPMENT FOR YEAR 1912

Date	Master Control — Switches Defective — Master Control	Master Control — Switches Defective — Circuit Breaker	Master Control — Control Fuse Blown	Master Control — Train Cable Jumper — Train Cable	Master Control — Train Cable Jumper — Grounded	Master Control — Train Cable Jumper — Loose	Motor Control — Relay — Current Limit	Motor Control — Relay — Potential	Motor Control — Controller	Motor Control — Fuses Blown — Main	Motor Control — Fuses Blown — Shoe	Motor Control — Fuses Blown — Trolley	Motor Control — Bus Line — Bus	Motor Control — Bus Line — Grounded	Motor Control — Jumper Defective	Motor Control — Circuit Breaker Defective	Motor Control — Reverser Defective	Motor Control — Contactors Defective	Motor Control — Resistance Grids	Motor Control — Snow in Contactor Box	Motors — Armature — Grounded	Motors — Armature — Short Circuited	Motors — Armature — Open Circuited	Motors — Fields Defective	Motors — Leads Defective	Motors — Flash-overs	Motors — Brush-holder	Motors — Broken Gears	Motors — Gear Case Broken	Motors — Broken Pinions	Motors — Broken Armature Shaft
[illegible]			1 2						2 7	1 2	1 10	1 6	2 5		2 7		2 4	5 22		5 70	4 9							1 2	1 3	1 3	1 5
[illegible]								1 1	2 5	1 1	1 11	2 10						2 4			3 7							3 13			
Mar.		1 4				1 4			1 3		2 72		1 2	1 3			1 3	4 10						2 5			1 17	1 3			
Apr.				1 99			1 1	1 2	2 12							3 9	2 13	2 4			3 11						1 3	1 16			1 3
May						2 5			1 1				1 2	1 3				3 5													
June			1 2														2 10	4 15			1 1					2 4					
July			2 6					1 3				1 13	1 2	1 2				6 15													
Aug.									1 9				1 2				2 3	4 10			1 2										
Sept.							1 4									1 3		4 16							1 4		1 2				
Oct.			[illegible] 6			1 8												2 5						1 5				1 3			
[illegible]			[illegible] 41	[illegible]					1 2			2 2					1 3	4 19			1 4										1 4
[illegible]						1 7	1 2						1 2					2 6	1 1												
[illegible]			10 77	2 105		5 24	3 7	3 6	10 39	2 3	4 93	6 31	7 15	3 8	2 7	4 12	10 36	42 131	1 1	5 70	13 34			3 10	1 4	2 4	3 22	7 37	1 3	1 3	3 12

[illegible] indicates the number of detentions, while the lower figure indicates the total time of detentions in

TABLE 7 (Continued)

WEST JERSEY AND SEASHORE RAILROAD

ELECTRIC TRAIN SERVICE

REPORT OF DETENTIONS TO PASSENGER TRAINS DUE TO FAILURES OF TRAIN EQUIPMENT FOR YEAR 1912

AIR BRAKES															TROLLEY				HEAD-LIGHT		HOT BEARINGS				COUPLERS		TR'KS						CAR MILES		
Compressor		Brakes			Hose				Valves																										
Fuse Blown	Governor Defective	Pump Defective	Fail to Release	Equalize	Defective Rigging	Burst	Defective	Pipes Broken or Defective	Feed	Triple	Brake	Drain Cock	Emergency Attach't	Slack Adjuster	Poles off Wire	Wheels Defective	Ropes Broken	Retriever	Fuse Blown	Burnt Out	Armature	Motor Axle	Journal	Compressor Motor	Broken	Defective	Contact Shoes	Signal—Whistle and Bell	Whistle Defective	Miscellaneous	Total Failures	Minutes Lost	Total	Per Detention	Per Minute of Detention
	1 2				1 6										**2** **7**		2 11		6 21	4 15			1 5				2 7				47	224	333588	7091	1489
															1 **2**					1 4								1 11			17	67	292804	17224	4370
																		1 2		1 2		3 6							2 4		23	140	321750	3989	2298
					2 7		1 3								**1** **1**		2 9						1 4			2 3	1 21				27	220	371887	13774	1690
			2 5									1 6					3 7					1 4	2 25				1 1		1 3		19	67	357745	18829	5339
					3 13						1 5				**2** **5**					1 2		1 4	8 79				1 1			1 14	26	150	417891	16072	2785
										9 33					**2** **4**			1 1	2 20	2 7			1 8					3 4	1 3		31	117	540933	17449	4623
1 2	1 3		2 17		1 6	1 10		1 6	1 5	3 10					**4** **13**					4 15							1 2			1 6	26	108	593667	22833	5496
	1 3													1 13	**1** **4**					8 19								1 3	1 1	2 16	22 22	84	461557	20979	5494
1 1					1 5				1 5											4 10	1 3						1 7				17	58	327025	19236	5638
						1 4				1 7					**2** **3**				1 3	6 22										1 2	24	119	310104	12921	2606
			1 11							1 4					**3** **10**				3 13	5 9			2 2				1 14		2 6		21	77	321285	15299	4172
2 3	3 8		5 33		8 37	2 14	1 3	1 6	2 10	14 54	1 5	1 6		1 13	**18** **49**		7 27	2 3	12 57	36 105	1 3	5 14	15 123			2 3	8 53	5 18	7 17	5 38	300	1431	4617236	15491	3247

Figures in **bold type** not included in totals.

TABLE 8
WEST JERSEY AND SEASHORE RAILROAD ELECTRIC TRAIN SERVICE
TRAIN DETENTIONS FOR YEAR 1912

Causes	TRAIN DETENTIONS, NUMBER, DURATION AND PER CENT FOR VARIOUS CAUSES				
	Number of Detentions		Minutes Detentions		Car Miles per Minute Detention
	Total	Per Cent of Grand Total	Total	Per Cent of Grand Total	
TRANSPORTATION					
Boat Connection	127	1.717	477	1.919	9,742.63
Baggage, Express and Mail	1230	16.633	4481	17.322	1,037.09
Heavy Travel	1581	21.379	3920	15.153	1,185.52
Collecting Tickets	112	1.515	364	1.404	12,767.13
Train Connections	918	12.414	3600	13.916	1,290.90
Traffic Ahead	1143	15.456	3886	15.022	1,195.89
Held at Signal	684	9.250	2029	7.842	2,290.41
Stops on Order	27	0.365	89	0.341	52,216.14
Fast Schedule	18	0.244	28	0.105	165,972.71
Picking Up and Cutting Off Cars	262	3.543	813	3.141	5,716.16
Signal Failure	272	3.678	1033	3.991	4,498.78
Accidents	30	0.406	478	1.845	9,722.25
Obstructions	60	0.811	478	1.845	9,722.25
Speed Limit	75	1.014	100	0.384	46,472.36
Miscellaneous	226	3.056	808	3.121	5,751.53
Total Transportation	6765	91.481	22584	87.351	205.78
MOTIVE POWER					
Power House Trouble	1	0.014	2	0.055	2,323,618.00
High Tension Line Trouble	33	0.446	380	1.466	12,229.57
Lightning (Affecting Transmission)	39	0.527	210	0.809	22,129.69
Overloads in Substations	73	0.987	178	0.685	26,108.07
Third Rail Shorts	14	0.189	82	0.314	56,673.61
Third Rail Out of Place	1	0.014	4	0.013	1,161,809.00
Third Rail Protection Out of Place	1	0.014	20	0.075	232,361.80
Trolley Wire Trouble	48	0.649	272	1.049	17,085.43
Train Equipment	300	4.057	1431	5.530	3,247.54
Sleet on Third Rail	43	0.581	391	1.509	11,885.51
Total Motive Power	553	7.478	2970	11.455	1,564.73
WEATHER CONDITIONS					
Snow, Head Winds, Wet Rail	43	0.581	208	0.802	22,342.48
Fog	34	0.460	102	0.392	45,561.13
Total Weather Conditions	77	1.011	310	1.194	14,991.08
Grand Total	7395	100.000	25864	100.00	179.68

Total Car Mileage, 4,647,236. Car Miles per Detention, 628.40. Car Miles per Minute of Detention, 179.68.

TABLE 9
WEST JERSEY AND SEASHORE RAILROAD ELECTRIC TRAIN SERVICE
GENERAL POWER DATA

	Alternating Current Kw-Hr. Power Station Output	Cost in Mils per Kw-Hr. Output	Lb. of Coal Kw-Hr. Output	Efficiency Power Station Bus to Substation Bus
January	2,940,500	5.285	3.289	83.3
February	2,633,600	5.313	3.097	81.7
March	2,640,500	5.318	3.180	80.0
April	2,516,000	5.266	3.180	80.0
May	2,309,900	5.604	3.229	79.0
June	2,449,800	5.850	3.294	79.5
July	3,020,400	5.109	3.159	80.6
August	3,179,800	4.776	3.190	80.4
September	2,734,500	5.094	3.228	78.1
October	2,342,100	5.639	3.181	77.1
November	2,501,200	5.276	3.191	77.2
December	2,871,600	5.292	3.066	75.8
Average for Year	2,678,325	5.319	3.193	79.6

THE WASHINGTON, BALTIMORE & ANNAPOLIS ELECTRIC RAILROAD FROM AN OPERATING STANDPOINT

By J. J. Doyle

Vice President and General Manager, Washington, Baltimore & Annapolis Electric R. R., Baltimore, Md.

The operation of the Washington, Baltimore & Annapolis Railroad as a 1200-volt system is of special interest, as it will be remembered that this road was formerly operated as a single-phase system. The costs of operation and maintenance of car equipments and of substation apparatus, as set forth in this article, reflect the greatest credit on the management of the road, and are also an eloquent tribute to the good inherent qualities of higher potential direct-current apparatus; the operation on 1200 volts direct-current having shown wonderful economies. Mr. Doyle has given statistics for the years 1910, 1911, 1912, and for the first six months of 1913.—Editor.

In 1908 the Washington, Baltimore and Annapolis Electric Railroad Company completed the construction of its double track interurban line from its terminal in the heart of the business district of Baltimore to the intersection of the Washington Railway and Electric Company tracks at the District of Columbia line. A contract was entered into with the Washington Railway and Electric Company to operate over their Columbia division from the above mentioned point to the new terminal, which was then located at the corner of 15th and H Streets, Northeast, in the City of Washington. This terminal was known as "White House Station."

The old Annapolis and Elkridge Railroad was constructed in 1838 from a point on the Baltimore & Ohio Railroad, known as Annapolis Junction, to the city of Annapolis, a distance of twenty miles. In addition to connecting with the Baltimore & Ohio Railroad, this line also connected with the Pennsylvania Railroad at Odenton, and was crossed by the new interurban line at a point now known as Naval Academy Junction, which is fourteen miles from Annapolis, twenty-five miles from the center of Washington, and fifteen miles from the center of Baltimore. This road was later known as the Annapolis, Washington and Baltimore Railroad, and in 1907, was acquired by the Washington, Baltimore and Annapolis Electric Railroad Company, and steps were immediately taken to electrify it throughout. The electrification was completed in the latter part of 1907, and in the early part of the following year a new interurban electric service was established between the cities of Washington, Baltimore and Annapolis. This new system was then operated as a single-phase road using 6600 volts, 25 cycle current.

When the road first started operating, twenty-three cars of the Pullman passenger type and two motor equipped freight cars were put in service. These cars were 62 ft. $2\frac{1}{2}$ in. in length over all and weighed approximately sixty tons, and, on account of their size and weight, it was impossible to operate them over the underground conduit section in the city of Washington, thereby necessitating the transferring of all passengers at White House Station to the line of the Washington Railway and Electric Company. It was of the utmost importance, from the standpoint of traffic, that the cars of the Washington, Baltimore and Annapolis Electric Railroad Company run direct to the heart of Washington, in order to eliminate the disadvantage of transferring passengers thirty blocks from the Treasury Building. Owing to the fact that the above mentioned cars were not permitted to operate to the center of the city over the underground conduit section, and also to the inherently unsatisfactory operation of the single-phase equipment which was greatly aggravated by local conditions, it was decided to change the system of operation to 1200 volts direct current. This change overcame all of the objections and further eliminated the necessity for the single-phase motor-generator sets which were installed in the substations at Baltimore and Annapolis for the purpose of furnishing 600 volts on the short stretches of track in the above mentioned cities.

The direct current apparatus was installed in such a manner that the change over was made in a single night on February 15, 1910, and the following comments bear chiefly on the operation of the equipments and substation apparatus as they exist today. The road has now been running for $3\frac{1}{2}$ years with the present equipment.

The thirty-three equipments placed in operation during February, 1910, have now averaged 225,000 miles each. Partly due to a systematic inspection and cleaning of the equipments and partly owing to the good inherent qualities of this type of apparatus, nearly all of the original brushes and bearings on the motors are still in use with no indication of failure or of excessive wear. The same holds true of the brushes and bearings of the dynamotor and air compressor motors. In fact, practically none of the apparatus and accessories, including the contactor burning tips, arc chutes and interlock contacts on the back of the contactors, have had to be replaced, except for what damage was done due to causes other than normal operation.

From the actual records it is observed that 50 of the original motor brushes have been replaced on account of breakage and one set of armature bearings have been replaced on account of collar wear. It has also been necessary to replace six contactor arc chutes and six burning tips, which were burned due to trouble with lightning in 1911. Recently lightning again struck one of the equipments, grounding an armature coil of one of the motors and doing other minor damage.

The equipments are inspected on a 1500 mile basis which averages once every eight days. This inspection consists of taking off top and bottom motor covers and blowing out with compressed air, cleaning the brush-holder insulators, gauging the motors to detect wear in the armature bearings, cleaning the master controllers, contactor burning tips, circuit breakers, reversers, dynamotors, air compressor and all switches and relays. In this way these parts are not only cleaned but any accident which may have happened to them is in this way detected.

All woodwork, both exterior and interior, including grab handles, steps, platform and under suspensions, are also inspected and a report of each item is made by the inspector. If a part of the equipment is found to be defective, it is repaired at this time and a proper notation made on the inspection card. This card is signed and filed, and if an equipment is found defective within a reasonable time after inspection, the man doing the work is held responsible for not having discovered and reported the defect. In this way careful work is insured. An inspection requires from two to three hours, depending upon the work to be done.

Along with the inspections, the equipments are given a general overhauling on the basis of approximately 45,000 miles, representing a period of about eight months. This is governed largely by the wheel wear, the overhauling being done whenever the car is ordered in for "wheels," requiring a turning down of the tread in order to build up a new flange. On many roads a greater mileage is obtained with one turning, but the wearing is rather high in this service, partly on account of the high speed and partly on account of the dimensions of the grooved rail used in the city streets of Washington and Baltimore; the flange on the interurban cars completely filling the groove, increasing the wear, especially on the inside of the flange. It is also held that if the wheels are turned before the flange is worn down to a minimum required for safe operation the cut necessary to obtain a new flange is enough less to make the ultimate life of the wheel considerably longer. A cut of from $\frac{3}{16}$ to $\frac{1}{2}$ in. is required to give a new flange, and several cuts can be obtained, giving a wheel life averaging over 240,000 miles.

The wheels used are 36 inches in diameter and are of solid steel construction, having a 3 in. tread and a $\frac{15}{16}$ in. flange. The average cost per wheel is approximately $17.00 and the scrap allowance about $4.00, making a net cost of about $13.00 per wheel.

When it becomes necessary to overhaul cars, the trucks are removed and the car-body placed in the paint shop. The motors are then removed from the trucks, disassembled and thoroughly cleaned. The exposed insulation of both the windings of the armatures and fields are then given two coats of insulating varnish. The compressors and dynamotors are also taken apart and thoroughly cleaned and the insulations on the windings varnished. The contactors, relays, plow-switch and circuit breaker are then thoroughly overhauled and properly adjusted. The trucks, brake-rigging, under-framing, etc., are then thoroughly inspected for defects, and after a thorough overhauling all of the above mentioned equipment is reassembled, painted and made ready for the car-body, which is being repaired and re-painted or re-varnished as the case may be.

The journal bearings are re-babbitted on an average of every 60,000 miles and motor axle bearings on an average of every 40,000 miles. The material used in the above bearings is made in the shop and consists of 75 per cent lead, 15 per cent antimony and 10 per cent tin, costing approximately 9½ cents per pound.

In order to take up the end play on motor and axle bearings, fiber collars are used with excellent results. When the end play has become sufficient from collar wear to necessitate the use of fiber collars, the bearings are taken out, trued up, and fiber of sufficient thickness to take up the excess play is inserted.

The fiber collars used on the armature bearings are solid, but those used on the axles bearings are split and cut in such a manner that they may be fitted together after they are sprung over the shaft.

The shop force required for the maintenance and repair of the rolling stock is as follows:

Electricians	3
Machinists	2
Blacksmiths	1
Carpenters	2
Painters	2
Inspectors	3
Truckmen	3
Electricians' helpers	2
Machinists' helpers	2
Blacksmith's helper	1
Carpenters' helpers	2
Painters' helpers	3
Car washers	4
Store room clerks	2

The brake shoes are furnished by the American Brake Shoe and Foundry Company and cost approximately 63 cents each. The average brake shoe wheel mileage is 7286, making a cost of 0.0667 cents per thousand wheel miles or 0.5336 cents per 1000 car miles.

The trolley wheels used are of the Holland Type B-5 in. This is a brass wheel having spring contact clips for carrying the current to the harp. The harp is made of malleable iron and the sides extend beyond the exterior of the wheel, performing the function of flanges, except that instead of having a tendency to "climb" on the wire the opposite effect is obtained on account of having the flange not only harder than the wire but also stationary.

The trolley wheels average about 3840 miles each, and the harps about 33,860 each. In this connection it should be noted that all cars operating in the District of Columbia between the District Line and White House Station, which is a round trip distance of 8.3 miles, use two trolleys on account of the overhead return. This necessitates four trolleys on every car.

Some of the operating conditions imposed on this company are unusual. For instance, in the city of Baltimore, the cars operate with one wire at 600 volts, using a rail return; on the entire Interurban section and in the city of Annapolis cars operate with one wire at 1200 volts using a rail return. From the District Line to White House Station, the rail return is eliminated and the return is procured through an overhead trolley. From White House Station to the Treasury Building in the city of Washington, the underground conduit system is used and contact is made by a double contact plow. The cars are run over a pit in the street and the plow is suspended from the plow support, which is attached to the truck frame. The leads from this plow are connected to the plow-switch and from the plow-switch to the main cable. The change from overhead to underground is made in about 12 seconds.

Substations

Power is purchased from the Potomac Power Company at their power station at Bennings about four miles north of Washington and is stepped up from 6600 to 33,000 volts for transmission to the railway substations. There are four railway substations.

Ardmore Substation—1200 Kw.

This was the only substation added when the change to 1200 volts d-c. was made, the others being altered to suit the new apparatus. The apparatus consists of:

Four 4 pole, 300 kw., 750 r.p.m., 600 volt rotary converters designed for operation two in series on 1200 volts.
Four 45 kw. oil-cooled reactances.
Six H 25 cycles, 160 kw., 19,100/33,000 volt primary 370/370 volt secondary oil-cooled transformers. Primary Y connected.
Switchboard for controlling above.

Naval Academy Junction Substation—1200 Kw.
Practically a duplicate of Ardmore.
(Spare converter and transformer installed in this station.)

Baltimore Substation (Near Scott St.) 1200 Kw.
Practically a duplicate of Ardmore.

Annapolis Substation—600 Kw.
Apparatus practically a duplicate of Ardmore, except for half the capacity.

There has been practically no maintenance cost of the substation apparatus. There have been no flashovers and none of the commutators have been turned. The original brushes are still in use on both the d-c. and a-c. ends.

The substation efficiencies average about 78 per cent and the machine load factor averages about 28 per cent.

The following is a list of the more important real properties owned by the road and used in its operation:

Right of Way

Washington to Baltimore and Annapolis to Annapolis Junction, a total of 60.59 miles. This includes the mileage in Washington and Baltimore on which traffic rights only are held. On the interurban sections practically all of the grade crossings have been eliminated at an expenditure of over $1,000,000. The Baltimore-Washington section is double tracked throughout and the Naval Academy Junction-Annapolis single track division is equipped with an alternating current automatic signal system of the Union Switch and Signal Company's semaphore type. The road bed is rock ballasted and consists of 80 lb. A.S.C.E. rails on wood ties.

Overhead Construction

A nine point suspension catenary trolley consisting of 4/0 Edison groove copper wire is used on the interurban sections supported by crosspan construction on the double tracked portions of the road and bracket construction on the single track sections. Duplicate 33,000 volt three-phase transmission lines, each consisting of three No. 2 aluminum wires carried on its own line of poles, extend between the Bennings step-up transformer substation and the railway substations at Ardmore, Naval Academy Junction and Baltimore and between the Naval Academy Junction and the Annapolis substation.

Rolling Stock

There are 48 motor cars in all, the number of different types being given below:

17 straight passenger cars put in service February, 1910.

13 combination baggage, smoker and passenger cars put in service February, 1910. These cars are equipped with G-E Type M automatic relay control and four GE-205 600/1200 volt motors.

3 express car equipment consisting of four GE-207 motors and G-E Type M non-automatic control. These cars are also used as locomotives in the interchange of freight business with the Pennsylvania Railroad and the Baltimore & Ohio.

1 express car equipment consisting of four GE-205 motors and G-E Type M non-automatic control. This car is used by the American Express Company.

10 four motor GE-205 equipments with automatic relay control similar to first equipments put in service April, 1911.

1 two motor GE-217 passenger equipment used for local traffic in the city of Annapolis. This car is equipped with R-200 A control, which is of the cylinder type. This car has been in service since September, 1910.

3 trail cars of the same dimensions as the express cars equipped with C-74 controller and hand control.

Substations, Buildings, Etc.

Baltimore
- Passenger terminal and office building.
- Freight terminal and light repair shop—for inspection and replacing brake shoes, etc.
- Baltimore substation at city limits.

Naval Academy Junction
- Substation.
- Car barns and repair shop.
- Trainmaster's office.
- Dispatchers' office.
- Waiting room.

Annapolis
- Passenger terminal.
- Freight terminal.
- Substation.

The new State House station, which has just recently been completed and which is located directly opposite the State House in the downtown section, is used for the accommodation of downtown patrons and also as an office for the Annapolis Public Utilities Company. This company was recently acquired and furnishes gas and current for commercial use in the city of Annapolis.

Washington and Vicinity
- Substation at Ardmore.
- Transformer substation at Bennings (Potomac power house).
- 15th and H Street passenger station car barn and freight terminal.
- 14th and New York Ave. passenger terminal.

Operating Expenses

The following is an itemized statement of the operating expenses for the years 1910, 1911, 1912 and 1913. The year 1910 is based on 9 months' operation and the year 1913 is based on 6 months' operation up to June 31, 1913. Following this list are the statistical data concerning the mileage and trains operated and statement of the revenue obtained during these years.

WASHINGTON, BALTIMORE & ANNAPOLIS ELECTRIC RAILROAD

Operating Expenses	Cents per Car Mile			
	*1910	1911	1912	†1913
I. WAY AND STRUCTURES				
1. Superintendence of way and structures	0.60	0.58	0.53	0.48
2. Ballast		0.03	0.03	0.01
3. Ties	0.28	0.10	0.27	0.34
4. Rails		0.01	0.01	
5. Rail fastenings and joints	0.04	0.02	0.02	0.02
6. Special work	0.02	0.06	0.04	0.06
7. Underground construction				
8. Roadway and track labor	1.29	0.94	0.89	0.57
9. Paving	0.10	0.10	0.07	0.06
10. Misc. roadway and track expenses	0.06	0.03	0.02	0.02
11. Cleaning and sanding tracks	0.07	0.08	0.07	0.06
12. Removal of snow, ice and sand	0.04	0.01	0.03	
13. Tunnels				
14. Elevated structures and foundations				
15. Bridges, trestles and culverts	0.25	0.04	0.06	0.30
16. Crossings, fences, cattle guards and signs	0.02	0.01	0.01	
17. Signal and interlocking systems	0.04	0.06	0.07	0.14
18. Telephone and telegraph systems	0.06	0.05	0.04	0.04
19. Other miscellaneous way expenses	0.01		0.01	
20. Poles and fixtures	0.06	0.05	0.06	0.06
21. Underground conduits				
22. Transmission system	0.03	0.05	0.01	0.01
23. Distribution system	0.39	0.26	0.22	0.26
24. Misc. electric line expenses				
25. Building and structures	0.11	0.19	0.15	0.42
26. Depreciation of way and structures				
27. Other operations—Dr.				
28. Other operations—Cr.				
TOTAL WAY AND STRUCTURES	3.47	2.67	2.61	2.85
II. EQUIPMENT				
29. Superintendence of equipment	0.22	0.15	0.07	0.07
30. Power-plant equipment				
31. Substation equipment	0.01	0.03	0.01	0.06
32. Passenger and combination cars	0.29	0.39	0.48	0.49
33a. Freight cars	0.05	0.08	0.08	0.15
33b. Express cars		0.03		
33c. Mail cars				
34. Locomotives				
35. Service cars	0.04	0.04	0.03	
36. Electric equipment of cars	0.19	0.21	0.18	0.24
37. Electric equipment of locomotives				
38. Shop machinery and tools	0.01	0.01	0.09	
39. Shop expenses	0.10	0.25	0.17	0.09
40. Horses and vehicles	0.04	0.01		
41. Other misc. equipment	0.01			
42. Depreciation of equipment				
43. Other operations—Dr.				
44. Other operations—Cr.				
TOTAL EQUIPMENT	0.96	1.14	1.11	1.10
III. TRAFFIC				
45. Superintendence and solicitation	0.40	0.32	0.28	0.46
46. Advertising	0.56	0.41	0.60	0.62
47. Miscellaneous traffic expenses	0.03	0.01	0.01	0.03
TOTAL TRAFFIC	0.99	0.74	0.89	1.11

* Based on 9 months' operation.
† Based on 6 months' operation.

WASHINGTON, BALTIMORE & ANNAPOLIS ELECTRIC RAILROAD—Continued

Operating Expenses	Cents per Car Mile 1910	1911	1912	1913
IV. CONDUCTING TRANSPORTATION				
48. Superintendence of transportation	0.40	0.43	0.39	0.39
49. Power plant employees				
50. Substation employees	0.32	0.32	0.35	0.33
51. Fuel for power				
52. Water for power				
53. Lubricants for power				
54. Misc. power plant supplies and expenses				
55. Substation supplies and expenses	0.01	0.02		
56. Power purchased	3.73	3.81	3.82	3.92
57. Power exchanged—balance				
58. Other operations—Dr.				
59. Other operations—Cr.				
60a. Passenger conductors	1.37	1.49	1.50	1.52
60b. Passenger motormen	1.42	1.48	1.53	1.54
60c. Other passenger trainmen	0.01	0.01	0.09	0.09
61a. Freight and express conductors	0.11	0.14	0.14	0.18
61b. Freight and express motormen	0.12	0.13	0.13	0.18
61c. Other freight and express trainmen	0.20	0.20	0.18	0.15
62. Misc. car service employees	0.14	0.19	0.16	0.17
63. Misc. car service expenses	0.45	0.34	0.30	0.33
64. Station employes	0.86	0.90	1.00	0.97
65. Station expenses	0.34	0.37	0.38	0.64
66. Car house employes	0.50	0.51	0.42	0.41
67. Car house expenses	0.01			
68. Operation of signals and interlockers	0.10	0.08	0.07	0.07
69. Operation of telephone and telegraph	0.03	0.04	0.03	0.03
70. Express and freight collections and delivery	0.07	0.02		
71. Loss and damage	0.02	0.02	0.02	0.01
72. Other transportation expenses	0.02	0.02	0.05	0.06
TOTAL CONDUCTING TRANSPORTATION	10.23	10.52	10.56	10.99
V. GENERAL AND MISCELLANEOUS				
73. Salaries and expenses of gen. officers	0.53	0.68	0.92	0.92
74. Salaries and expenses of gen. office clerks	0.44	0.46	0.40	0.42
75. Gen. office supplies and expenses	0.15	0.17	0.08	0.09
76. Law expenses	0.16	0.21	0.36	0.23
77. Relief department expenses				
78. Pensions				
79. Miscellaneous general expenses	0.18	0.24	0.20	0.15
80. Other operations—Dr.				
81. Other operations—Cr.				
82. Injuries and damages	1.00	1.01	1.07	0.46
83. Insurance	0.12	0.09	0.07	0.06
84. Stationery and printing	0.18	0.13	0.16	0.14
85. Store expenses	0.05	0.04	0.04	0.05
86. Stable expenses	0.01	0.01	0.02	0.01
87. Rent of tracks and terminal	0.07	0.10	0.09	0.08
88. Rent of equipment	0.15	0.14	0.15	0.20
TOTAL GENERAL AND MISCELLANEOUS	3.04	3.28	3.56	2.81
TOTAL OPERATING EXPENSES	18.69	18.35	18.73	18.86

STATISTICAL DATA

GENERAL

a–Miles of single track, W.B & A.E. R.	54.950
b–Miles of second track, W.B. & A.E. R.	33.570
c–Miles of sidings and turnouts, W.B. & A.E. R.	8.708
d–Total mileage operated, W.B. & A.E. R.	97.228
e–Miles of single track operated under cont. W. Ry. & E. Co.	6.970
f–Miles of second track operated under cont. W. Ry. & E. Co.	6.970
g–Total mileage operated under cont. W. Ry. & E. Co.	13.940
h–Total mileage operated, 12/31/12, all tracks	111.168

	1910	1911	1912	1913
1. TRAINS AND CARS OPERATED				
a–Number of trains operated	50,636	47,071	52,132	53,390
b–Number of cars operated	56,494	54,225	59,895	63,926

	1910	1911	1912	1913
2. CAR MILES				
a–Passenger cars on W.B. & A. tracks		1,618,020	1,763,245	1,860,934
b–Special cars on W.B. & A. tracks		11,688	19,219	14,446
c–Total pass'r and special on W.B. & A tracks	1,642,111	1,629,708	1,782,464	1,875,380
d–Freight cars on W.B. & A. tracks	64,019	67,795	82,327	96,470
e–Total pass'r spl. and frt. on W.B. & A. tracks	1,706,129	1,697,503	1,864,791	1,971,850
f–Service cars on W.B. & A. tracks	25,995	20,624	24,398	27,516
g–Total car miles on W.B. & A. tracks	2,732,124	1,718,127	1,889,189	1,999,366
h–Passenger cars on W. Ry. & E. tracks	271,444	270,463	287,825	298,140
i–Freight cars on W. Ry. & E. tracks	3,281	3,226	4,603	3,536
j–Total car miles on W. Ry. & E. tracks	274,725	273,689	292,428	301,676
k–Total car miles on W. Ry. & E. tracks	2,006,849	1,991,816	2,181,617	2,301,042
l–Items c and h on all tracks	1,913,555	1,900,171	2,070,289	2,173,520
m–Items d and i on all tracks	67,300	71,021	86,930	100,006

	1910	1911	1912	1913
3. TRIPS				
a–Passenger on W.B. & A. tracks	23,332	22,590	23,662	27,142
b–Freight on W.B. & A. tracks	591	748	1,100	2,086
c–Total on W.B. & A. tracks	23,923	23,338	24,762	29,228
d–Passenger on W. Ry. & E. tracks	18,256	17,916	18,281	20,274
e–Freight on W. Ry. & E tracks	375	387	555	418

	1910	1911	1912	1913
4. PASSENGERS CARRIED				
a–Revenue on W.B. & A. tracks	1,571,787	1,525,931	1,703,409	1,703,848
b–Free (chiefly employees) on W. B.& A. tracks	130,587	122,495	139,883	176,648
c–Total on W.B. & A. tracks	1,702,373	1,648,426	1,843,292	1,880,496
d–W. Ry. & E. Co. (incl. in a.) on W. Ry. & E. tracks	987,271	936,977	1,026,059	1,016,794
e–Daily average	4,642	4,513	5,050	5,194
f–Monthly average	141,864	137,369	153,608	156,708

STATISTICAL DATA—Continued

	1910	1911	1912	1913
	Dollars	Dollars	Dollars	Dollars
5. OPERATING REVENUE				
a- Total operating revenue	715,871.79	697,729.93	778,287.11	800,621.44
b- Total operating revenue excl. of freight	681,742.45	655,176.98	721,005.66	740,481.14
c- Largest day				
d- Smallest day				
e- Daily average	1,859.29	1,796.00	1,975.00	2,046.00
f- Monthly average	55,811.67	54,599.00	60,084.00	61,707.00
g- Freight revenue	34,129.00	42,552.95	57,281.45	60,140.30
h- Largest day				
i- Smallest day				
j- Daily average	93.08	117.00	157.00	166.13
k- Monthly average	2,844.11	3,546.00	4,773.00	5,011.70
6. FREIGHT REVENUE BY STATIONS				
a- Total freight revenue	34,129.00	42,552.95	57,281.45	60,140.30
b- Washington		4,035.0[illegible]	4,632.63	6,216.02
c- Baltimore		19,217.42	24,914.31	24,929.22
d- Annapolis		16,308.49	18,429.94	17,611.54
Miscellaneous		2,991.95	9,304.57	10,474.50
f- Eastern Shore (in-out bound)				454.51
7. OPERATING EXPENSES				
a- Total operating expense	355,026.53	347,723.29	388,955.62	414,563.40
10. PER TOTAL MILES ALL TRACKS OPERATED				
a- Total operating revenue (5a)	6461	6285	7006	7206
b- Total operating revenue, excl. of frt. (5b)	6153	5903	6472	6664
c- Freight revenue (5g)	308	383	514	542
d- Operating expenses (7a)	3205	3132	3492	3732
	Cents	Cents	Cents	Cents
11. PER FREIGHT CAR MILES (2m)				
a- Freight revenue (5g)	50.70	5[illegible].92	65.89	60.16
17. PER TOTAL CAR MILES (2k)				
a- Total operating revenue (5a)	35.68	35.03	41.68	34.80
b- Operating expenses (7a)	17.69	17.46	20.83	18.03
18. PER PASSENGERS CARRIED (4e)				
a- Total operating revenue, excl. of frt. (5b)	40.04	39.76	39.12	39.37
b- Operating expenses (7a)	20.85	21.10	21.10	22.05

Number o[illegible] per car operated—revenue only—both 1912 and 1911—28.
Number of [illegible] per car operated—revenue and free—both 1912 and 1911—31

THE OREGON ELECTRIC RAILWAY, A 1200-VOLT SYSTEM

NOTES ON CONSTRUCTION AND OPERATION

By W. C. Campbell

Railway Department, District Office, Portland, Ore., General Electric Company

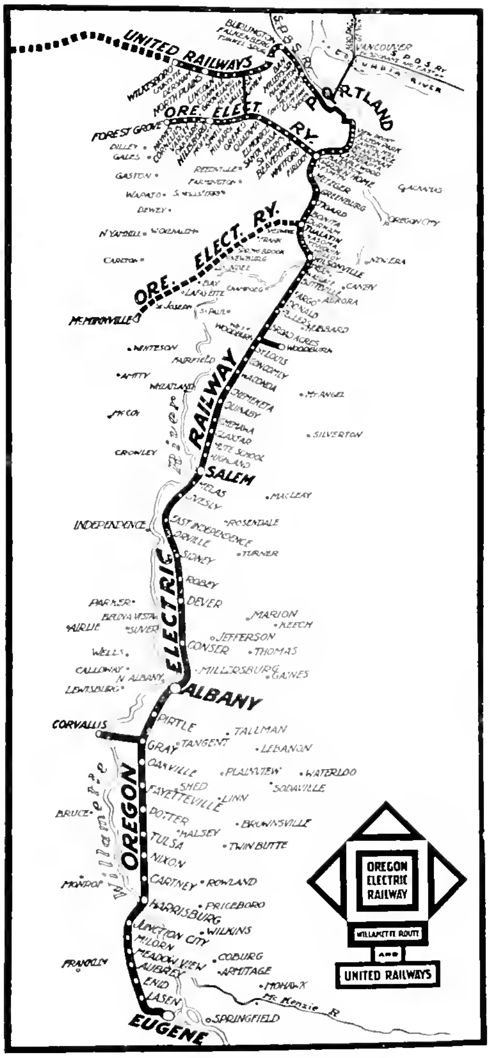
These notes on the construction and operation of the Oregon Electric Railway as a 1200-volt system are instructive as showing the trend of modern electric railway construction and equipment. It will be noticed that the service which is being given on this road is comparable in most essentials to first class steam operation. The type of equipment provides every facility for the comfort and convenience of the travelling public. The general descriptive data given in this article, together with the test data and operating statistics, all help to show the progress made in electric railroading in the West.—Editor.

The Oregon Electric Railway was built in 1907 and was orginally operated as an independent 600-volt interurban road. In 1910 the property was acquired by the Spokane, Portland & Seattle Railway Company, a steam road owned jointly by the Great Northern and the Northern Pacific Railways. Operation is strictly in accordance with steam railway practice and, in most cases, the corresponding departments of the steam and electric roads have been consolidated.

In addition to the Oregon Electric, this Company operates the United Railways of Portland, Oregon, a 1200-volt d-c. line; the Spokane and Inland Empire Railway, a 6600-volt a-c. road, and the Spokane Traction Company, of Spokane, Washington, a 600-volt d-c. road, a, well as several subsidiary steam lines. The whole system is operated under one management and aggregates 746 miles of st am and 401 miles of electric road.

The Oregon Electric Railway extends 122 miles up the Willamette Valley south from Portland, serving a territory of great beauty and productiveness, which yields a varied and growing freight business as well as a good passenger business. This valley is also served by the Southern Pacific steam lines, part of which are now being electrified under the name of the Portland, Eugene & Eastern Railway.

In 1911 an extension of the road from Salem to Eugene was decided upon. As this meant approximately doubling the existing mileage, the question of the best distributing system and trolley voltage was gone into thoroughly. Owing to the lower cost of a 1200-volt electrification and the savings t be secured in operation, it was decided to build the extension for 1200 volts, and change over the old



Map of the Oregon Electric Railway

line, rather than continue the 600-volt trolley to Eugene. It is interesting to note that not only have the 600-volt rotary converters been utilized, but the 600-volt motors have also been retained. The rotary converters are operated two in series with the high machine insulated from ground, while the 600-volt railway motors are connected permanently in series with new 1200-volt

Interior of Sleeping Car

motors, the old motor being on the low side. By following this practice, the amount of apparatus relegated to the scrap pile was reduced to a minimum, and the investment in new equipment correspondingly decreased. As this is the only company operating any considerable number of 600-volt railway motors in this manner, it may be well to state here that motor failures have been no more numerous than would be expected on a 600-volt trolley road using motors of similar type and age.

The substations had previously been supplied from a 33,000-volt 33-cycle transmission line on the railroad right-of-way; but when making the extension, the voltage was raised to 60,000, and it is worthy of note that both the transmission and trolley were changed over without any interruption of traffic or the annulment of a single train. The portable 1200-volt substation was utilized while changing over the old substations. The cars are equipped with change-over switches, permitting of full speed running on either 600 or 1200 volts.

Service was begun as far as Albany in July, and to Eugene in October, 1912. During the current year, 1913, two extensions have been made, aggregating about 10 miles, and 39 cars, two 60-ton locomotive equipments, and one 500 kw. 1200-volt rotary have been purchased. Also 7 miles between Portland and Garden Home, the junction point with the Forest Grove division, are being double tracked to relieve congestion. This section is equipped with automatic block signals.

The combination buffet, parlor and observation cars and the sleeping cars offer interesting features of this service. The former are attached to the limited trains, and on them is maintained a refreshment service similar to that to be found on the standard buffet cars of steam roads. An extra fare is charged for reservations in these cars. The sleepers which are attached to the owl trains are 10-section cars built along standard Pullman lines, with modifications to adapt them to local requirements. Pullman type berths were adopted in order that the cars might be suitable for daylight service when required.

Service

South-bound passenger trains start from the North Bank Depot, in Hoyt Street, which is also the terminal of the Great Northern and the Spokane, Portland and Seattle Railways. Between Hoyt Street and the uptown depot, in Jefferson Street, passengers are picked up and discharged at several street intersections, fifteen minutes being consumed between these stations, although the distance is only 1.3 miles. This portion of the road lies upon business streets where there are several heavy grades, sharp curves and the usual interruptions incident to operation upon city streets. The schedule is further lengthened by regular five minute stops at Jefferson Street and Salem, so that the speed maintained over most of the road is faster than indicated by the schedule speeds given below, which are based upon total time between Hoyt Street and the destination. The following passenger service is maintained in each direction:

	Miles	Sta. Stops	Flag Stops	Schedule M.P.H.
2 Ltd. Portland—Eugene	122.4	10	7	30
3 Local Portland—Eugene	122.4	15	60	24.5
2 Local Portland—Corvallis	88.2	14	48	23
3 Local Portland—Salem	50.8	10	38	24.5
9 Local Portland—Forest Grove	27.4	8	28	23
1 Local Portland—Wilsonville	22.5	6	24	17

NOTE.—All of the above are daily trains running throughout the week, including Sunday, with the exception of the last mentioned, which does not run on Sundays.

Including branches, the total daily revenue passenger train mileage is 2606. Trains consist of from 2 to 5 cars, the average being 2.54 cars.

A local freight is operated in each direction at night between Portland and Eugene on a schedule of about 17 m.p.h. These trains are handled by the 60-ton locomotives. Similar service is given on the Forest Grove division.


Three-Car Train, showing Combination Buffet, Parlor and Observation Car on Rear End

GENERAL DESCRIPTION

The electrification of the Oregon Electric has been carried out in general along standard lines, and therefore a full detailed description of the property is unnecessary. It is thought, however, that the information given below on those features affecting the electrification will be of interest in connection with the operating statistics and test run data which follow.

Power

Power is purchased from the Portland Railway, Light & Power Company at the low tension side of the substation transformers. The power company owns and operates the substation serving the 2.5 miles of 600-volt trolley in the city of Portland; the railway company owns and operates the step-up transformers at the power house and the transmission line.

Track

Main Line, Portland to Eugene	122.4 miles
Main line, Garden Home to Forest Grove	19.2 miles
Branch lines, Corvallis, Woodburn, Helvetia	12.4 miles
Total length main and branch lines	154 miles
Total length single track including sidings	180 miles
Rail weight	70 and 75 lb.

Roadbed, gravel ballasted; 7 in. by 9 in. by 8 ft. ties spaced 18 to 20 to 30 ft. rail length.

Grades

Hoyt St. to Jefferson St. Sta.	1.3 miles	+4 % max.	0.0% av.
Jefferson St. to Multnomah	5 miles	+2.87% max.	+1.6% av.
Multnomah to Tigard	5 miles	−1.65% max.	−1.1% av.
Tigard to Mile Post 20	10 miles	+1 % max.	0.0% av.
Mile Post 20 to Salem	29.5 miles	+ .8 % max.	0.0% av.
Salem to Eugene	71.6 miles	+ .4 % max.	0.0% av.

Difference in elevation between Hoyt Street Station and Eugene is approximately 400 feet.

Curvature

Max. 70 ft. radius at city street corners between Hoyt and Jefferson Streets.
Max. 8° between Jefferson Street Station and Salem.
Max. 3° between Salem and Eugene.
Longest tangent 24 miles.

[illegible]

[illegible]	[illegible]
[illegible]	[illegible] grounded neutral
[illegible]	[illegible] miles
[illegible]	[illegible] c.m. aluminum
[illegible]	[illegible] ft. wood poles, pin type insulators [illegible] 6 ft. between conductors.

[illegible] which are located at substations and junction points.

Substations

[illegible] Pennoyer Station [illegible] miles from the Portland terminal. [illegible] operation will, however, [illegible] a point near the Jefferson Street Station. The 1200-volt [illegible] are of the three-phase [illegible] type and have a momentary overload capacity [illegible] per cent.

TROLLEY AND TRACK BONDING

A [illegible] grooved copper trolley wire is used, and is supported from a bracket catenary construction. The suspensions are in the form of flat strap trolley hangers looped over the messenger and designed to allow a vertical movement of 8 inches. The pole spacing on tangent track is 150 ft., and the hangers are spaced 25 feet apart. The brackets are supported on the same poles as the transmission line. The messenger wire is 5/8 in. in diameter, and is made of extra high grade steel. The track bonding consists of one 0000 bond per joint welded to the outside of the rail.

SUBSTATION DATA

Substation	Miles from Pennoyer	Miles between Substations	Rotary Converters
[illegible]	[illegible]		2–500-kw. 600/1200-v.
			1–500-kw. 1200-v.
[illegible]	[illegible]	[illegible]	2–500-kw. 600/1200-v.
[illegible]	[illegible]	[illegible]	1–500-kw. 1200-v.
[illegible]	[illegible]	[illegible]	1–500-kw. 1200-v.
[illegible]	[illegible]	[illegible]	1–500-kw. 1200-v.
[illegible]	[illegible]	[illegible]	1–500-kw. 1200-v.
[illegible]	[illegible]	[illegible]	1–500-kw. 1200-v.
[illegible] from the Eugene terminal.			
[illegible]	[illegible]	[illegible]	2–500-kw. 600/1200-v.
[illegible] the terminal and 12 miles from Garden Home [illegible] Portland-Eugene line, which is 1.9 miles from [illegible]			
[illegible] substation			1–500-kw. 1200-v.
[illegible]			6500-kw.

FEEDERS

PORTLAND-EUGENE DIVISION

			Conductors
[illegible]	[illegible]	[illegible]	[illegible] c.m. copper
[illegible]	[illegible]	[illegible]	4/0 copper
[illegible]	[illegible]	[illegible]	[illegible] c.m. copper
[illegible]	[illegible]	[illegible]	[illegible] copper
[illegible]	[illegible]	[illegible]	[illegible] copper
[illegible]	[illegible]	[illegible]	[illegible] copper
[illegible]	[illegible]	[illegible]	[illegible] copper
[illegible]	[illegible]	[illegible]	477,000 c.m. aluminum
[illegible]	[illegible]	6.1	477,000 c.m. aluminum
[illegible]	[illegible]	[illegible]	4/0 copper

FOREST GROVE DIVISION

[illegible]	[illegible]	[illegible]	4/0 copper
[illegible]	[illegible]		477,000 c.m. aluminum

Gear Ratios

GE-73	53/21
GE-205	53/22
GE-66	56/22
GE-222	55/23
GE-207	64/17
GE-212	65/18

All passenger cars are equipped with Type M relay automatic control, arranged for full speed operation on either 600 or 1200 volts; both motor and trail cars are equipped with a 1200-volt bus line in addition to the regular 7 point control cable, so that trains may be made up as desired and operated from a single trolley wheel. The cars are equipped with master controllers for either single or double end operation, according to the type of car and the requirements of the service. It is interesting to note that all cars have 37 in. wheels.

The locomotives are equipped with Type M non-automatic control arranged for full speed operation on both 600 and 1200 volts, the superstructures are of standard design, consisting of a rigid steel frame, upon which the center or main cab and the two sloping end cabs are mounted. The rating of the locomotives with 36-inch wheels is as follows:

60-ton locomotives: 1200 volts, 570 amps., 19,000 lb. tractive effort, 15.8 miles per hour on level tangent track.
50-ton locomotives: 1200 volts, 300 amp., 13,300 lb. tractive effort, 11.3 miles per hour on level tangent track.

ROLLING STOCK

PASSENGER EQUIPMENTS

No.	Type	Seating Capacity	Length Over Buffers	Weight Tons	Motors	Master Controllers
8	3 comp.	54	57 ft. 8 in.	42	2 GE-73 2 GE-205	1
6	3 comp	54	57 ft. 11¾ in.	47	2 GE-205 2 GE-73	1
9	2 comp.	38	57 ft. 11¾ in.	47	2 GE-73 2 GE-205	1
3	Coaches	62	57 ft. 8 in.	44	2 GE-73 2 GE-205	0
3	Coaches	62	58 ft. 4½ in.	46	2 GE-73 2 GE-205	0
21	Coaches	62	58 ft. 4½ in.	46	4 GE-205	2
2	Parlor	25	62 ft. 2 in.	46	2 GE-73 2 GE-205	1
2	Sleepers	50	57 ft.	42		0
3	Coaches	62	57 ft. 8 in.	33		0
7	Coaches	62	58 ft. 4¼ in.	34		0
4	2 comp.	66	62 ft. 3 in.	34		0

BAGGAGE AND EXPRESS EQUIPMENTS

No.	Type	Length Over Buffers	Weight Tons	Motors	Master Controllers
2	Express	57 ft. 8 in.	42	2 GE-66 2 GE-222	2
6	Express	62 ft. 5 in.	49	4 GE-222	2
6	Express	62 ft. 5 in.	36		2
1	Non-revenue line car		32	2 GE-73 2 GE-205	2
1	Non revenue line car		34	4 W-321-E	2
1	Portable substation, 500-kw. 1200-volt, D-C., 60,000-volt, A-C.				

LOCOMOTIVES (10)

No.	Type	Weight Tons	Motors	Master Controllers
6	Freight	60	4 GE-212	2
4	Freight	50	4 GE-207	2

FREIGHT EQUIPMENT (135)

82	Flats	40,000 to 80,000 lb. capacity
40	Box	40,000 to 80,000 lb. capacity
4	Hart convertibles	80,000 lb. capacity
2	Stock	60,000 lb. capacity
7	Cabooses	

The locomotives are equipped with blowers for supplying forced ventilation to the motors, which materially increases the continuous capacity of the machines.

View along Right of Way, Showing Semaphore Signal

Shops

The repair shop is located two miles from the Portland terminal on the main line. Inspection pits are located in the terminal yards. The present arrangements are considered temporary and the new shops when built will possibly serve both the steam and electric roads.

Operating Statistics

Such available data as seem of general interest have been compiled from the records for the first six months of the current year and are given below. No attempt is made here to distribute the power consumption among the various classes of service nor to express it on a car or ton mile basis, but it is thought that the information given will be of interest as representative of performance on this class of railroad. The new track and equipment, previously mentioned as built or purchased in 1913, was completed so late that very little of it went into service before July, and the operating conditions may therefore be considered as constant over this six months period.

Power Consumption

More attention has recently been given to the shutting down of idle rotary converters, which accounts, in part at least, for the better showing in the later months.

Approximately 25,000 kw-hr. per month, used for station lighting and shop motors, are included, as well as car lighting and heating.

Substation Efficiency

The all day efficiency of the various substations, as measured at the low tension side

MILEAGE

	Jan.	Feb.	March	April	May	June	Total
Pass. train miles	82,769	69,332	76,476	76,567	80,345	79,055	464,544
Motor car miles	138,494	118,497	138,791	142,431	161,467	159,958	859,638*
Trailer miles	72,069	53,226	57,960	53,423	44,782	52,819	334,279
R. frt. tr. miles	9,083	8,098	9,213	9,234	9,324	8,930	53,882
Locomotive miles	14,210	13,287	15,257	13,009	14,960	15,064	85,787
Freight car miles (L)	38,158	37,204	42,151	43,868	43,662	46,002	251,045
Freight car miles (E)	28,157	27,134	30,040	30,218	30,250	30,727	176,526
Freight car miles (NR)	49,750†	50,540†	82,300†	56,337	55,595	82,300	376,822†

L = Loaded, E = Empty, NR = Non-revenue.

* Of the total motor car mileage for six months, 128,248 miles were made by cars received during 1913. There is also included 11,198 non-revenue miles made by the two line cars.

† Steam locomotives were used to some extent during this period and it has been necessary to estimate the amount of freight car mileage handled by them. The figures given are approximately the correct mileage handled by electric locomotives. This non-revenue mileage was made in construction work, principally in handling ballast.

	Jan.	Feb.	March	April	May	June	Total
Power consumption by months, Kw-hrs.	1,064,800	974,100	1,019,900	972,310	979,800	959,875	5,970,785

TRAIN DETENTIONS

REVENUE PASSENGER SERVICE

1913	Motor Car Miles	Total Detentions		Electrical Detentions		Mechanical Detentions		Air Brake Detentions	
		No.	Min.	No.	Min.	No.	Min.	No.	Min.
Jan.	137,142	7	317	6	310	1	7	0	...
Feb.	117,369	8	275	7	230	0		1	45
March	136,326	7	200	5	140	1	25	1	35
April	140,488	3	120	2	85	1	35	0	...
May	159,183	0	.	0	.	0		0	
June	157,932	3	115	1	35	1	20	1	60
Total	848,440	28	1027	21	800	4	87	3	140

Average miles per detention—total	30,302
Average miles per detention—electrical	40,402
Average miles per min.—total	826
Average miles per min.—electrical	1,060

of the transformers and outgoing feeders, varies from 81 per cent to 86 per cent at the various substations. The efficiency of the combined substations is 83.9 per cent.

Load Factor

The load factor (monthly average hour load to monthly hour peak) varies considerably at the various stations. Taken over the entire system, it averaged 48.9 per cent over a period of five months during which it varied between 47.57 and 51.47 per cent.

The failure of a train to arrive at destination within five minutes of schedule time is classed as a detention. In the above detentions are included those due to the mistakes made by the train crews in handling equipment, as well as those due to apparatus failures. Bent or broken trolley poles are classed as electrical failures. One train was annulled in January due to electrical failure and one in June due to air brake failure. In calculating miles per minute detention, the annulled trains are counted each as 60 minutes detention.

MOTOR FAILURES

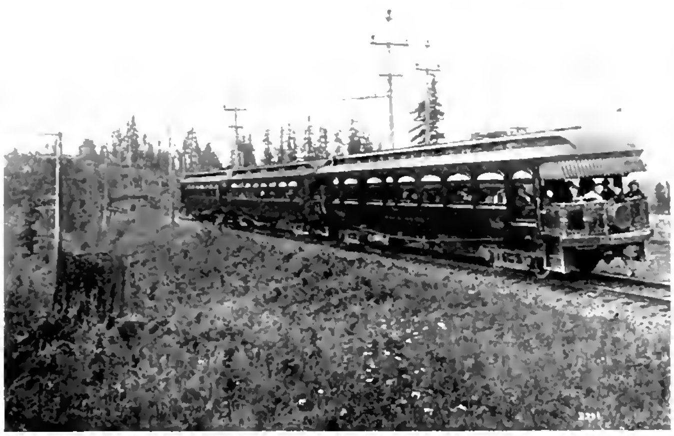
During the first six months of the current year, failures occurred necessitating the sending to the shop of motors for the following work:

	Motor Miles	Commutator	Field	Brush-holder	Armature Winding	
GE-73	1,457,806				6	Rewound
		2	1	1	1	Repaired
GE-205	1,978,398		1			Rewound
		1	1	2	5	Repaired
GE-66	51,830	..	..	..	..	Rewound
		..		..	..	Repaired
GE-222	51,830	..		..	..	Rewound
		.		.	..	Repaired
GE-207	119,108	..		..	1	Rewound
		..	.		..	Repaired
GE-212	216,924	..	..			Rewound
		..	..	..	.	Repaired

TROLLEY WHEELS

The current is collected through standard 6 in. trolley wheels with 15 ft. poles and roller bearing bases. The practice is to use one wheel per train and two per locomotive when handling heavy trains on grades. Damaged poles are replaced before proceeding, though this has seldom been necessary. The wheel replacements were as follows, including both cars and locomotives:

Jan.	Feb.	March	April	May	June
155	149	70	57	51	47



Limited Three-Car Train on the Oregon Electric Railway

TEST DATA

Watthour meters have recently been installed on the electric locomotives for the purpose of segregating the power consumption in freight service from that used in passenger service. The following results were obtained from through trips made in the regular night freight service handled by the 60-ton locomotives. The trains varied in length from 2 to 30 cars and in weight from 100 to 850 tons gross, including locomotive; loads were picked up and distributed along the route, the heavier service being on the north end of the line. The power consumption as metered at the locomotive, including switching, is given below.

The average watthours per gross ton mile on the round trip, as determined on these test runs, was 33.32 at the locomotive, or 47.6 at the substation, at the a-c. side of the rotary converter, assuming 70 per cent efficiency for rotary converters and direct current distributing system.

In order to obtain various data relating to passenger service for the information of the railway company's officials test runs have

4 TRIPS SOUTH BOUND—PORTLAND-EUGENE

Kw-Hr.	Car Miles	Kw-Hr. per Car Mile	Gross Ton Miles	Watthr. per Gross Ton Mile
4798	4191	1.145	140,290	34.20

3 TRIPS NORTH BOUND—PORTLAND-EUGENE

Kw-Hr.	Car Miles	Kw-Hr. per Car Mile	Gross Ton Miles	Watthr. per Gross Ton Mile
3299	3773	0.874	102,590	32.15

been made, duplicating as far as possible the conditions of regular service. Some of this data secured from a round trip in local service is summarized below. The train consisted of two motor cars and one trail car, the total weight being 126 tons. This run was made without heat, light, or passenger load.

The time on the round trip was as follows:

Power on	59.1 per cent
Coasting	25.1 per cent
Braking	8.1 per cent
Standing	7.7 per cent

The average power consumption at the train was 52.5 watthours per ton mile.

Division	Distance	SOUTHBOUND Kw. per Car Mile	NORTHBOUND Kw. per Car Mile	ROUND TRIP Kw. per Car Mile
Between Hoyt and Jefferson Sts.	1.3 mls.	7.70	4.61	6.15
Jefferson st. and Garden Home	6.9	4.73	3.62	4.18
Garden Home and Salem	42.6	2.25	2.40	2.33
Salem and Albany	26.9	1.82	2.04	1.93
Albany and Eugene	44.7	1.83	1.83	1.83

N.B.—Acknowledgment is due the Oregon Electric Railway Company for courtesy in permitting access to portions of its records and the friendly assistance of its officials in collecting such data as is given.

60 Ton Locomotive Employed for Freight Service

THE USE OF HIGHER DIRECT CURRENT VOLTAGES

By G. H. Hill

Assistant Engineer, Railway and Traction Department, General Electric Company

Mr. Hill's article, coupled with several others published in this issue, brings out in a very striking manner the advantages of adopting higher direct current potentials in railway work. Mr. Hill emphasizes the fact that 1200 volts should not be considered as constituting a new system, but rather that the adoption of higher direct current potentials is a logical development from the older 500 and 600 volt railway apparatus. All the apparatus employed in higher direct current operation is so similar to the older standards that there are no untried features in the newer equipments; the chief difference between the 600 and 1200, 1500 or 2400 volt apparatus being briefly "more insulation."—Editor.

The fact that 1200 volts and higher direct current potentials are used on more than nineteen hundred miles of electric railroads in this country, furnishes in itself convincing evidence of the success of this application with respect to initial cost, reliability and low costs of maintenance.

Several years of operation has fully demonstrated the ability of the apparatus to withstand the most severe service without "nursing," and with most satisfactory economic results. In fact results have surpassed expectations in many respects, and it is conservative to state that 1200 volt apparatus costs no more to operate than 600 volt apparatus.

Reports of remarkable endurance and reliability, including every feature from power house to rolling stock, have been the rule. Coming from unprejudiced, practical operators and supported by a formidable array of statistics there is no room for skepticism. Records show that with 90 per cent of the available equipment in hard and continuous service, cars have averaged over 250,000 miles without renewing any motor brushes or bearings, control contacts, or similar parts. The generating apparatus has run continuously for months without interruptions or renewals of parts, and has endured heavy overloads for long periods without distress. Inspection and maintenance crews have been reduced to a minimum unusual with even the best known practice.

To those who are not familiar with the details of the apparatus used with the higher voltages these results undoubtedly appear remarkable, since we are accustomed to expect a period of development, and more or less experimenting, with new methods and systems.

The idea that the application of higher d-c. voltages constitutes a "system" differing from 600 volts was perhaps natural, inasmuch as the initial application came at a time when much was being said about "systems," the single-phase system especially being much discussed.

Properly considered, the use of the higher d-c. voltages does not involve a new "system." It is simply a logical advance along established lines, wherein not a single good element is discarded or replaced. The necessity for a higher distribution voltage than 600 was generally recognized as soon as electric interurban and heavy freight railways became economically possible. The operating voltage had been increased from 500 to 600 and 700 volts in many instances, and the increase to 1200 was a natural step as soon as the improvements in generators, motors and control apparatus made this commercially possible. The one improvement that permitted this step in advance was the successful application of the old idea of commutating poles to motors and generators. With a full understanding of the commutation problem, the proper application of an intermediate flux to neutralize armature reaction removed the chief limitation in electrical design, and made the problem of higher voltage one of insulation and the perfection of auxiliary details.

A short experience with 1200 volt apparatus indicated the feasibility of still higher potentials and led at once to the use of 1500 and 2400 volts, where such voltages were economically desirable. By regarding these higher voltages for railways as the natural development and extension of the existing standard system, unnecessary mystery and incredulity attendant on new systems disappears.

A brief analysis of the elements of 1200, 1500 and 2400 volt apparatus will support this point of view by exhibiting their simplicity and the absence of untried or doubtful features, and may as well be of interest as indicating the solutions of some of the attendant detail problems.

With any d-c. voltage the usual and desirable three-phase generation and transmission are applicable, so this need not be considered when making comparison with 600 volts. The great importance of a balanced polyphase transmission, capable of tying in with any standard power system and free from disturbing inductive influence on other neighboring circuits, is being more and more recognized and can not be over estimated. The elements more or less affected by the higher voltages are the substation apparatus, the distribution conductors and the rolling stock.

The conversion of alternating current to direct current may be made, as with 600 volts, by rotary converters or motor-generator sets. With 25 cycle transmission it is usual to employ rotary converters for 1200 or 1500 volts. These may be single units where there is no need for power at half voltage. Where such half voltage is desired for city running or to supply existing equipment, two converters are connected in series.

Single unit converters of 1200 or 1500 volts are provided with commutating poles to neutralize armature reaction and provide good commutation with the necessarily increased volts per bar, as compared with 600 volt machines. They are started from the a-c. side by $\frac{1}{2}$ or $\frac{2}{3}$ voltage taps as usual. The use of commutating poles makes it desirable to lift the brushes from the commutators during the starting period, to avoid the sparking set up by the leakage flux through the unexcited commutating poles. By a simple mechanical arrangement all brushes but two are raised by a single lever, and a semaphore at the top of the field frame is lifted to clearly indicate the fact to the switchboard attendant. The two brushes not lifted are special narrow pilot-brushes and are left in contact to excite the shunt fields. The use of commutating poles on converters gave such satisfactory results that they have been introduced on all large 600 volt machines, and are being applied in numerous cases to small 600 volt units. Likewise the brush lifting device has been received as an inherent improvement, quite aside from the initial purpose, and has created a general demand for such an arrangement on account of the convenience it affords in caring for the commutator.

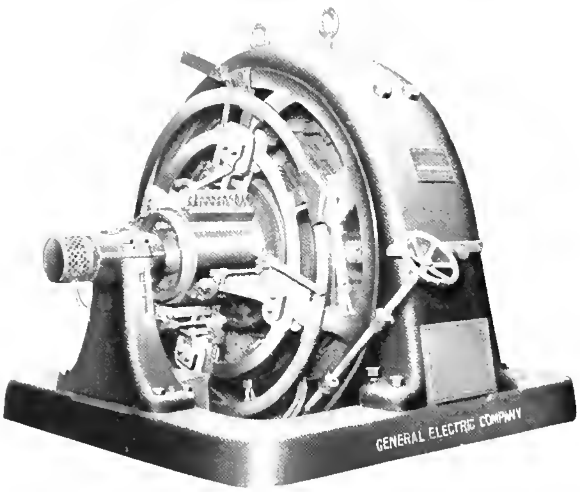


Fig. 1. 1200 Volt Synchronous Converter with Brush Raising Device

Where 60 cycle transmission is employed, two converters in series may be used for 1200 volts.

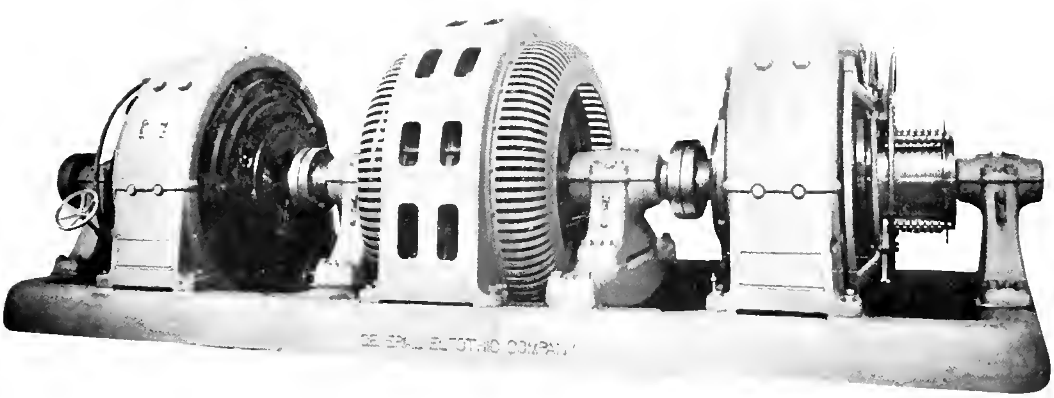


Fig. 2. 2400 Volt Motor-Generator Set

The inherent limitations of design, namely, volts per bar, peripheral speed of commutator, and permissible minimum width of bar, combine to place the limit of possible voltage at about this point. Sixty cycle transmissions are frequently extensive and contain a large proportion of inductive load. For this reason the more stable synchronous motor-generator set is usually employed, especially when control of power-factor is a desideratum. The generator of such a set, wound for 1200 or 1500 volts, with a single commutator, is similar to a 600 volt generator with the addition of a compensating winding as well as the commutating poles. This compensating winding consists of a number of series turns through the face of the exciting field

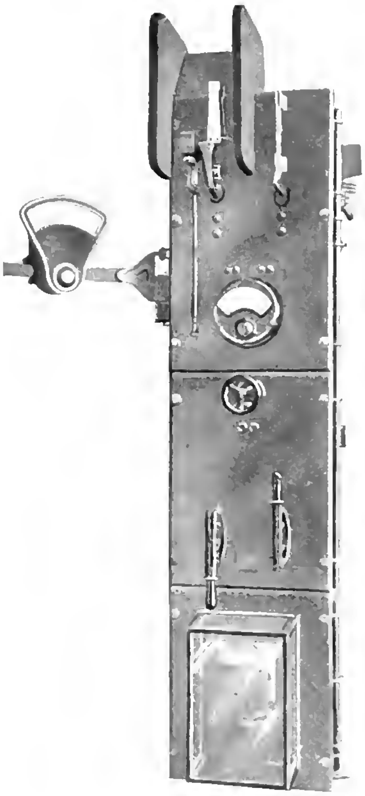


Fig. 3. Switchboard for 1200 Volt Rotary Converter

pole, to supplement the action of the commutating poles and completely neutralize the armature reaction. Such machines properly designed are fully equal to the best 600 volt designs as to commutation and reliability, and are superior to them in ability to handle heavy overload.

For 2400 volts the three unit set is employed, having two 1200 volt generators connected in series and driven by a single synchronous motor. For the excitation of the synchronous motor a direct current exciter of low voltage is usually directly connected to the set. It is economical in space and cost to supply the shunt field of the generator also from this exciter, although, if wide control of power-factor on the synchronous motor is desired, it is better to have two direct connected exciters, one for the motor and one for the generators.

The transformers which supply the rotary converters or motor-generator sets have practically no features different from the standard low voltage apparatus. The secondary voltage is approximately double for a single unit, or two secondary windings are provided, each giving half voltage where two converters are connected in series.

The switchboard for the a-c. circuits does not differ from low voltage apparatus. For the direct current panels the difference consists in improved circuit breakers for handling the higher voltage arcs, and in isolating these devices more effectually and insulating all live parts from contact with the operator. The circuit breaker and main switch for 1200 and 1500 volts are placed high on the panel and connected to operating handles by wooden rods at the back of the panel. For 2400 volts these parts are separately mounted over, and back of, the panel.

The meters, voltmeter jacks and all live parts are thoroughly covered and insulated. As an additional precaution against leakage currents through any metallic seams that may be in the slate, all conductors which pass through the panel are bushed with porcelain.

Distribution Conductors

The trolley and distribution feeders differ only in the use of somewhat better insulation. The introduction of wooden strain insulators in cross-spans, guys and pulloffs, in addition to the standard 600 volt appliances, has been found ample. Incidental with the development of heavy interurban projects and heavy freight electrifications made feasible by the higher voltages, marked improvements have been made in the trolley construction. The ordinary direct suspended trolley wire and wheel collector are unsuited to heavy and fast traffic, because of:

First. Insufficient resilience due to the rigidity of the wire supports and the inertia of the trolley wheel.

Second. Insufficient collecting capacity.

Third. Inconvenience of reversing the trolley pole and keeping it on the wire.

These are overcome by use of the catenary suspension with hangers permitting a vertical movement of the conductor and the elimination of all heavy fittings at crossovers, switches, etc. This produces a perfectly flexible conductor free at all points to yield to the upward pressure of the collector, and effectually solves the problem of high speed operation, at the same time permitting the use of a heavier collector with greater upward pressure. Instead of a trolley pole and wheel a pantograph with wide roller is used, which may be run in either direction and raised or lowered pneumatically by the motorman. This combination can successfully collect from two to three times as much current as the older types, and is suitable for the heaviest freight or highest speed passenger locomotive.

Third rail collection on 1200 volts has been in successful operation for several years, and has been found entirely feasible in test for 2400 volts. The under running type of rail is used, the rail being smaller and the insulators larger than for 600 volts. Wooden protection over the rail is provided and is effectually insulated from the rail by porcelain supports.

Rolling Stock

The series-parallel connection of motors with or without field weakening is used as with 600 volts. For operation on a 1200 volt line the motors may be wound for 600 volts each, and insulated for 1200, or may be wound and insulated for 1200 volts. The first arrangement permits operation on 600 volt connecting lines at full speed; the second provides series-parallel control with two motor equipments. It is not economical in design to build motors for 1200 volts each smaller than about 125 h.p., and as most interurban road operators prefer four motor equipments requiring not over 100 h.p. per motor, the usual selection is the first alternative. For 2400 volt lines the motors are wound for 1200. As 2400 volt installations chiefly require haulage by locomotive and a limited number of heavy passenger cars, the motors are large enough for economical design at this voltage. In every case the motors lend themselves mechanically and electrically to the best modern practice. Low armature speeds, large air gap, ample be ring surfaces, full ventilation with self-contained fan, heat proof insulation, and all the other well known desirable features of the perfected railway motor are embodied in the high voltage designs. Likewise the control retains its simple rugged contactor with improved magnetic blowout and insulation. The contactors are assembled in sheet iron boxes which are thoroughly grounded as with the lower

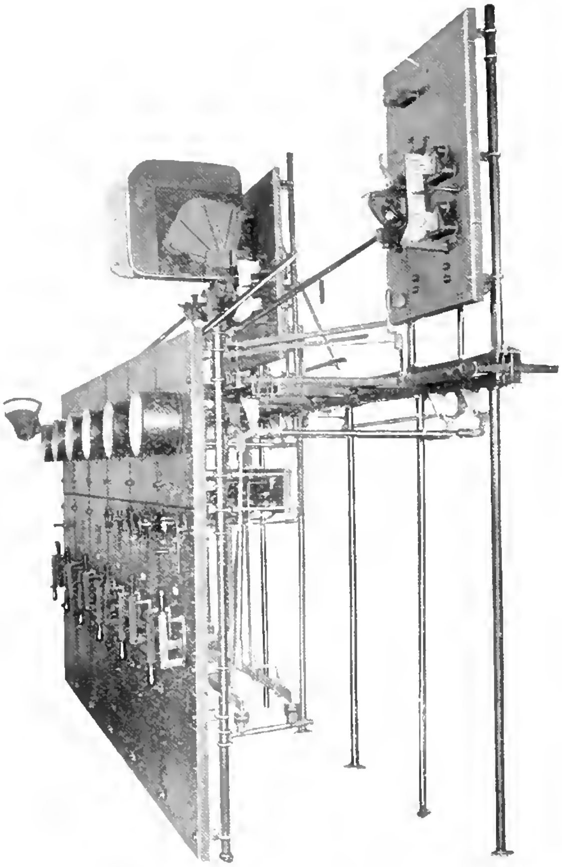
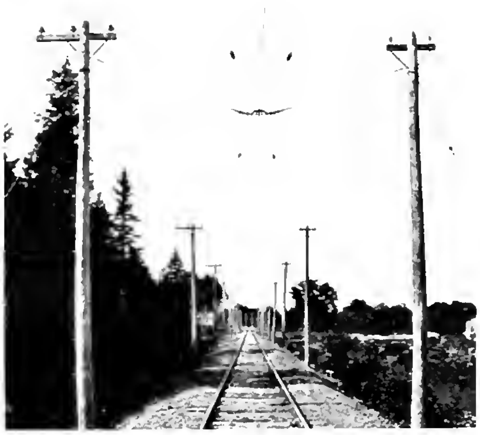


Fig. 4. Switchboard for 2400 Volt D-C. Substation

voltages. The secondary circuits are the same as for 600 volts and are operated direct from the trolley when the car is on a division with this voltage. When on the high voltage trolley the control current is derived from a small auxiliary dynamotor or motor-generator set.

For 1200 or 1500 volt motor cars the dynamotor is used, it is lighter and more compact. This dynamotor consists of an armature with double windings and two commutators with a single field. The two armature windings are in series across the line, and the half voltage for the auxiliary circuits is obtained from a tap between the armatures. The device is simple and reliable, and requires little attention. The bearings have light duty, as there is practically no mechanical torque on the shaft.

The master controller, control couplers and jumpers are exactly the same for the high



Direct Suspension, 1200 Volt Trolley

voltage as for the low, and the control can be made for automatic or hand control as desired.

For the smaller size of 1200 or 1500 volt equipments the ordinary platform controller can be provided. This makes available the very simplest form of equipment. These cylinder controllers are built along the same line as for 600 volts, but with the improved magnetic blowout and with greater space and insulation for the isolation of the arcs. The insulation in the controller is made ample so that the frame of the controller may be grounded, which is the only thorough manner of protecting the motorman. For locomotives, the Type M control is used, and instead of the dynamotor a small generator provides current for the auxiliary circuits at low voltage. This small generator is driven by the same motor that drives the ventilating fan. As a ventilating fan is always furnished with the locomotive, in order to give the locomotive motors the highest possible continuous rating, the addition of a small generator adds practically no complications.

The auxiliary circuits outside of the control, viz., air compressor motor, the lights for motor cars, and the heaters for motor cars and locomotives, required more or less special development. The simplest arrangement, which was adopted on the first high voltage cars, was the use of standard 600 volt lights, car heaters and air compressors supplied with low voltage current from the dynamotor. This, however, makes the dynamotor of considerably greater capacity and weight, and is, from an engineering point of view, unnecessarily indirect. The design of 1200 volt car heaters was not a serious matter, it being necessary chiefly to provide against foreign objects coming in contact with the live parts, and at the same time not restrict the free circulation of air. Various plans have been suggested and tried for the air compressor. One method is to connect a 600 volt compressor across the high armature of the dynamotor and the other auxiliaries across the low dynamotor armature. This tends to reduce the required size of the dynamotor, and if the loads on the high and low circuits are fairly well balanced, is a satisfactory arrangement. Another scheme provided for a combination dynamotor-compressor in which the dynamotor was connected to the air compressor by a clutch. The disadvantage of this is the inherent unsuitability of the dynamotor to do mechanical work. When acting as a dynamotor there is no torque on the shaft and no armature reaction, but when it is coupled to the compressor, and is called upon to do mechanical work through the shaft, the device becomes more motor than generator, and the result of armature reaction

Fig. 6. Catenary Suspension, 2400 Volt Trolley

causes sparking at the brushes. This cannot be corrected properly in the designing, since the same armature may be called upon to be a generator at one time and a motor at another. The most satisfactory arrangement for the air compressor is to keep it independent of other circuits and provide it with a high voltage motor. It is found that a 1200 volt motor of this size can be built with very excellent characteristics. A very satisfactory arrangement consists in having two motors on the compressor, one on each side. On 1200 volts these two motors are connected in parallel and for 2400 volts they are connected in series. If the equipment is to operate on 600 and 1200 volts, the two small motors are each wound for 600 volts, so that full compressor speed may be obtained both on high and low voltage.

In many cases the amount of current required for car lighting is small enough to make it desirable to supply the lights from the dynamotor, but if there are a large number of lights. and if a large headlight is desired, it is desirable to remove these circuits from the dynamotor. Experiments show that it is not safe to connect a sufficient number of the ordinary car lights in series across 1200 volts. The reason for this is that the contacts and leading-in wires of the sockets on the standard 600 volt lamp are close enough together so that the breaking of a filament in one lamp on the 1200 volt circuit might hold the arc

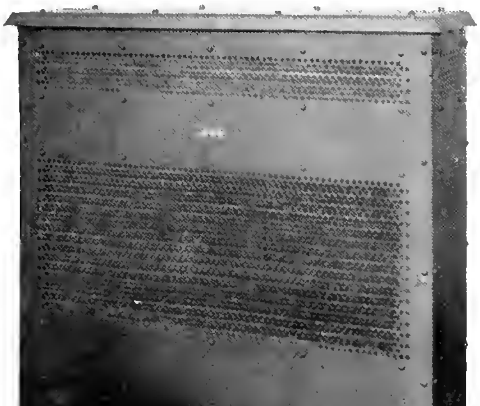


Fig. 7. Electric Heater for 2400 Volt Locomotive Cab

across the leading-in wires of the lamp, which would continue to burn until it destroyed the lamp base and socket, and this might possibly become a fire menace. Accordingly a new design of socket and lamp was necessary. This has been produced, and is somewhat similar to the parts used for series street lighting. With this new socket either six-200 volt lamps or twelve-100 volt lamps may be used in series. The lamps and lamp sockets are installed in iron receptacles and the wiring

Fig. 8. Lamp and Receptacle for 1200 Volts

is placed in iron conduit. The receptacle for the socket is designed to cover the lamp base and all live parts and is thoroughly grounded. This gives very thorough protection to persons handling the lamps. The switches for the heater circuits and for the lamp circuits are thoroughly enclosed and protected. The usual arc headlight on 1200 volts necessitates consuming a large amount of energy in resistance. Experiments with incandescent lamp headlights have shown that, with a properly made parabolic reflector, a lamp with a small centralized filament, which can be accurately focused in the reflector, makes a very excellent headlight and is much more economical than the arc headlight. This incandescent headlight may be placed in series with the car lights or even in series with a certain amount of resistance, as the high efficiency tungsten filament is used and the current is much less than for the arc light.

The lights for locomotives on either 1200 or 2400 volts require but little energy and this is best furnished from the low voltage generator.

Car equipments for 2400 volts are provided with a small motor-generator set to supply the low voltage auxiliary circuits. In some instances on either 600, 1200 or 2400 volts, operators have considered the lighting question important enough to warrant an arrangement which will provide very steady voltage on the lighting circuit, and also one that will provide lights in case power is cut off at crossings or for any other reason. Such an arrangement consists of a storage battery with small motor-generator, the motor being fed from the line and the generator floating across the storage battery. When this arrangement is used the lights are usually wired on 125 volt circuit

For lighting waiting rooms along the railroad on 1200 or 1500 volts, series lamps fed from the trolley are used. For voltages of 2400 or higher it is desirable to feed such lighting circuits separately from the a-c. transmission.

Higher voltage direct current for railways is not to be considered as superseding 600 volts. The voltage to be used in any case depends upon the character of the service and the conditions to be met. For congested service having a large number of small equipments the 600 volt system is undoubtedly the most economical in every way. For interurban lines having heavier equipment operating on longer headway, and with light freight service, 1200 or 1500 volts is most economical, while for heavy trunk line electrification 2400 volts is required. There undoubtedly will be cases where higher potentials than 2400 volts will be advantageous, and there is no reason why apparatus cannot be designed for higher direct current potentials than 2400 volts. In fact, it seems entirely feasible to carry this development successfully to say 5000 volts. This voltage will undoubtedly take care of any train movement that exists on even the heaviest grade sections of trunk railways.

One of the requirements of heavy grade work is a means for electrically braking the train, and this ability has been one of the principal advantages of the polyphase a-c. system. It has been found, however, that the direct current locomotive can be provided with regenerative control which is very simple, feasible and practical. The addition of this valuable element to the direct current locomotive places the direct current system in the enviable position of meeting all conditions with apparatus throughout of well known characteristics and thoroughly established reliability and practicability. It contains no elements which are objectionable from an operating point of view, and provides all of the flexibility that can be desired for meeting different situations.

As opposed to the direct current system, the single-phase system with commutator motors has the objectionable feature of heavy motors with poor electrical constants and high maintenance costs, while the split phase system using polyphase motors introduces the untried feature of the phase converter, and both these a-c. systems have the objectionable inductive disturbances of the single-phase trolley and transmission. The straight three-phase locomotive is hampered by the double overhead trolley which restricts its use to special situations.

AN ANALYSIS OF THE EXISTING HIGH VOLTAGE DIRECT CURRENT RAILWAYS

By John A. Dewhurst

Railway and Traction Engineering Department, General Electric Company

This article brings very forcibly to our attention the phenomenal strides that have been made in the adoption of higher direct current potentials and gives a very complete resumé of the work done in this direction up to the present time. The article is of very great value as a record of accomplishments, and in the large table attached such a mass of data have been collected that it virtually forms a description of every higher potential d-c. road in the country.—Editor.

The month of October, 1913, marks the sixth anniversary of the introduction of high voltage direct current into the field of electric railroading in the United States. Although the Pittsburg, Harmony, Butler and New Castle Railway was the first to adopt this system, the Indianapolis & Louisville was the first road to actually place this type of equipment in operation, having started in regular service during October, 1907. Because of the extensive construction work necessary on the Pittsburg road operation was not started until July of the following year.

The Indianapolis & Louisville Railway is 41 miles long and formed the last link in a chain of 600 volt roads connecting Indianapolis and Louisville, a distance of 110 miles. This required an equipment that would operate equally as well on 600 or 1200 volts, and in cities or on interurban sections, thus introducing at the very beginning of the art practically all of the conditions that have since been imposed, necessitating a system of great flexibility. Since this time 1200 volt apparatus has passed through the experimental and development stage and for the past few years this system has been considered as the standard for interurban roads.

That this is true is readily shown by a study of the table accompanying this article, in which it will be noted that 28 distinct roads, either in operation or under construction, are either 1200, 1500 or 2400 volt systems. This constitutes an aggregate road mileage of 1964, or 2260 miles considered on a single track basis. A total of 273 miles of this distance is over 600 volt tracks, this being distributed among all but six of these roads.

Railway activities are often considered as a barometer to indicate times of prosperity or depression, and this is shown in an interesting manner by segregating this list of roads by years, it being remembered that the activity prompting the electrification preceded date of installation by a period averaging about a year.

Date of Installation	Number of Roads	Total Road Mileage
1907	1	41
1908	2	134
1909	0	0
1910	6	424.6
1911	2	201
1912	3	196.5
1913	14	967
Totals	28	1964.1

Five of these roads, or 625 miles, are at present under construction, being scheduled to start during this year or early in 1914.

It is interesting to note that California heads the list with a total of 448 miles of track either under construction or in actual operation, and with 100 additional miles under immediate consideration. Oregon comes second with 325 miles in operation and 300 miles additional under immediate contemplation. The Portland, Eugene & Eastern Railway alone is planning extensions amounting to 250 miles. Michigan comes third with 242 miles now under construction, Texas fourth with a mileage of 178, Iowa fifth with 175 miles, and Pennsylvania sixth with 132 miles. The Piedmont Traction Company in the Carolinas has also laid plans for a future network of over 400 miles.

There are a total of 640 motor car equipments operating or under construction for these roads, and 73 locomotives. The equipments are about half and half straight passenger cars or combination cars having baggage and smoking compartments. The average weight equipped, but without load, is about 43 tons, and the average seating capacity is 55 persons. The maximum speed of operation on a level tangent track varies between 30 and 65 m.p.h.; the majority averaging about 45 m.p.h. A free running speed greater than this amount has often proven to be uneconomical from both the standpoint of energy consumption and maintenance of way and equipment. Speeds greater than this are, however, frequently required to meet competitive schedules.

The average motor equipment consists of four 80 h.p. motors per car, wound for 600 volts and insulated for operating two in series on 1200 or 1500 volts, as the case may be. About 70 per cent of the cars are equipped with an automatic type of contactor control which has the effect of giving the highest rate of acceleration and a minimum power consumption. The control equipment on the balance of the cars is either a non-automatic contactor type or in case of small, light weight equipments, a cylinder control. By far the larger proportion of the cars are equipped with coupler sockets and cables for multiple unit operation, and approximately 75 per cent of the total number are arranged for double end operation.

Except where there are long 600 volt sections or where high schedules are maintained, the equipments are arranged for half speed operation on 600 volts. In these cases the control circuits and lights are commutated by a relay operated from the motorman's cab, so that the controller and lighting circuits are connected either to the middle point of the dynamotor or to the trolley direct, depending upon the voltage. For operating at full speed on 600 volts an additional commutating switch is used for connecting the motors either in series or parallel.

Of the 73 high voltage locomotives in service, the average weight is approximately 50 tons with all the weight on the drivers. On many roads, notably the Washington, Baltimore and Annapolis, the locomotives are of the express car type and are used in the express and package business either singly or with a trailer for certain trips during the day, and as locomotives for hauling foreign cars in the interchange of freight traffic during other parts of the day.

The most common motor equipment consists of four 125 h.p. motors per locomotive with non-automatic contactor control and automatic air brakes.

A notable installation and one that marks a distinctive advance in the art of electrification is the Butte, Anaconda and Pacific Railway in Montana, which in June of this year started operation using 2400 volts direct current. This is chiefly an ore hauling road and the present equipment consists of 17 locomotives weighing 80 tons each. The general equipment is similar to a 600 or a 1200 volt locomotive, except that the four motors are wound for operating at a potential of 1200 volts, and insulated for operating two in series on 2400 volts. A non-automatic contactor control is used, similar in general principle to the 1200 volt control except for certain features necessitated by the higher voltage.

Except for six of the installations, catenary trolley suspension has been adopted, as this gives much more satisfactory operation, especially for high speeds. There is one instance, namely the Central California Traction Company, of a third rail distribution to the cars, and the Michigan United Traction Company contemplate the use of a third rail on both their 1200 and 2400 volt lines.

Three of the roads listed feed the 1200 volt trolley direct from the power house, using engine-driven direct current generators. Nearly all the rest of the roads purchase power from some large central station system, since this has been found to be more economical and more reliable than to operate small power stations to supply the railroad alone. The power is generally transmitted to the substations on power lines erected either on poles set on the right of way or on the trolley poles, at a potential depending upon the distance to be transmitted, but averaging about 33,000 volts for the majority of installations.

The substation equipments vary widely and depend largely upon the frequency as well as the voltage of supply. For 25 cycles, 1200 or 1500 volts, rotary converters are extensively used, although motor-generator sets are used in many instances. In case a 600 volt road is changing over it is common practice to insulate two 600 volt rotary converters by setting them on wooden blocks and operating them two in series. For 60 cycle work either two 600 1200 volt rotaries are used in series, or motor-generator sets with straight 1200 volt generators are employed. The particular equipment for each installation depends, to a great extent, upon local conditions, so that no definite statement can be made as to the most common practice.

It is interesting to note that of a total of 28 roads now using high voltage d-c. apparatus, seventeen of these were completely new roads, six were either wholly or in part operated by steam, three were previously operated by single-phase alternating current, and three by 600 volts direct current.

HIGH VOLTAGE DIRECT CURRENT RAILWAY INSTALLATIONS IN THE UNITED STATES

Compiled by
GENERAL ELECTRIC COMPANY
Railway and Traction Engineering Department

Schenectady, N. Y. Oct. 1, 1913 — J. A. D.

	PERMANENT WAY				OVERHEAD CONSTRUCTION					POWER			ROLLING STOCK																				
					Trolley or Third Rail		Transmission Line			Generating Stations	Substations		Passenger Equipment					Pass. Trailers	Locomotives			Control (Pass.)				Air Brakes						Previous System of Operation	Chief Points Connected
ROAD	Length of Route	Length of Track (Single Track Basis)	Miles of 600 V. City Operation	Track Gauge (4 ft. 8½ in. = Std.) Weight of Rail	Type	Voltage	Voltage	Frequency	Phases	Number, Capacity and Type of Generating Equipment	No. of Subs.	Type, Capacity and Voltage of Apparatus	Number	Weight Equipped Tons	Principal Motor Equipment	Free Running Speed	Seating Capacity	Number	Number	Weight Equipped	Motor Equipment	Type A=Auto NA=Non Auto K=Cyl.	Multiple Unit Operation	Single or Double End Operation	Speed on 600 Volts	Heaters	Type of Air Brakes	Type of Compressor	Capacity—Ft. Min.	Voltage	Date Started Operation		
Indianapolis & Louisville Traction Ry. Co., Scottsburg, Indiana	41	11	Traffic Rights 75	S 75	Direct Suspension	1200		None		(4) 300 kw. 600/1200 volt d-c. Engine Driven Generators G.E.	0	Direct Feed	13	34	(4) G.E. 205-600 V.	42	53	0	0			M A	Yes	S	Full	Hot Water	Emergency Straight Air	C P. 22	24	600	Oct 1907	New	Seymour and Sellersburg and Indianapolis & Louisville via 600 d-c lines
Central California Traction Co., Stockton, California	69	69	7	S 75	Catenary and Third Rail	1200	60000	60	3	Power purchased from Amer River Elec. Co.	3	(2) 300 kw. (W.) (2) 500 kw. G.E. Ind. & Syn. M.G. 1200 V.	10 11	38	(4) G.E. 205-1200 V.	45	55	33	1		West.	M. N.A	Yes	D	Half	1200 V.	West. G.E. Comp	C.P. 22	24	600	June 1908	New	Stockton & Sacramento
Pittsburg, Harmony, Butler & New Castle Ry., Evdenau, Pa	65	75	4	5 ft. 2½ in. 80	Direct Suspension Double Trolley	1200	13200	60	3	(2) 1500 kw. Curtis Turbines General Electric	3	(6) 200 kw 600/1200 Syn M G. Sets General Electric	23 G E 7 W.	32	(4) G.E. 205-600 V.	45	50	17	0			M. A.	Yes	S	Half (1) Full	Hot Water	Emer. St Air	C P. 22-28	24	600	July 1908	New	Pittsburg, Harmony Butler and New Castle
Washington, Baltimore & Annapolis Elect. Ry., Baltimore, Md.	60.6	103	14	S 80	11 Point Catenary	1300	33000	25	3	Power Purchased from Potomac Elect. Power Co.	4 1 Trans	(15) TC-4-300-750-600/1200 Rot. Con. H Type Trans. & H.T. React. G E.	44 3 Ex	40	(4) G.E. 205-600 V. (4) G.E. 207-600 V.	45	54	Frt.	0		Express Car Type	M 40 A. 4 N A.	Yes	D	Half	1200 V.	West. G E. Comp.	C P. 29	25	1200	Feb 1910	6600 V., 1 φ and steam	Wash., Balt. & Annapolis
Milwaukee Elect. Ry. & Lt. Co., Milwaukee, Wis.	135	135	47	S 80	Catenary	1200	13200 38000	25	3	Part of an Extensive System	6	Rot. Con. 600/1200 W.C R. Transformers General Electric	25 7 others	43.5 39.5	(4) G.E. 205-600 V. (4) G.E. 207-600 V.	45	64	59	0			M. N A	Trailers Only	D	Full	Hot Water	West D-3-N			600 1200	Mar 1910	3300 V Single-phase	Milwaukee, East Troy, Burlington and Watertown
Aroostook Valley Ry. Co., Presque Isle, Me.	32	37	0	S 70	Direct Suspension	1200	11000	60	3	Power purchased from Maine New Brunswick El. Pr Co	2	(4) TC-6-200-1200-600/1200 Rot. Con. HR Transformers G.E.	4	30	(4) G E. 217-600 V (4) G.E. 205-600 V.	30	50	Frt.	2	40	(4) G E. 206-600 V.	M.-N A (2) K.	Yes No	D	Half	1200 V	St & St & Auto	C P 22 29	24	600	July 1910	Steam & New Exten	Presque Isle & Caribou
Oakland, Antioch & Eastern Ry., San Francisco, Cal.	100	100	4	S 80	Catenary	1200	11000	60	3	Power purchased from Great Western Power Co.	2	(2) 300 kw. (1) 500 kw and (4) 750 kw. I. & Syn. M.G. 1200 V. G.E.	3 G.E 18 W.	40	(4) G E. 205-1200 V (4) W. 321 (4) W. 322	45	50	8	4 West	47	(4) W. 308 B-6 120 h.p. 600 V.	M -N A W -H L.	Yes	D	Half W-Full		West & G E Air Comp.	C P 29	25	1200	1910	New	Oakland, Antioch, Sacramento and San Francisco
Southern Cambria Ry. Co., Johnstown, Pa.	23	24	0	S 70	Direct Suspension Double Trolley	1200		None		(2) 300 kw. 600/1200 (2) 500 kw 600/1200 Engine Driven Generator G E	0	Direct Feed	8 G E. 2 W	38	(4) G.E. 205-600 V (4) G.E. 217-600 V	43	46	0	0			M.-A. K	Yes No	D	(4) Full (2) Half	Hot Water	Emer St Air	C P 22	21	600	1910	New	Johnstown & Ebensburg
Shore Line Electric Ry. Co., Saybrook, Conn.	74	74	4	S 70	Bracket Catenary	1200	11000	25	3	(1) Steam Station at Saybrook, Tot. 9000 kw., 12 units G.E.	3	(2) G E Subs. (8) TC-4-200-750-600 V (1) Stanley Sub. (2) 300 kw. 600 V.	14 G E. 8 W	30	(4) G.E. 205-600 V. (4) W. 327C-600 V	43	44	2	0			M -N A. W -H L.	Yes	D	(14) Half (8) Full	1200 V	Emer St. & Auto	C P. 20-28	25	600 1200	Sept. 1910	New	New Haven & New London
Southern Pacific (Oakland, Alameda & Berkeley Div.), Cal.	81	121	0	S	Catenary	1200	13200	25	3	Power purchased from Great Western Power Co	3	(20) TC-4-750-750-600/1200 V. Rot. Con. General Electric	81	50.5	(4) G E. 207-600 V	40	88 116	40	1	60 W		M. A.	Yes	D	Half		West			1200	Apr 1911	Steam	Suburban Service in Oakland Alameda & Berkeley
Ft. Dodge, Des Moines & Southern Ry., Boone, Iowa	120	145	5	S 70	Direct Suspension	1200	22000 △	25	3	6500 kw. Curtis turbine, 2300 V. and W. Engine Driven units G E.	6 1 Port	(8) TC-4-400-750-1200 Rot. Con. (1) TC-4-300-750-1200 Rot. Con. General Electric	20	38	(4) G E. 205-600 V.	45	50	Frt	7 2	40 60	(4) G E. 206-600 V. (4) G.E. 212-600 V.	M. N.A	Yes	S	Full	Hot Water	West St & Auto			600	Sept. 1911	Steam & New	Ft Dodge, Boone Des Moines and Rockwell City
Southwestern Traction & Power Co., New Iberia, La	12.5	12.5	0	S 60	Catenary	1200		None		(1) 200 kw. 1200 V G E Engine Driven Generator	0	Direct Feed	3	26	(4) G E. 217-600 V	36.5	46	0	0			K	No	D	Half		Straight	C P 29	25	1200	May 1912	New	New Iberia & Jeanerette
Oregon Electric Ry., Portland, Oregon	154	180	25	S 70 and 75	Catenary	1200	60000	33	3	Power purchased from Pt Ry & Lt Co.	8 1 Port	(6) TC-4-500-900-600/1200 Rot. Con. (7) TC-4-500-990-1200 Rot. Con. General Electric	53 8 Ex 1 W		(4) G E 205-600 V (4) G E 222-600 V (1) W. 321-600 V	45	62	28	6 4	60 40	(4) G E. 212-600 V. (4) G E 207-600 V.	M A	Yes	D	Full	Hot Water 1200 V	West D-3		35	600	July 1912	600 V. & New	Portland, Salem Albany & Eugene
Davenport & Muscatine Railway Co., Davenport, Ia.	30	30	4	S 70	Catenary	1200	33000 Y	60	3	Power purchased from Tri City Ry. & Lt Co., Steam	2	(4) 300 kw 1300 V M.G Sets General Electric	6 1 Ex	32	(4) G E. 217-600 V	39	52	0	0			K.	No	S	Half		West. D-2-K	West	18	1200	Aug 1912	New	Davenport & Muscatine
Kansas City, Clay County & St. Joseph Ry., Kansas City, Mo.	72	72	9	S 70	Catenary	1200	33000	25	3	Power purchased from Metropolitan St. Ry Co., Steam Turbines	3	(6) 500 kw. 750 r p.m. 1200 V. Rot Con. (Insul. for 1500 V) Westinghouse	22	41	(4) G.E 225-600 V.	45	66	0	0			M A	Yes	D	Half	Hot Water	Variable Release	C.P 29	25	1200	June 1913	New	Kansas City, St Joseph, & Excelsior Springs
Nashville, Gallatin Interurban Ry., Nashville, Tenn.	27	27	3.5	S	Direct Suspension	1200	33000 Y	25	3	Power purchased from Nashville Ry. & Lt. Co	1	(3) TC-6-200-1200-600/1200 Rot. Con H R. Type Transformers G E	4 1 Ex.	38	(4) G E 205-600 V	40	50	0	1				No	S	Half		Straight	C P. 29	25	1200	April 1913	New	Nashville & Gallatin, Tenn
Piedmont Traction Co. (South Pr. Co.) Charlotte, N. C.	130	130	10	S 80	Catenary	1500	100000 and 50000	60	3	Power purchased from Southern Power Co. (Hydro Elec.)	8	(20) 250 kw. 750/1500 V M G. Sets. Two in Series for 1500 V. Westinghouse	31	42	(4) W 325-750 V	45		0	6 W. 6 G E.	60	(4) G E. 212-750 V.	W -H L.	Yes	S	Half		W-Variable Release	Dyn. Comp	25	1500/750	1913	New	Charlotte to Kings Mountain
Butte, Anaconda & Pacific Ry., Butte, Mont.	30	90	0	S	Catenary	2400		None		Power purchased from Butte Elect. & Pr. Co. (Hydro Elec.)	2	(4) 1000 kw. M G Sets, 1200/2400 V. General Electric	0					Pass. and Frt	17	80	(4) G E. 229-1200 V	M N A	Yes	D		2400 V	W-St & Auto G E Comp	C P. 26	100	600	June 1913	Steam	Butte & Anaconda & Mines
United Railways Co., Portland, Oregon	28	35	3.5	S 60 and 90	Catenary	1200	60000	33 60	3	Power purchased from Portland Ry. Lt., & Pr. Co.	1	(2) Westinghouse 500 kw 600 V. M.G Sets in Series	7	40	(4) G E 73 and 205 (4) G E. 205-600 V.	45	62	3	1	40	(4) G.E. 55-600 V.	A.	Yes	D	Full	1200 V	West Auto	W	35	600 1200	June 1913	600 V D-C	Portland, Wilkesboro
Southern Traction Co., Dallas, Texas	158	158	5	S 70 and 80	11 Point Catenary	1200	33000	60	3	Power purchased from Texas Pr & Lt Co., Steam	6 1 Port	(4) Subs. Ea. (1) 400 kw 1200 V M G (3) Subs. Ea. (2) 400 kw. 600/1200 V M G. General Electric	22 6 Ex	41	(4) G.E. 225-600 V.	65	56	12	2	25	(4) G E. 225-600 V.	M N A	No	7-D 23-S	Full	1200 V	W-A M N G E Comp	C P. 29	25	600	Oct. 1913	New	Dallas, Waco & Corsicana
Pittsburg & Butler Ry Co., Pittsburg, Pa.	33	33	5.25	5 ft 2½ in.	Catenary	1200	22000	25	3	(1) 6000 kw Engine & Turb units, West.	2	(4) TCC-4-300-750-1200 V. Rot Con. General Electric	13	36	(4) G E 225-600 V.	47	48	0	0			M K N A	Yes	D	Full		West G.E. Comp	C P 28	25	600	1913	6600 V Single-phase	Pittsburg & Butler
Pacific Electric (San Bernardino Division) Los Angeles, Cal.	57	114	1.7	S 80	Catenary	1200	60000	50	3	Draws power from an Extensive System		Several 600 V. Subs. used for 1200 V. Equip. Westinghouse	44	44	(4) W. 333A 600 V.	45	64	0	10	65		W.-H L A		D			West	Dyn Comp.	28	600 1200	Building	New	Los Angeles & Vicinity
Tidewater Southern R.R., Stockton, Cal	40 100 Future	44	2	S 65	Catenary	1200	104000	60	3	Power purchased from Sierra & San Francisco Pr. Co.	1	Westinghouse M G. 1200 V.	3 1 Ex	30	(4) G E 201-600 V. (4) G E 207-600 V.	43	40	0	0			M-A MK	Yes	D	Half	1200 V.	West	Dyn. Comp		600 1200	1913	New	Stockton & Modesta
Portland, Eugene & Eastern Ry. Co., Portland, Oregon	95 350 Future	110	1	S 75 and 90	Catenary	1500	13200	60	3	Power purchased from Portland Ry., Lt. & Pr. Co	3	(6) 500 kw. 1500 V. Syn. M.G. Set General Electric	30 5 Ex	46	(4) G.E. 205-750 V.	45	60	11	3	60	West WB-4 W 308-750 V.	M A.	Yes	D S	Full	1500 V	West	Dyn Comp	35	600 1500	Building	Steam	Portland, McMinnville, Oswego, (future) Salem, Albany & Eugene
Southern Illinois Ry. & Pr Co., Harrisburg, Ill.	17	20	0	S 80	5 Point Catenary	1200	33000	60	3	(2) 1000 kw. Curtis Turb. installed at Muddy, G.E.	1	(2) 300 kw. 1200 V. M.G. Sets General Electric	4 1 Ex.		(4) G E. 205-600 V.	38	52	2	0			M N.A	Yes	D S	Half		St and Auto	C P. 29	25	1200	Sept. 1913	New	Eldorado, Harrisburg and Carrier Mills
Jefferson County Tract. Co. (Eastern Texas Elec. Co., S.&W.) Beaumont, Texas	20	20	4	S 70	Catenary	1200		None		Power purchased from Beaumont & Pt Arthur Lt & Pr Co.	2 In P H.	(2) Syn. M.G Sets 60 cy., 2300-1200 V. D-C. General Electric	6 1 Ex	30	(4) G E. 233-600 V.	45	46	4	0			K	No	S	Half			West.	25		Building 1913	New	Beaumont & Pt. Arthur
St. Paul Southern Electric Ry., St. Paul, Minn.	18 125 Future	18	7	S 70	Catenary	1200	33000	60	3	Power purchased	1	(2) TC-6-200-600/1200 V. Rot. Con. General Electric	4 1 Ex	32	(4) G E. 225-600 V.	35	84	0	0			M.	Yes	S	Half	Hot Water	Variable Release	C P 29	25	1200	Building 1913	New	St. Paul & Hastings
Michigan United Traction Co., Jackson, Mich.	92 150	92 150	0 25	S 70	Third Rail and Direct Suspension Trolley	2400 1200	140000 40000	30 60	3 3	Power purchased from East. Mich. Pr. Co	3 7	(8) 500 kw Rot. 1200/2400 G.E. (4) 500 kw. M G 1200/2400 G.E (11) 500 kw. 1200 V M G. Set G.E. (6) 300 kw. 600/1200 V. Rot. G.E.	20 40 W.	58 45	(4) G E. 239-1200 V. (4) W 333-600 V.	66 60	70 55	0 0	0 0			M.-N.A W.-H L.	Yes Yes	S S	Half Full	Hot Water	Comb. St & Auto West	C P 28 W	25	125 600	Building 1914 Building 1914	New 600 V.	Kalamazoo, Grand Rapids & Battle Creek Kalamazoo, Battle Creek Jackson, Saginaw, Bay City & Flint

There are several instances where roads have specified 600 volt apparatus insulated for 1200 volts for their additional equipment in both substations and cars, the intention being to ultimately change over to the higher voltage. In every one of the five roads that were previously operated at either 600 volts or single-phase the change over to the present system was made without interrupting the regular service, which in itself speaks highly for the flexibility of the system.

Two of the roads, namely the Oregon Electric and the Milwaukee Light, Heat & Traction Company, operate sleeping cars on their midnight runs, and *de luxe* limited trains with observation platforms during the day, thus closely resembling the best steam road service.

It can be seen from a study of the accomplishments of the past six years that the field of electric traction has widened from the street railway systems to the suburban and interurban systems, and lastly into the field of heavy steam traction. Some of the most notable examples of heavy steam traction, such as the New York Central, New York, New Haven & Hartford, the Baltimore & Ohio, The Great Northern, and the Detroit River Tunnel, have not been mentioned because of the limitations of the title of this article to high voltage direct current installations, whereas these are included under different classes.

There are at present seven of the greater steam railroad systems in the United States and Canada that are contemplating electrification or extension of certain divisions within the immediate future. These divisions are in each case the "neck of the bottle" or the limiting traffic sections of the lines, consisting of either a tunnel, a maximum grade, or a congested terminal. In each of these cases the increased efficiency of operation, the elimination of smoke and dangerous gases, and the cleaner operation of these sections are deemed sufficient to warrant the large capital outlay entailed by electrification.

RELATIVE EFFICIENCIES OF ELECTRIC RAILROAD DISTRIBUTION SYSTEMS

By C. E. Eveleth

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The much discussed and ever present question of the relative all-day efficiencies of various systems of electrification is dealt with in this article in a concise and authoritative manner. The value of this contribution is unquestionable; and while the values given in the tablé are not meant to be taken as absolute, we believe that these data will be used extensively and will prove a most valuable guide when figuring the efficiencies of electric railway installations.—Editor.

The accompanying table shows the approximate all-day combined efficiencies from prime mover to train wheels for various methods of electrification. They are based on trunk line conditions with trains hauled by electric locomotives. For any load conditions different from those assumed, there will be minor differences in individual all-day efficiencies, but the overall or combined efficiencies will not be found to vary materially. This tabulation is not intended to be used as absolute values for every concrete condition which may arise, but it is intended to outline the elements which involve losses that should be taken into consideration and gives reasonable values for the percentage of loss for conditions ordinarily encountered.

In each instance a considerable length of line is contemplated, making it necessary to have a 100,000 volt high tension primary distribution or a multiplicity of power sources.

The systems of distribution may be briefly commented upon as follows:

Systems 1 to 4 inclusive cover direct current installations with geared and gearless motors. Frequencies of 25 and 60 cycles are assumed, as either may be most desirable depending upon the location of the project under consideration. Generally in the eastern part of the United States either frequency may be considered, but in the West there is practically nothing but 60 cycles, and ordinarily power would be purchased at this frequency, or at least provision would be made to connect with

AVERAGE ALL DAY EFFICIENCIES—PER CENT

Number	1	2	3	4	5	6	7	8	9	10	11	12
Source of power	Three Phase	Three Phase	Three Phase	Three Phase	Three-Phase	Three-Phase	Single-Phase	Single-Phase	Three-Phase	Single-Phase	Single-Phase	Three-Phase
Frequency	25	25	60	60	25	60	25	25	60	25	25	60
System, i.e., Locomotives	D-C.	D-C.	D-C.	D-C.	Three-Phase	Three-Phase	Split-Phase	Split-Phase	Split-Phase	Single-Phase	Single-Phase	Single-Phase
Gearing	Gearless	Geared	Gearless	Geared	Geared	Geared	Geared	Geared Side Rod	Geared	Geared	Geared	Geared
1. [illegible]	93	93	93	93	92	93	89	89	93	89	89	93
2. [illegible]	97	97	97	97	97	97	96	96	97	96	..	97
3. [illegible]									..		97	..
4. [illegible]	95	95	95	95	95	95	95	95	95	95	97	95
5. [illegible]	97	97	97	97	96	97	96	96	97	96		97
6. [illegible]						85			84			84
7. [illegible]			85	85								...
8. [illegible]	91	91										.
9. [illegible]						97						..
10. [illegible]									98			98
11. [illegible]						97	97	97	97			97
12. [illegible]						96						
13. [illegible]							9[illegible]	97	97		97	97
14. [illegible]	[illegible]	90	90	90	95	95	97	97	97	97	97	97
15. [illegible]					96	96	96	96	96	96	96	96
16. [illegible]							92	92	92			
17. [illegible]			94	94	95	95	95	95	95	96	96	96
18. Motors			93	91	91	91	91	91	91	88	88	88
19. Tractive [illegible]					97	97	97	97	97			
20. Gearing, side rod				95	94	95	95	90	95	95	95	95
21. Weight			98	100	100	100	98	98	98	98	98	98
Combined all day eff.	58	55	54	51	59	46	49	46	43	57	59	47

a 60 cycle power system in case of emergency. By the use of 60 cycle rotary converters instead of motor-generator sets for systems 3 and 4 their efficiencies would be identical with systems 1 and 2, or vice versa. System 1 is in a general way similar to the New York Central and system 4 similar to the Butte, Anaconda & Pacific installation.

Systems 5 and 6 contemplate the use of 25 cycle, three-phase motors on the locomotives. System 5 is similar to that used in the electrification of the Cascade Tunnel of the Great Northern Railroad.

Systems 7 to 9 inclusive, designated as "split phase," contemplate the use of 25 cycle polyphase induction motors on the locomotives, taking power through transformers and a phase converter from a single-phase trolley. The secondary transmission here considered is deemed desirable on account of the higher cost of stepping down directly from the high tension transmission line to the trolley with substation spacing of ten miles or less, such as has been found necessary to mitigate telephone and telegraph disturbances. Items 11 and 13 might be eliminated, increasing the combined efficiency from 49 to 52 and from 46 to 49. (Systems 7 and 8.)

System 8 is identical with 7 with the exception of the mechanical structure of the locomotive, the latter having side rods and gears and the former having gears only.

Systems 10 to 12 contemplate the use of 25 cycle compensated commutator single-phase motors on the locomotives, taking single-phase power from the trolley through the requisite step-down transformers.

System 11, which has distribution connections similar to the New York, New Haven & Hartford Railroad, has a limited application on account of the moderate distance over which power can be transmitted, particularly if applied to single track lines. It therefore necessitates power houses at no great distance apart.

Item 19, called "tractive equalizer," is a value inserted to represent the necessary average loss due to provision on each locomotive equipped with induction motors to permit the operation of locomotives in the same trains which have different diameters of driving wheels. The inherent characteristics of induction motors are such that 2 or 3 per cent difference in speed makes the difference between full tractive effort and no tractive effort. Locomotives with same diameter of driving wheels will divide the load properly, but as the wheels on some locomotives are decreased in diameter due to wear, these locomotives will not take their share of the load if coupled with machines having full sized wheels. To equalize the load this necessitates the insertion of an artificial resistance or other provision for adjustment of the motor slip to obtain identical characteristics for motors in locomotives with different diameters of driving wheels. If 6 per cent variation were allowed between new wheels and old, the loss due to equalization of draw bar pull would be about 6 per cent in the locomotive with new wheels adjusted to divide the load properly with a locomotive having worn wheels; the latter not having any artificial loss, as its adjusting resistance would be all cut out. The average loss for conditions where locomotives with old and new wheels are operated miscellaneously is estimated to average 3 per cent due to the tractive equalizers.

Item 21, called "weight efficiency," is a value inserted to equalize the difference in average train weight due to difference in weight of the locomotives.

It is interesting to note that, with 25 cycle power supply, the overall efficiency for the direct current, three-phase and single-phase systems is essentially the same, but that the split phase will take 10 to 15 per cent more power. With the 60 cycle power supply the direct current is about 10 per cent more efficient than the three-phase and single-phase, and 15 to 20 per cent more efficient than with the split phase.

THE DEVELOPMENT OF THE MODERN D-C. RAILWAY MOTOR

By Edward D. Priest

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Mr. Priest's article will be read with great pleasure by all railway men interested in the development of the railway motor. There is perhaps no one better qualified to write on this subject than the author, who has been so closely associated with the development of the railway motor for a long period of years. The author tells of developments that, while they were vital to the success of the railway motor, are unknown to many engineers who have entered the field of electrical engineering at a later date.—Editor.

The modern d-c. railway motor is a comparatively simple machine with few elemental parts, and therein it possesses a marked advantage over other types of "motive power." It has gone through a process of evolution from a crude machine requiring frequent inspection and repairs to a machine which runs for days and weeks and sometimes months, covering thousands of miles without being given any inspection or attention whatever.

There is no other "motive power" which can compare with the modern d-c. railway motor in reliability.

The development of the railway motor has been accomplished during a comparatively brief period, less than 30 years. Although motors of the pioneer period performed remarkably well for their day, considering the newness of the art and the lack of suitable materials with which the inventor and designer had to work, they were decidedly unreliable and costly to maintain.

Costs

In the beginning, had it not been for the novelty of the thing which induced people to ride in large numbers, it is doubtful if electric traction would have been a financial success, owing to the high initial cost, as well as cost of maintaining the equipment, track, transmission lines, power house, etc.

Once a two-motor equipment of about 30 h.p. sold for $4500. Now a much superior equipment of the same rating can be purchased for less than $1200. It is interesting to note that while at first the electric equipment for a car cost several times as much as the equipment of horses required to keep a car in service, now a car can be equipped with electric power for less money than it would cost to equip with horses, and this does not take into account the greater daily mileage of the electric car as compared with the horse car. This illustrates the large decrease in cost of electric equipments as the art of electric traction has advanced. The reduction has been accomplished by a large expenditure of money in the development of designs and the perfection of manufacturing methods. Development of designs should perhaps not be mentioned in this connection, for as a matter of fact the quality of motors has been so much improved that the inherent manufacturing cost of a modern railway motor is greater than a motor of the early days of the same capacity.

Materials

Some of the difficulties of the early designer are well remembered. Suitable materials were not available; insulating materials had to be developed; cast steel could not be obtained. It would be difficult to design a modern railway motor without using cast steel. The first gears were made of cast iron, as were also the magnet yoke, pole pieces, bearing housings, etc. It is now considered bad practice to use any cast iron in the construction of a railway motor. It was thought to be a marked advance when forged pole pieces and magnet yokes were substituted for cast iron. Later, in 1889, castings were secured from the Mitis Iron Co. of Neponset, Mass. Mitis iron was a ductile metal similar to cast steel, and some parts of the F-30 motor were cast from this metal. The facilities of the foundry were inadequate, and to meet this situation the Thomson-Houston Co. furnished capital and took over the making of castings. The foundry was later moved to South Boston. WP-30 magnet frames were cast from mitis iron. The WP-30 was the pioneer of the now universal type of railway motor enclosed by its own magnet frame.

Brushes

At first copper brushes were used on commutators; carbon brushes had not been discovered. In 1887, the Thomson-Houston Company manufactured some railway motors for the Bentley Knight Company, which were run on a road in Allegheny, Pa. These motors had copper brushes, and to keep them on the road nightly express shipments of brushes were made from the factory, in response to frequent telegraphic requests for more brushes. It was said that there was a small fortune in copper along the streets of Allegheny over which the motors ran. The carbon brush saved the day. It was thought at the time too good to be true. I remember the anger of a university graduate who was given an all day job of shaking a running motor suspended from a hoist to see if it had any destructive effect on the carbon brushes; just why such shaking should have a destructive effect is not clear.

While the discovery of the carbon brush was a boon to the railway motor, it by no means completely solved the problem of commutation, and carbon brushes are not all good even today, after years of development. The problem of producing good brushes and then duplicating them is a difficult one, and conditions of operation vary so widely that brushes which work well on one type of motor on one road, may fail on the same type of motor on another road. The life of brushes is affected by commutating characteristics of the motor, overloads to which the motor is subjected, condition of commutator, condition of brush-holders, and not least, the condition of road bed. A rough track will cause bad commutation and breakage of brushes. Indeed rough tracks are responsible for many motor failures.

Commutators

Years ago when commutators ran black and developed flat spots, it was charged to high mica, and in truth, it usually was the mica. The difficulty of making two such dissimilar materials as mica and copper wear away evenly is apparent. During the fall of 1898 much trouble was experienced with some GE-52 motors which would run but a few weeks at most, without developing black commutators. The commutators had to be frequently sandpapered to keep the motors on the road. Various schemes were tried to overcome the trouble and the expedient of cutting the mica out between segments was hit upon. It resulted in perfectly smooth running commutators. Grooving was then tried on a large shop generator which was used for miscellaneous testing under widely varying load conditions. Previous to grooving, the commutator had to be stoned every day or two to keep the machine from flashing; after grooving the machine ran without giving trouble and the commutator took on a good polish. This was the beginning of the practice of grooving commutators which is now in such general use, not only on railway motors but on other types of commutating machines. It is almost a "cure-all remedy."

A more recent experience with railway motors flashing over at commutators will be of interest On a certain road trouble was reported from flashing at commutators; it was confined principally to the winter months. The flashing seemed somewhat mysterious. On a stand test the motor commutated perfectly and full potential could be instantly thrown on with the armature standing still without flashing over. Commutation was watched in service and under ordinary operating conditions it was perfect. On reversal while running the motor appeared better than most motors. Running at full speed on a very rough track, with a frozen road bed, when striking bad rail joints the motors would sometimes flash. It was evident that the flashing was caused by the brushes being knocked off of the commutator by the blow when striking bad joints. Longer, more resilient springs in the motor suspension were tried with marked improvement. Increased brush tension also reduced flashing.

In an attempt to duplicate operating conditions on a stand test some interesting phenomena were noted. A brush lifting device was arranged so that a falling weight engaged a spring trigger which lifted the brush and instantly allowed it to drop back on to the commutator. The device was designed to allow the brush to be lifted a pre-determined distance. A number of different types of motors were tested and it was found that at speeds and loads corresponding to the free running speed of the car the motors would frequently flash over with from 5 to 10 mils lift of the positive brush and nearly always with lifts of from 15 to 20 mils. It appeared that the length of time the brushes were off the commutator also affected flashing. Negative brushes could be lifted as much as 100 mils without flashing. It made little or no difference whether the frame was ground to the positive or to the negative brush. Flashing usually occurred from brush-holder to brush-holder and not to frame. It was thought that the difference in the nature of the gases in the arc when the current flowed from carbon brush to commutator, or from commutator to brush, accounted for the difference in flashing when the positive or negative brush was lifted. In an attempt to stop flashing when the positive brush was lifted, it was found that a small block of insulating material attached to the front of the holder, extending the length of the commutator and close to it, was effective.

It would appear that most flashing of modern commutating pole railway motors in service is caused by the brushes failing, from one cause or another, to maintain contact with the commutator. Probably in service the amount of brush lift from the commutator is small, not ordinarily more than 5, or possibly 10 mils. If it were permissible to increase the brush tension the desired amount, contact with the commutator could probably be maintained. Too high a tension may cause breakage of brushes and more rapid wear of the commutator. It is evident that the motor suspension and truck design largely affects flashing.

In the early days of the GE-800 motor there was an epidemic of trouble from grounded commutators, through the cone or shell micas. After the ground occurred, a hole of considerable size would be found burned through the mica and into the shell or cap. It required the examination of many commutators before the real cause of the trouble was located. It appeared to start from minute short circuits between segments which in time gradually burned a hole through the mica until a ground was established. By carefully removing during manufacture, the tiny spurs of copper which were drawn partly across the segment mica when the cone surfaces were machined, all trouble was eliminated.

Some curious results of short circuits between segments were noted. Segment micas were found through which a narrow channel had been gradually cut from the inside to the outside surface of the commutator by the action of an arc, so that the side mica was cut completely in two without the copper segments being burned at all, or if any, so little that it could hardly be detected with the naked eye.

At one time it was the practice to clamp a moulded insulating ring against the front end of the commutator segments to prevent short circuits and grounds. This practice was abandoned for the present well known method of extending the shell mica out some distance from the segments and covering with string or tape. Years of experience has shown that the varnish used in pasting and sticking together the mica used in commutators must be of just the right quality or trouble from short circuited and grounded commutators is sure to result.

Those who have had experience with the older types of motors, especially before grooving of commutator segments was adopted, will remember the frequency with which commutators had to be sandpapered or turned. Commutator wear was so rapid that it was considered good practice to make the segments very deep; a wearing depth of 1¼ in. was not thought excessive. With a modern commutating pole motor the wear on the commutator is usually so slight that it can hardly be detected after a year's run. Ten mils wear in a year is not exceptionally low. At this rate a depth of ½ inch will last fifty years. It is now not economical to make as deep segments as was the practice with old types of motors.

Brush-holders

Brush-holders of many different designs have been tried on railway motors. On the first motors the holders were adjustable to allow for circumferential adjustment to permit correct setting. As the accuracy of manufacturing was improved this became unnecessary and a pre-determined fixed position was provided. The problem of successfully insulating brush-holders from the magnet frame was a difficult one. The old types of moulded or wood insulation when wet or coated with copper and carbon dust were liable to become charred by leakage current or destroyed by flashing. Grounding of brush-holders was of rather frequent occurrence until the mica insulated holder, now in such general use, was developed in 1895. The first motor on which this type of insulation was used was the GE-55. Holders in general use today are much alike. The insulating support is a metal stud or pin covered with mica protected with a sleeve usually made of porcelain. The brush-holder finger is made up of a cast or pressed sheet metal part, to which is attached a bronze leaf spring tipped with a copper shoe which rests on the brush. The spring acts quickly and provides for slight movements of the brush. The finger as a whole is actuated by a coiled wire spring or a ribbon clock spring.

Voltage

The early selection of 500 volts potential for the trolley circuit has always seemed to the writer most fortunate. Considering early limitations in motor design, such as insulating materials, commutation, line losses, etc., no better selection could have been made. I am not sure who was responsible for the selection of this voltage. It was certainly a wise selection in its day, whatever the future may bring forth in higher d-c. potentials.

Until 1907 the highest potential in use on d-c. railway motors in America was 600 to 700 volts. During that year the Pittsburg, Harmony, Butler and New Castle Railway was supplied with G.E. 75 h.p. 1200 volt motors. The success of the installation was so pronounced that other installations rapidly followed. In the spring of 1913, 2400 volt motors were put in successful operation on the Butte, Anaconda and Pacific Railroad.

Gears and Gear Cases

Each part of the modern railway motor has been developed through costly experience and strenuous effort. The early motors, as previously noted, had cast iron double reduction gears. At first it was not altogether clear that spur gearing was the best type of drive, or that motors had best be mounted on the axle as is now the common practice. It was a decided step in advance when single reduction gears were substituted for double reduction gears. It helped out the motor design and in general made a more reliable motor. Those who think that the modern railway motor, with single reduction gearing, is noisy should have heard the ancient double reduction motors coming down the street; the gear noise was sufficient to indicate the car's approach some blocks away. Cast iron gears were superseded by medium carbon cast steel gears, and then by forged heat treated gear rims. The old soft cast iron gears with 20,000 pounds elastic limit, good for about 25,000 miles, have now been superseded by case hardened cast steel gears or forged hard tempered gears, of from 80,000 to 140,000 pounds elastic limit, good for 300,000 miles.

Early motors were run without gear covers. Gear covers of all sorts of design and material have been tried; cast iron, sheet iron, canvas, wood, cast steel, malleable iron, etc. Not so many years ago gear covers were expected to break in service as a matter of course, and frequent renewals were necessary. Not so with modern malleable iron covers with modern suspension; they last for years without failure. They are so strong and so securely attached to the motor, that in the winter time it not infrequently happens that the truck wheels are lifted from the track by the gear covers riding on the frozen snow and ice projecting high above the rails. If the gear cover or magnet frame breaks under such treatment, the manufacturer is expected to make good. It is certainly a high compliment to the modern railway motor that so much endurance is expected from it under such adverse conditions. However, it all makes for the advancement of the art and incidentally keeps the designer "onto his job."

Bearings and Lubrication

Few parts of the railway motor have been given more attention by designers than the bearings. If the bearings don't run well the motor may be put out of commission. Many armatures and fields have been wrecked because of low bearings. One inventor and his attorney were much disappointed because the writer could not recommend the purchase of a patent designed to make it possible for the motorman to throw the motor gears out of mesh when an armature struck the pole pieces, and thus save the armature windings from complete destruction. The plan was to have the motor so suspended on the axle that it could be forced away from the axle until the pinion was disengaged from the gear—not an easy thing to do, as can well be imagined. Another inventor proposed a more simple plan which consisted of a device arranged so that when the armature approached close to the pole pieces an electrical contact would be made and a bell rung to warn the motorman that it was time to go to the barn.

Some of the early motors had grease lubricated bearings; oil bearings were then tried and later given up; then oil and grease combined, and finally oil and waste. One of the principal difficulties with grease was that it depended on the heat of the bearing to make it feed and also on climatic temperature, which is altogether unreliable. Grease cups with adjustable covers were tried, but the covers were not always screwed down at the right time. If a spring was depended on to force the grease against the bearing the grease might be so hard that it would not feed at all, or so soft that it would feed all at one time.

Years ago it was thought that the problem of lubrication had been solved on an F-30 motor. The journal portion of the shaft was enlarged about 1 in. in diameter and the shaft bearing housing designed with flanges at each end, forming a pocket as it were, in which the journal ran. The pocket was connected with an oil reservoir on the same level so that the journal ran in a bath of oil. In theory this seemed a fine idea, but in practice it did not work so well. In a short time the oil worked out of the box, or grit got into the oil and cut the bearing. Moreover the bearing was a difficult and expensive one to manufacture. A modification of this type of bearing was made by shortening the enlarged portion of the shaft until it became a ring on the shaft. This divided the journal into two parts with short bearing linings for each part. The ring dipped in the oil and lubricated the bearing, and also served to take the end thrust of the shaft against the linings. It is only a step from this way of lubricating bearings to ring lubrication with a loose ring on the shaft, a method of lubrication which, when tried on railway motors in this country, has not been found altogether successful, owing to wide variations in climatic temperature changing the fluidity of the oil, and the further difficulty of keeping the oil free from dirt under the severe conditions of railway motor operation.

Many motors were designed with bearings lubricated with both grease and oil. Grease cups were cast in the magnet frame over each bearing on motors which opened downward, and oil wells in the caps bolted to the under side of the bearings. The grease was fed to the bearings by gravity and the oil by capillary attraction through wicks bearing on the shaft. This type of bearing, in its day, gave fairly good results. That, however, was when 20,000 miles for life of linings was not unreasonably low. The fault of this method of lubrication was that it had the disadvantages inherent in grease lubrication and was imperfectly oil lubricated. The bearing surface of the wicks became glazed and [illegible] partly filled with grease so that the oil would not feed. There are many thousands of motors in service today which were equipped with this type of bearing. To improve the operation innumerable oil cups have been designed to be placed in or attached to the bearing boxes, oil being fed to the journal through wicks or valves actuated by the jolting of the motor.

In 1895, a GE-51 motor was designed with a rather novel form of bearing. The bearing housing was cast in one piece and the interior slotted to receive bronze bearing blocks, one located over the journal and one under. Each block was supported midway of its length on a bolt of large diameter with a rounded end which passed through the housing with a head on the outside. The bearing blocks with this construction were self-aligning and could be adjusted to take up wear. A narrow surface of the shaft on each side was exposed for the full length of the bearing. The housing contained an oil reservoir which was packed on each side with oily waste. This method of lubricating bearings was the beginning of oil and waste lubrication now universally used on motors. The adjustable block scheme did not work out very well in practice; the severe pounding and shaking which railway motors receive in service caused the parts to wear rapidly.

The modern solid head oil and waste lubricated motor bearing, with oily waste pressed against the low pressure side of the bearing, was first used on the GE-53 motor in 1896 and at about the same time on the GE-55. It proved so successful that its adoption became universal on railway motors. From time to time minor improvements have been made, but the bearing remains today substantially as originally designed. A modification of this type of bearing was made on a GE-80 motor, the object being to facilitate handling by the use of a split bearing housing. In this type the oily waste bore on top of the journal through an opening in the bearing housing, the waste dipping in oil in a reservoir located at the side of the bearing. The reservoir was packed with waste through a cover directly over the journal and could be filled with oil through a hole with a separate cover at one side of the bearing. Through this hole the depth of oil in the reservoir could be measured.

Many experiments have been made with ball and roller bearings on railway motor armature shafts and, although such bearings have attractive features and considerable promise, it will require long service tests on a large number of motors to determine their real value.

Perhaps the best measure of the advance which has been made in the design of railway motor bearings is the comparative life of bearings and the attention they require. In the early motors it was the practice to lubricate bearings every night, and from 10,000 to 20,000 miles life of armature linings was considered normal. Modern motors are lubricated about once in 10 days or 3 weeks, depending on service conditions. They have been known to run 6 months without renewing the oil, and the life of linings is commonly from 50,000 to 200,000 miles. Improvements in material and perfection in manufacture as well as design have contributed to these results.

Field and Armature Coils

Years ago the advent of spring always brought with it reports of innumerable grounded field coils, and this even with the enclosed types of motors. It was the practice at one time to enclose GE-800 field coils in a lead casing to keep out moisture. The modern coil is compounded in a vacuum tank, insulated with specially prepared fabrics to resist moisture, and covered with strong webbing to prevent mechanical injury. Such coils are almost "bullet-proof" and reports of grounded coils are rare. Another common source of trouble with field coils was the chafing of insulation due to movement of coils caused by the jolting and shaking incident to service operation. In modern motors the coils are securely held by suitable sheet steel springs so that all movement between the coils, frame and pole pieces is eliminated. Field coils are now as reliable as other parts of the motor. Originally it was the practice to wind field coils with round wire; now it is common practice to use ribbon copper. With ribbon copper a larger amount of copper can be gotten into a given space, and moreover such a coil is more easily repaired in case of damage. Perhaps the first motor on which ribbon copper was used with asbestos between the turns was the AXB-70 in 1893. Ribbon copper was also used on the GE-1200 in 1895, and later on the GE-51, GE-57 and other motors.

Pole pieces were once cast as a part of the magnet frame. The adoption of polycoil armatures with large core teeth made it necessary to use laminated poles to prevent excessive core loss. The GE-51 motor was probably the first motor in which a polycoil armature with bolted-in laminated pole pieces was used. The use of polycoil armatures made it possible to design an armature of increased capacity for a given diameter, since the total space required for insulation was largely reduced. Furthermore, the reliability of the armature was improved by reducing the number of core slots.

The first railway motor armatures had smooth cores and the wire was wound directly onto the core by hand. It was a decided improvement when formed coils were adopted. The imbedding of coils in core slots greatly protected them from injury. With the early method of banding armatures, the bands were the first thing to strike when the armature got onto the pole pieces. The result was that the armature was practically sure to be wrecked. The present practice is to wind the bands in grooves below the surface of the core and, with the large strong core teeth of modern construction, the armature can rub against the pole pieces a considerable length of time before it is seriously damaged.

Much could be written on the development of railway motor armature coils. It is thought that railway motor armature coils were the first armature coils to be pressed to size and shape in steam moulds. The first coils to be insulated with mica were railway motor armature coils. In 1896 steam moulds were used in the manufacture of GE-51 coils. In 1893 asbestos insulated armature coils were used on the AXB-70, and in 1897 moulded mica insulated coils were used on the GE-55 armature.

Ventilation

As already noted the first railway motors did not have an enclosing frame. All parts were completely exposed and consequently well ventilated. The electrical parts were easily damaged and the serious problem was not how to dissipate the heat, but how to protect against mechanical injury, short circuits and grounds. Variously designed screens were tried. Protecting metal pans were suspended under the motor and curtains of canvas or other material around the sides.

When cast steel became available it was possible to make the magnet frame of such form as to enclose all the vital parts. This added much to the reliability of the motor, although it greatly retarded ventilation. Up to this point in the development of the motor the principal effort had been to get a motor which would stay on the road. Heating, efficiency, or the amount of material used for a given output was of secondary importance.

With a reliable motor assured it became a question of getting as much work as possible out of the motor, making a given amount of material do maximum work. To accomplish this, ventilation was necessary.

The first step in this direction was to ventilate the armature. Although some of the first armatures were of the ring type, and consequently had some internal circulation of air; the drum type of armature was soon adopted, and with this type all heat was radiated from the external surface. The AXB-70 and the GE-51 were the first motors to have longitudinal and radial ducts through the core for cooling the interior of the armature. The fan action of the armature also tended to keep all the air in the interior of the motor in circulation and thereby maintain a more nearly uniform temperature of the various parts. While this was a step in the right direction, all the heat had still to pass through the frame by conduction—an inefficient way of dissipating it.

As service conditions grew harder through increasing traffic, motors were at times overloaded, and not infrequently burned out from roasting. To prevent this the practice was sometimes resorted to of leaving frame covers off. With the improvements in insulating materials it was practical to do this, as less damage resulted from exposing the parts than from overheating, when completely inclosed.

It became evident that motors ought to be designed for fully ventilating the interior parts with external air. With this object in view the GE-203-A motor was developed in 1910. In the construction of this motor radial ducts in the armature core were omitted and internal longitudinal ducts provided through the whole length of the armature, including the commutator. These ducts were connected to a centrifugal blower or fan which was made a part of the pinion end core head. With the armature in rotation a strong current of air was drawn through it. The air was deflected by an annular shield or ring surrounding the fan and expelled through holes in the frame head to the outside of the motor. Holes through the magnet frame at the pinion end allowed cool air to enter and take the place of the hot air exhausted, thus creating a continuous circulation of cool air through the motor. At first it was thought that it might be necessary to extend an intake pipe to the side of the car to obtain a supply of clean air, but in practice this was not found necessary.

By this method of ventilation a remarkable increase in the service capacity of motors was secured. As an illustration, on a road operating high speed interurban cars weighing about 50 tons loaded equipped with four GE-73 motors weighing about 4100 pounds each, GE-203-A motors weighing each 2150 pounds were substituted, geared for the same speed. The GE-203 motors performed the service with practically the same temperature rise as the GE-73 motors. The GE-203 equipment has now been in service for about a year and a half and its operation is entirely satisfactory.

A large number of motors of different types are now operating with marked success on various roads throughout the country with this method of ventilation. The evidence seems conclusive that the modern railway motor will be ventilated internally with air drawn from the outside.

Magnet Frames

At first all inclosed magnet frames were of the split frame type, the idea being to so construct the frame that the armature and field coils could be taken out without completely removing the motor from the truck or axle. This idea was enforced by the fact that armature and field coils gave far more trouble than in modern motors and required rather frequent removal and replacement. Mechanically the split frame motor has some serious defects.

The box frame motor was first developed in the GE-53 and GE-55, in 1895. The box frame, in addition to being a better mechanical structure, requires less space for a given size of motor than the split frame. For large motors the box frame is a practical necessity and its advantages even for the smaller sizes are so pronounced that split frame motors are rapidly going out of favor.

Suspension

Motor suspension was one of the early problems. How should the motor be mounted on the axle and suspended or supported on the car or truck? While today it seems a simple problem, it was not so plain at the beginning. Horse cars were to be equipped with motors. There were no double truck horse cars in common use and the single trucks were made light and fragile as compared with the modern motor truck.

There were three distinct methods of supporting a motor on the axle, which were patented by their respective inventors. One way was to suspend the front end of the motor from the car floor. A second method was to bolt the ends of forged bars to the magnet yoke over and under the axle, and extend the bars in a triangular frame some distance back from the motor, the extreme back end of the frame resting against the car floor. The axle carried the full weight of the motor, the back end of the suspension being held down by the car body. Some of the first motors suspended in this way had bearing housings on the axle similar to a locomotive driving axle box. This type of bearing did not work well, since when running in one direction the torque of the motor was sometimes sufficient to lift the motor off the axle. This trouble was overcome by bolting to the magnet yoke an auxiliary bearing underneath the axle, midway between the bearings on top of the axle.

The third method of suspension was independent of the car body or truck frame. Forged or rolled bars, with ends resting on the axle bearing housings of the motors, were carried over the motors from axle to axle. There was one bar on each side and the front end of each motor was supported from these bars. The motor with suspension was a self-contained structure, the total weight being carried on the axles through the motor bearings.

Trucks, designed especially for electric motors with provision for supporting the front of the motor on the truck, were soon developed.

At one time what was known as a side bar suspension was in quite general use, the idea being to carry the weight of the motor approximately under its center of gravity and relieve the motor axle bearings of the load. It was also incorrectly thought that this suspension largely relieved the track of the hammer blow due to the weight of the motor. A modification of this suspension, designed to accomplish the same purpose, consisted of a forged bar bolted to the front end of the motor, the ends of the bar being bent back to form a yoke with the ends resting through springs on the truck side frames. This was approximately the equivalent of the center of gravity suspension. Later the practice of bending the bar back was discontinued.

This method of suspension with a straight bar is now in common use, although in many instances the bar is not extended to the side frame of the truck but is supported on the truck transom. The nose suspension with a nose or horn cast on the front of the magnet frame, designed to rest on a bracket attached to the truck transom was first introduced on the GE-55.

Motor Characteristics with Respect to Service Conditions

In the early motors not so much thought was given to carefully designing the electrical characteristics of a motor for service requirements. The fundamental thing was to get the motors big enough and mechanically strong enough to stay in service. However, the advantages of field control were recognized even in some of the first motors. The F-30 field coils were wound in sections so that part of the field could be cut out for full speed running. The GE-800 was designed for shunted field operation. On some of the early Sprague motors the fields were wound in sections and commutated, that is, connected in series or multiple to obtain speed control. These early motors did not have commutating poles and with a weakened field some trouble was experienced from bad commutation.

In about 1895 a somewhat exhaustive study was undertaken to determine the relation between motor characteristics and service operation as affecting motor temperatures and energy consumption. Previous to that the selection of motors had been more or less a matter of guess work. Railway companies when purchasing equipments did not make a practice of specifying in detail the character of service to be performed. Consequently when motors were put in operation they did not always give satisfaction. This was equally disappointing to the railway company and the manufacturer.

In order to determine by actual trial the service characteristics of different motors under varying conditions of operation, the manufacturer built, in 1896, about two miles of experimental track at Schenectady on which motors could be thoroughly tested. As a result of these tests it became possible to accurately predetermine the proper characteristics of a motor to fit a given service. Printed forms were prepared for prospective customers to fill out service conditions in detail.

The manufacturer took the stand that he would be responsible for the successful operation of motors if operating conditions were specified, but the customer must be responsible if he did not furnish such information. This policy was most satisfactory, as it placed the selection of motor equipments on a scientific basis. The railroad company was persuaded, much to its advantage, to thoroughly study conditions before purchasing motors, and consequently knew just what to expect of them, and the manufacturer was rewarded by having a satisfied customer. The direct result was to encourage and enforce the perfection of railway motors. It is doubtful if in practice the energy problem in moving cars or trains ever before received such careful investigation. Power consumption and heating as affected by schedule speed, rate of acceleration, amount of free running, amount of coasting, rate of breaking, stops, weight, gear ratio shape of motor speed curve, relation of I^2R and core loss, friction, windage, energy in moving parts both in translation and rotation, etc, were given careful study and analysis.

Commutating Pole Motors

G-E commutating pole railway motors were made in 1906. The first standard motor built was the GE-205. This type of motor greatly improved commutation and made the tap or shunted field motor a practical working proposition when service conditions warranted its use. That is where first cost or energy saving justified the increased complication.

Nomenclature

At one time significant letters and numbers were used in naming railway motors. The F-30 motor was so named because it had a flat field in distinction from a motor with a round field which it superseded. The number 30 indicated the h.p. rating. At that time an hourly rating had not been established. The continuous rating of the motor was about 15 h.p. therefore the number of the motor represented twice the continuous rating. In this series of motors there was an F-6, F-20, F-30 and F-40. The "F" motor had double reduction gearing. When an improvement was made by eliminating the intermediate gear and pinion the new motor became the SRF single reduction F.

The F motors were followed by the G motors, G-20, G-30 and G-40. The letter G was used because it signified Gramme ring armature and also because G was next in the alphabet after F. The G motors had double reduction gearing and were superseded by the SRG motors, single reduction G motors. In addition to single reduction gearing the SRG was not quite the same type of motor as the G.

The WP-40 and WP-50 were so named because they were designed to be water proof motors. The LWP motor was a light weight WP. The ANB-[illegible] was an axle motor for the B. & O. Railroad. The LRR was a locomotive railroad motor.

The GE-800 was the first of the series of GE motors, GE being the initials of the manufacturer. All General Electric railroad motors beginning with the GE-800 have had the letters GE in the name of the motor. There was a GE-800, GE-1200, GE-2000, etc. The number in the names of these motors indicated the pounds tractive effort with 33 inch wheels at normal rating of the motor. This method of rating motors proved to be impractical, since a change in winding or gear ratio changed the rating. There was a GE-800 A and B. The "A" motor had a Gramme ring armature. The "B," which superseded the "A," had a drum type armature.

The GE-50 was the first of a series of GE motors with a name which had no significance, other than the letters GE. There are a large number of different motors in this series.

When GE commutating pole railway motors were first designed the series was started with GE-200 in order to readily distinguish between commutating and non-commutating pole motors which had numbers less than 200.

Conclusion

In such a short paper it is impossible to review the detail development of d-c. railway motors except in a very general way. A volume could be written on the subject without exhausting it. Every detail in the design of the modern railway motor is the result of the survival of the fittest. The service is most exacting and only through repeated trials of various designs has it been possible to select the best. Motors which in their day were thought to represent a high standard of perfection have been superseded by still more perfect machines capable of performing their work with greater economy in energy and lower maintenance cost.

There will be further perfection of details, perhaps radical changes in design. Insulating materials which will successfully withstand higher temperatures will probably come into more general use. The question of efficiency will possibly determine the temperature limit and not the life of the insulation. Improved methods of ventilation will be adopted and a pound of material will be made to do more and better work.

RAILWAY MOTOR PERFORMANCE AND RATING

By A. H. Armstrong

Assistant Engineer Railway and Traction Department,

General Electric Company

This article deals with a most important subject in a very concise manner. The rating of railway motors has always been more or less hard for people, not thoroughly familiar with their design, to understand. Mr. Armstrong has been in a large measure responsible for giving railway motors rational ratings, and therefore an article by him on this subject is of great value.—Editor.

The early problem of railway motor design was intimately connected with the cycle of operation represented by successive periods of acceleration, coasting and braking. The duty of the motor comprised a series of runs during which it was taking current for a portion only of the complete cycle. The intermittent character of the work performed by the railway motor gave rise to certain forms of design best suited to meet operation requirements as represented in a service which rarely permitted reaching full speed, and then only for very short periods.

As the service demanded a heavy current input for short periods only, the motor was necessarily designed to have as low copper resistance as feasible together with a large flux per pole, in order to provide as much torque per ampere as possible. These rather conflicting requirements lead to a motor design having low copper loss and high iron loss. In fact, the iron loss of many motors in early use was so large that the motor would not operate continuously on iron loss alone without burning up. As the service demanded no operation at full voltage and full speed for any considerable length of time, the inherent high iron loss of such motors was not felt as a handicap in a service performance comprising operation at fractional speeds and voltages.

In all stationary motors or generators it is possible to use a concise method of rating which will convey a fairly accurate idea of the continuous performance of such apparatus, and will furthermore be short enough to serve as a commercial rating. In other words, the continuous rating expressed in horse power or kilowatts for a given temperature rise fairly accurately indicates the service capacity of a stationary motor or generator used in miscellaneous work requiring a more or less continuous output.

Owing, however, to the intermittent character of the work performed by the railway motor it is obviously difficult to express in a short commercial term any adequate idea of the service capacity of a motor designed to meet the requirements of city or short haul service. For such service a railway motor is sold on the basis of its ability to haul a given tonnage at a stated schedule speed under the conditions of frequency of stops, train resistance, braking and interval of rest obtaining. From the mass of experimental runs available the manufacturer is able to closely determine the temperature rise of a railway motor when operating under the complexities of short haul runs, but no single term has been proposed which will adequately serve to indicate the comparative service rating of motors for this class of service. Hence, the general acceptance of the one hour rating, early adopted and still in use, which gives the horse power output with a temperature rise of 75 degrees C. after one hour continuous run, starting cold at 25 deg. C. This one hour rating indicates in a general way the comparative sizes of motors of the same type of design, and furthermore affords data as to commutator performance. A commercial one hour rating, however, does not fully indicate the service capacity of the railway motor, nor does it indicate definitely whether the motor may be of such a design that it can be used to advantage in interurban service with long periods of continuous running or whether the motor is better suited to short haul service calling for high acceleration for short periods and no continuous running.

The development of the commutating pole motor practically eliminated the question of commutator performance as limiting the service capacity of the motor, and the question of this type of motor design has narrowed itself down to improvements in methods of keeping the motor from overheating.

In this direction two important steps have been taken; first, the motor has been opened up and external air forced through it, and second, the internal construction has been so improved as to greatly increase the radiating surface.

The early railway motor was of the enclosed type and all heat developed in the armature windings and core had to be carried to the outside shell through the intervening air before it could be dissipated. All heat given out by the field windings also had to follow the same path before it could be dissipated from the outside shell; hence, the heating of either field or armature windings was greatly dependent one upon the other. With the introduction of forced air ventilation direct access of the cooling stream of air was obtained, thus making the heating of the individual parts of the motor more nearly correspond to their inherent losses. Armature copper heating constitutes the real limiting factor in the service capacity of a motor, and providing direct heat dissipation upon its external surface as well as internal surface through longitudinal holes in the punchings has done much toward the development of a motor having greater output for a given weight and outside dimensions.

The elimination of the commutator as a limiting factor and the improvements made in the ventilation and construction of railway motors have had a most important bearing upon their field of application. The character of the work performed has been materially changed with the expansion of the early city systems into the present long distance interurban lines. The characteristics of motors designed for short haul or acceleration service have been modified to meet the new conditions calling for more or less continuous running; but it was not until the coming of the electric locomotive that the real necessity was [illegible] a railway motor capable of continuously operating at heavy loads.

Electric locomotives have been in general use on [illegible] and in terminal yards for some time [illegible] nearly every case the duty corresponded [illegible] to that demanded by motors on [illegible] cars performing short haul service. [illegible] words, the extent of track electrically [illegible] has been so short or through runs [illegible] broken by intermediate stops that [illegible] continuous operating capacity of the motor has been called for.

The electrification of main line steam railroads, covering a full engine division or more, calls for a type of motive power capable of long sustained outputs amounting practically to continuous running. It is obvious that the method of rating railway motors on the one hour performance basis becomes inadequate either as a guide to the service capacity of such motors for main line service, or as a proper commercial test to determine their fitness for such service. Locomotive motors of this class are invariably of the forced ventilation type, and their design must be restricted by fixed weight and space limitations obtaining. Whether the locomotive motor is gearless or of the well known type geared to the axle, or whether it be connected thereto through intermediate jack shaft and side rods, it is desirable that the motors shall be designed to give maximum output for minimum weight and outside dimensions.

In rating electric locomotives it is desirable to in some way express the service capacity of the motor in terms of tractive effort and speed when operating continuously with forced ventilation, and with a temperature rise limited by the character of the insulation employed. The continuous horse power rating of a railway motor, although it is the product of tractive effort and speed, does not adequately define its service performance. What is needed is a more fully comprehensive rating, such as tractive effort and the speed at which this tractive effort is delivered in continuous performance.

For example, two motors of the same continuous horse power rating may not be capable of performing the same service in either freight or passenger locomotive runs, owing to the fact that one may be low speed and the other high speed at its rated load. This applies to both geared as well as gearless motors, and a study of operating conditions discloses the reason why it is desirable to express the rating of locomotive motors in both tractive effort and speed in miles per hour at maximum continuous output. In addition to this, it would even be desirable to include the revolutions per minute of motor at rated load, its armature diameter, diameter of driving wheels and sundry other data, all of which are intimately connected with the design of a locomotive to perform a given service.

It may seem at first glance that in entering the main line locomotive field the electric motor becomes so emancipated from the intricacies of the acceleration cycle as to permit giving it a continuous rating of the same character as expresses the service capacity of a stationary motor. A study of the operating conditions, however, discloses the need of having available much more data than the mere continuous horse power output of the motive power. The coefficient of adhesion between drivers and rail presents the only safe limitation as to overloading the locomotive motor during its starting or accelerating period. Owing to the uniform torque delivered, it is conservative to expect 30 per cent coefficient of adhesion as representing slipping conditions between wheels and rail with both in good condition. Tests have shown individual results in excess of 30 per cent, but the motive power should be designed to withstand a tractive effort corresponding to this coefficient of adhesion for the full period required to accelerate the train. The starting coefficient of adhesion is no respecter of gearing or motor design and applies equally to high speed passenger and low speed freight locomotives, the only difference being that the rate of acceleration is less and the accelerating period longer in freight service.

The tonnage rating of an electric locomotive should follow nearly the same practice established in the rating of steam engines; that is, it should be based upon approximately 18 per cent coefficient of adhesion for running conditions on ruling grade, the gross tonnage rating including the locomotive weight. A study of the profiles of the mountain divisions of our steam roads shows but one or two instances where the ruling grade is maintained unbroken for a sufficient distance to make it a controlling factor in determining the continuous performance and consequent heating of the electric locomotive motor. A modern motor of the forced air ventilated type will rise in one hour to approximately 80 per cent of the temperature it will reach in continuous running at the same load. Unless the unbroken ruling grade therefore is of such length as to demand more than one hour continuous running, the heating of the motor will depend upon the average rather than the ruling grade, in each case, of course, including compensation for curves. It would seem possible therefore to rate freight locomotive motors at such tractive effort and speed as will be given with approximately 16 per cent coefficient of adhesion between drivers and rail.

Thus, a freight locomotive weighing 100 tons should be equipped with motors proportioned to withstand continuously, without overheating, a tractive effort of approximately 32,000 lb. at say 15 miles per hour, corresponding to a coefficient of adhesion of 16 per cent of the weight upon the drivers, assuming the locomotive to have no idle guiding trucks. Such a locomotive should provide for a maximum speed of nearly 30 miles per hour on level track or nearly double the speed reached on ruling grade.

It is evident therefore that the speed reduction, if the motor is geared, must provide for continuous and safe operation of motor bearings and armature periphery at a speed of nearly double that at which motor is rated for its maximum output. This brings into the matter of rating the locomotive the vital questions of gear ratio, armature speed and diameter.

If the locomotive is equipped with polyphase induction motors and intended to operate at one speed only, it is obvious that armature speed and gear ratio may both be a maximum, if safe operation be guaranteed only when motor operates on its own power. While it is true that regenerative braking down grades will restrict the speed of the locomotive to but little more than synchronism, it would hardly be safe to operate a locomotive so designed that it would fly to pieces if run at much higher speed than say 18 miles an hour. On the other hand, if the locomotive is equipped with direct current motors capable of operating on level track at nearly double the speed available on ruling grade, the question of gear ratio, armature speed and diameter must be proportioned for safe operating speed on level or slightly down grade track. The question of rating electric locomotives therefore involves a consideration of the mechanical parts if the motors are to be geared to the drivers.

With motors of the gearless type there are no limitations imposed as to armature peripheral speed, and the question of high speed operation on level or down grades becomes a matter of truck rather than motor design. The gearless motor therefore presents a comparatively simple problem as to its performance and rating, both of which may be expressed in terms of the tractive effort and speed which the motor can deliver continuously without deterioration of its insulation. A gearless motor locomotive can therefore be rated in such terms as will indicate weight on drivers, co-efficient of adhesion at which motor will operate continuously and speed in miles per hour.

The amount of space available for motors is very restricted in locomotives of the larger capacities and it is desirable to keep both outside dimensions and weights of the motors as low as possible. On this account it will probably be found desirable to provide a type of insulation that will withstand high temperatures. It may be desirable also in the larger locomotive motors to provide for the determination of temperature rise of motors by the increased resistance of the copper circuits rather than by thermometers, and with the improved character of the insulation it seems feasible to consider a temperature rise of possibly 100 degrees C. or more above air at 25 degrees C.

In conclusion it seems desirable to supplement the one hour rating of railway motors now applying to single car service, by adding a continuous output rating for locomotive motors of the larger sizes intended for main line operation; such a rating to be in the nature of the tractive effort and speed delivered continuously with 100 degrees C. rise by increase in resistance of copper windings. Furthermore, it seems feasible to fix upon a coefficient of adhesion of approximately 16 per cent of the weight upon the drivers for freight locomotive rating and a lesser coefficient, in the order of perhaps 10 per cent of driver weight, for main line passenger locomotive rating. In every case it will probably be found desirable to express the locomotive rating in tractive effort and speed at which it is delivered, rather than give the rating in terms of their product, or horse power output.

MODERN ELECTRIC RAILWAY EQUIPMENTS

By J. F. Layng

Railway and Traction Engineering Department,
General Electric Company

The author sketches the development of the modern electric car and its equipment, and deals with the later requirements of both city and interurban railways. The illustrations for this article have been collected from all over the country and show the diversity of types of cars employed. The development of the modern railway motor and control are briefly described; a fuller description of the development of the railway motor and of the controller being given elsewhere in this issue by Mr. E. D. Priest and Mr. F. E. Case, respectively.
—Editor.

In the modern railway car there is combined a tremendous amount of experience and the efforts of several distinct classes of men. The application of electric power for car propulsion opened up a broad field and the magnitude of the problems presented by present day conditions are engaging a host of men who, having made a life study of the work, are producing a system of transportation that is extremely efficient. Within the past few years there has been a combined effort to produce cars and equipments that would not only operate economically but would also meet the demands of the public, which among other things include high schedule speeds, comfort, good lighting, good ventilation, pleasant temperatures at all seasons of the year and a generally attractive appearance.

Near Side Car, International Railway Co., Buffalo, Equipped with 55 65 H.P. Ventilated Motors (GE-201)

The first successful electric road in America was started in Richmond, Va., in 1888. One of the spectators who witnessed the first car start on its maiden trip, in relating the operation and the many eventful happenings, tells how the car on leaving the track at a curve was replaced by several of the riders alighting and placing their shoulders against the car, pushing it back onto the track. Such an incident, recorded at this time, shows very forcibly the difference between the first trolley car and the latest developments as we know them today.

From these small beginnings electric traction has been gradually extended to cover

Train of Steel Cars on Alameda Division of the Southern Pacific Railway. Each Motor Car is Equipped with Four 125 H.P. 600/1200 Volt Motors (GE-201) and Sprague G-E Type M Control

Three-Car Interurban Train, Aurora, Elgin & Chicago Railway. Each Car is Equipped with Four 125 H.P. Motors (GE-66) and Sprague G-E Type M Control

Box Car L[illegible] Hauling Train of Freight Cars on Washington, Baltimore & Annapolis Electric Railroad. L[illegible]comotive with Four 125 H.P. 600/1200 Volt Motors (GE-207) and Sprague G-E Type M Control the entire field of transportation. The range of equipment required can partially be appreciated if we consider the principal types of application, which include city cars, storage battery cars, elevated roads, subways, urban, interurban, both trolley and third rail, terminal electrification, tunnel electrification, mountain grade lines, switching service and main line service. In subway and elevated service trains vary from two to ten car trains.

Interurban service today represents by far the greatest variation of work, including passenger trains which consist of one to four cars, and on some properties luxurious chair cars, dining cars and sleeping cars. These roads are called upon to operate a package express and also a freight service interchanging with steam roads. This gives three distinct classes of equipment for interurban properties, that is, passenger cars, express cars and locomotives.

At present we have many different types of city cars. The transportation men have been active in designing and putting into service many combinations of car entrances, exits and seating arrangements and systems of fare collection. In fact, everything has been done to provide for the movement of the passenger from the time he signals the car to stop until he has been transported to his destination and has safely alighted from the car.

Express Car, Gary & Interurban Railway Company, Equipped with Four 100 H.P. Motors and Sprague G-E Type M Control

The severe work a railway car has to perform is seldom realized. In ordinary city service a car makes a yearly mileage of from 30,000 to 45,000 miles, and frequently interurban cars run over 400 miles a day.

The successful operation of the early electric cars stimulated development and led

Five-Car Train on West Jersey and Seashore Railway

to the rapid extension of the trolley car systems, and the longer lines necessitated increased free running speeds and higher schedule speeds. To meet present day demands the seating capacity of city cars has been increased from about 24 in the older style of single truck cars to from 45 to 54 in the modern double truck cars now so commonly used.

The cost of maintenance of the older cars was high and the service was frequently interrupted. In order to cut these high maintenance costs and maintain reliable schedules, the weight of all the individual elements of which a car is composed was increased to give a more substantial construction. The car builders and the manufacturers of equipments worked together to produce a trolley car that would stand the severe service and show reasonable operating and maintenance charges.

Within the past few years it has been generally recognized that there is an added fixed cost for power and maintenance of way expenses when hauling unnecessary car weights.

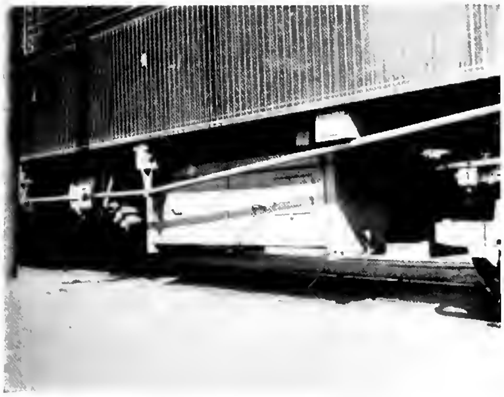
Three-Car Train on Northwestern Elevated Railway, Chicago. Equipped with Two 160 H.P. Motors (GE-55) and Sprague G-E Type M Control

Five-Car Elevated Train, Manhattan Division, Interboro Rapid Transit Co. Each Motor Car is Equipped with Two 125 H.P. Motors (GE-66) and Sprague G-E Type M Control

Five-Car Subway Train, Interboro Rapid Transit Company. Each Motor Car is Equipped with Two 225 H.P. Motors (GE-212) and Sprague G-E Type M Control

Three-Car Train, Hudson & Manhattan Railroad. Each Car is Equipped with Two 225 H.P. Motors (GE-212) and Sprague G-E Type M Control

This was emphasized very strongly by the saving of power shown by the operation of storage battery cars. The designers of this type of car realized that there is a demand for cars which have not got a free running speed of 23 to 25 miles per hour, but have a lower speed of approximately 15 m.p.h.; which made it possible to use relatively small motors. They also materially changed the designs of car bodies, building them with reduced sections and introducing innovations in the bracing and construction of under framing as well as changing other parts of car body to secure strength and reduce weight. Ball or roller bearings are used to reduce power consumption and advantage has also been taken of high grade steels to further reduce weights. This reduction in weight

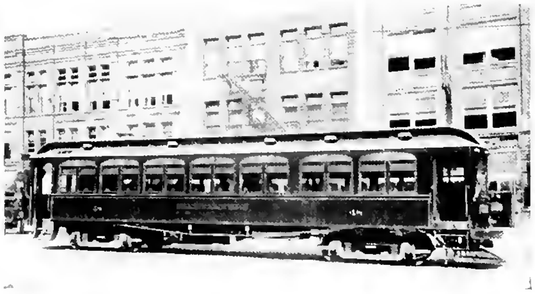


MK Control Contactor Box

in the storage battery cars greatly influenced general city car design, and the present tendency in city car construction is to build the car bodies and trucks as light as is consistent with sufficient mechanical strength to do the work properly and keep down maintenance costs. Light strong pressed steel shapes are now frequently used to brace and support the platforms and other parts of the car.

In the modern truck the weight-strength idea has been carried to the point where malleable iron and steel castings have been practically eliminated and superseded by forgings, bolted plates and pressed steel sections. Even smaller diameter axles, made of high grade steel, are used to obtain lighter weights than could be secured by using larger diameters of a lower grade of steel. Truck designs have been made in such a manner as to facilitate the replacement of all wearing surfaces and to make the parts readily renewable.

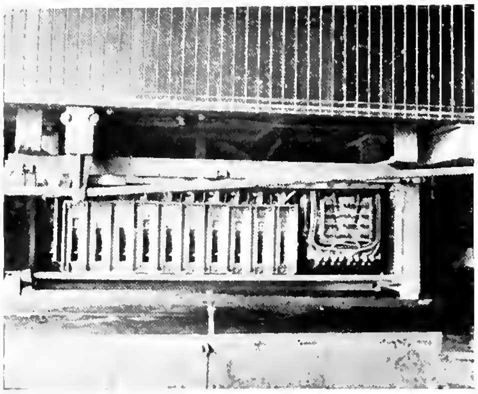
The all-steel car has been gaining favor



A Northern Ohio Traction and Light Co. Car, Equipped with Four 75 H.P. Motors (GE-204) and Sprague G-E Type M Control

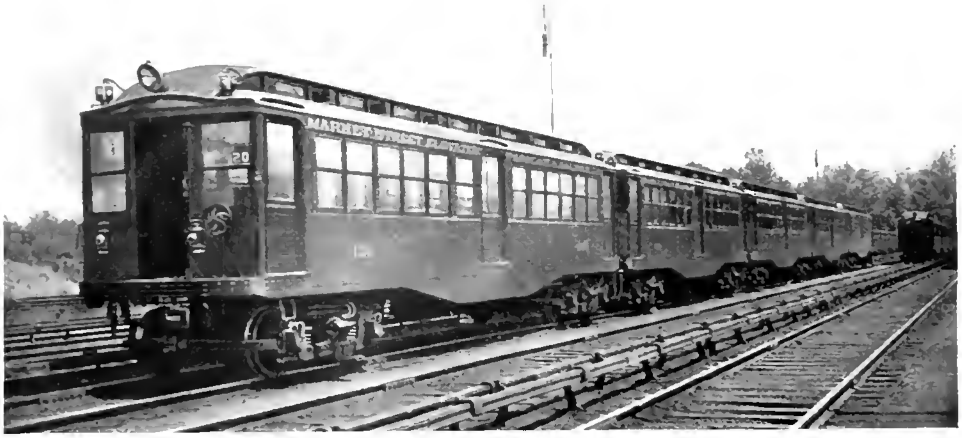
within the past few years for subway and suburban work, but for city car work comparatively few have been built. The reason for this is that with present designs city car bodies, when built of steel, will weigh approximately 10 per cent more than the wooden car bodies.

There is another point that also greatly influences the railway man in the selection of the wooden car, that is, the all-steel cars require an entirely different class of labor to repair damaged car bodies. As long as we

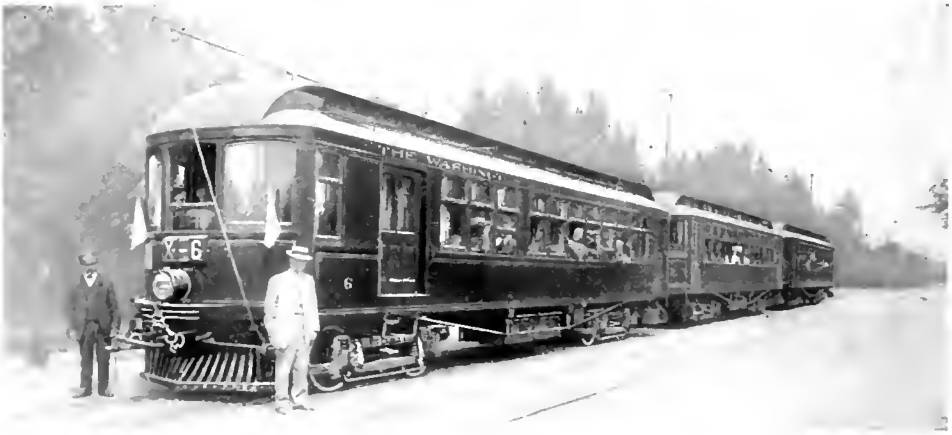


MK Control Contactor Box with Cover Removed Showing Contactors and Reverser

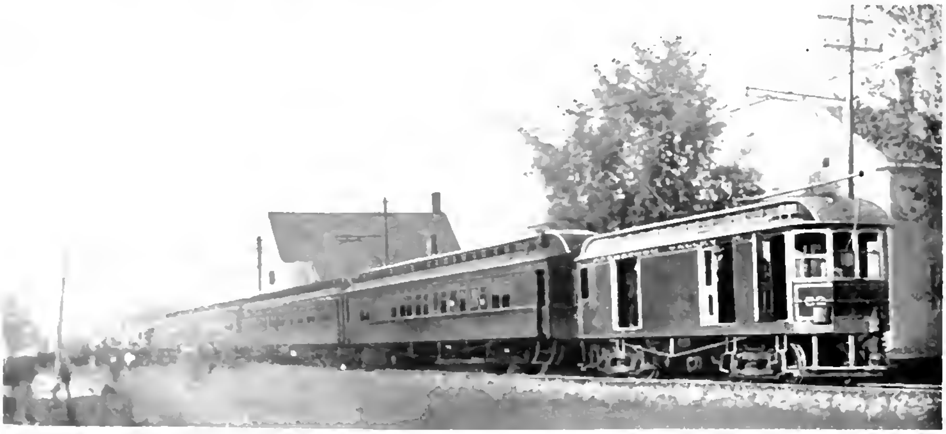
have city cars running on narrow congested streets they will have collisions with other vehicles and the repairs of this nature will constitute a large proportion of car repairs.



Five-Car Elevated and Subway Train, Philadelphia Rapid Transit Company. Each Motor Car Equipped with Two 125 H.P. Motors (GE-66) and Sprague G-E Type M Control



Three-Car Train, Washington Water Power Company, Spokane, Wash. Each Motor Car Equipped with Four 125 H.P. Motors (GE-73) and Sprague G-E Type M Control



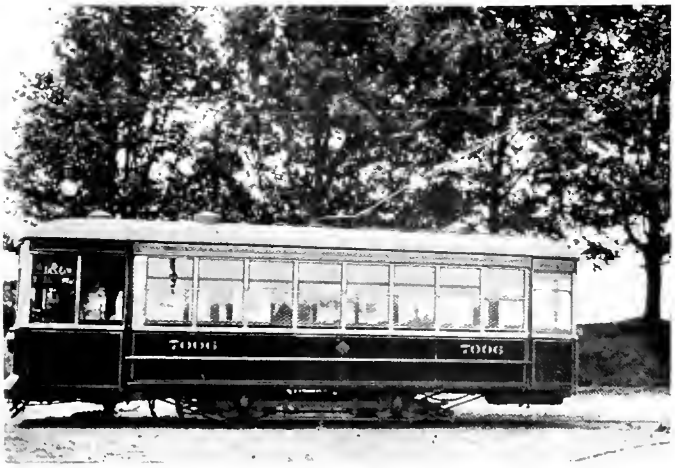
Express Car Hauling Four Passenger Coaches, Aroostook Valley Railroad, Presque Isle, Maine. Express Car is Equipped with Four 75 H.P. 600 1200 Volt Motors (GE-205)

Railway operators have shown their individuality in a very marked degree in the different types of cars they have had built. The development of the different ideas has recently set a very rapid pace for the car builders and equipment manufacturers. Small wheel, low step, center entrance, nearside, one man cars and double deck cars have brought with them almost an entirely new line of apparatus. Motors for city cars have been developed for 24 in., 26 in. and 28 in. wheels. However, comparatively few motors of these types have been put into operation. The low step feature which is gained by some of those designs is very desirable, but if adopted would mean many changes.

To meet city schedule requirements the motors must be capable of developing from 35 to 50 h.p., and to get this rating a certain amount of actual material must be used which will take up a certain amount of space. Before low steps were in demand motor designers had used up all of the available space between the car body and axle. So when wheel diameters are reduced it is necessary to lengthen out the motor practically in proportion to the amount of wheel diameter reduction. These motors necessarily are of a rather restricted design, the small diameters making it difficult to secure proper space for the field coils and other motor parts. Due to restricted dimensions it is not possible to take full advantage of ventilation with these types of construction.

City Car, Twin City Rapid Transit Co., Minneapolis, Equipped with Four 40/50 H.P. Motors (GE-203)

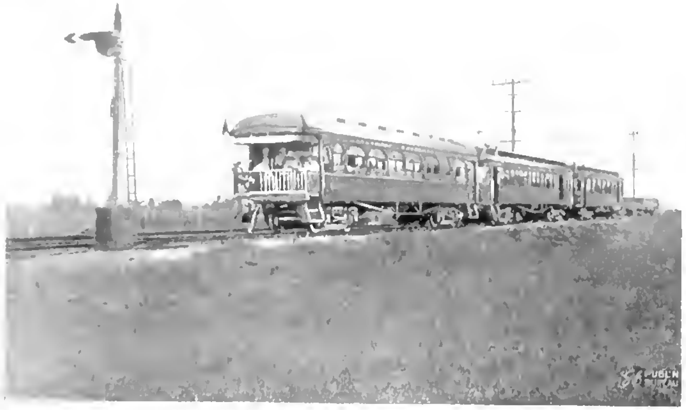
On city street railways, where grades do not exceed 4 or 5 per cent, and in districts where they have little snow, much favor is given to cars with a seating capacity of from 46 to 54 passengers, equipped with maximum traction trucks and two motors, which, when completely equipped but without passengers, weigh from 36,000 to 38,000 lb. These cars, not having all the weight on driving axles have not the adhesion available for tractive effort that is attained with four motor equipments, and therefore are not suitable for operation on grades exceeding those just mentioned. With cars of this seating capacity it was the general practice until recently to use four 40-50 h.p. motors. With the two-motor equipment either two 50-60 h.p. motors can be used, or, for the same service, two 40-50 h.p. motors with field control can be employed. The two-motor equipments have advantages, the principal of which are: the first cost is lower, the total weight of the car is approximately from 7000 to 7500 lb. less, lighter controller can be used, few power cables are needed, and there are only half the motors to inspect. There are, of course, a great number of cases where trailer service, grade, and schedule conditions make it impossible to take advantage of two-motor equipments.



Near Side One-Man Car, International Railway Co., Buffalo, Equipped with Two 32/38 H P. Ventilated Motors (GE-200)

During the past year some of the large city systems have been inaugurating trailer service, in which the motor cars seat approximately

60 Ton Locomotive, Illinois Traction System, Equipped with Four 225 H.P. Motors (GE-69) and Sprague G E Type M Control



Three-Car Train, Illinois Traction System. Motor Cars Equipped with Four 100 H.P. Motors (GE-73) and Sprague G E Type M Control

Two-Car Train, Illinois Traction System. Motor Car Equipped with Four 100 H.P. Motors (GE-73) and Sprague G-E Type M Control

Motor Car, Pittsburg & Butler Street Railway Co., Equipped with Four 100 H.P. Ventilated 600/1200 Volt Motors (GE-225) and Sprague G-E Type M Control

46 passengers and haul trailers having a seating capacity of approximately 70. These motor cars do not differ radically from past practice, but the trailers are arranged for center entrance with folding doors. No steps are needed, as only 22 in. diameter wheels are used, which give a sufficiently low floor to make it possible to step directly into the car.

In one of the cities referred to, the motor car weighs, completely equipped but without passengers, 43,000 lb., and the trailer, without passengers, 22,000 lb. The electrical equipment consists of four 40-50 h.p. motors and K-35 control.

For other service where it is necessary to use four-motor equipments and it is not necessary to haul trailers, 32-38 h.p. motors are usually suitable and are adopted. These motors weigh slightly more than 2000 lb. each, while four 40-50 h.p. motors will weigh approximately 2600 to 2700 lb., and with some types of motors the weight would exceed this. This saving of approximately 2500 lb. in weight per car represents a large saving in power, and also in first cost of equipment.

For city service, the operators as a rule purchase the lightest weight car that it is believed will give low maintenance; but with interurban cars this rule is not always followed. One of our largest interurban systems uses a car with extra heavy underframing and strong bodies, believing it far cheaper to haul around the extra weight to secure a car body sufficiently strong to resist the impact of collision. These cars operate over long distances and the extra weight makes a much more comfortable riding car, this feature alone bringing business to this type of car that would frequently be secured by the competitive steam roads.

All modern interurban cars have the underframing built of steel, or a combination of steel shapes and wooden sills that give practically the same effect, and the general tendency is to have arched roofs of the same style as in modern city cars. Steel side plates and rolled sections for many parts are largely superseding wood.

Motors

In the first trolley cars put into operation an effort was made to adapt the stationary motor to traction work. These first motors were small bi-polar units having cast iron gears, rawhide pinions, and were lubricated with grease cups that required attention every half trip or more often. These early equipments were crude in many ways, but the possibilities of the system were so great and varied that the work rapidly extended and went forward on a large scale. Any defects that were inherent to the early designs were remedied as quickly as possible by new designs until something capable of fulfilling the severe demands was finally attained.

In the modern motor the lightest, strongest and most efficient materials are used and these are distributed to take the minimum space for the power developed.

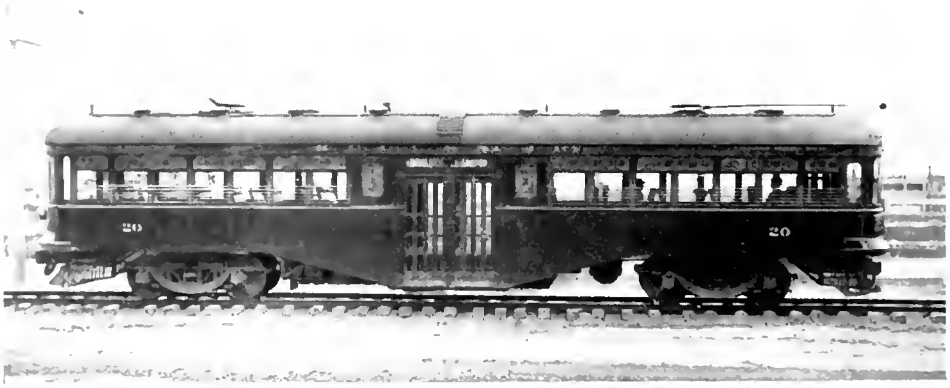
The majority of railway motors produced have been good motors electrically, and nearly all the troubles experienced have been primarily caused by mechanical weaknesses. The railway motor of today has but two features which especially distinguish it from designs of ten years ago. These are commutating poles and ventilation. Motors having better commutating characteristics were necessary because of the increased voltages required, and therefore commutating poles were adopted. For city and interurban systems voltages have gradually been increased in steps from 500 volts to 550, 600, 650 and 700 volts. The commutating pole motor also made the 1200, 1500 and 2400 volt systems possible.

The latest development in motors is ventilation. The older motors were designed to be as near water and dust-proof as possible. Unfortunately, a motor that is perfectly dust-proof and water-proof is also a good heat retainer, the hottest part being the center of the mass, the armature, which is the most vital part of the motor. Modern ventilated motors have a fan made as an integral part of the armature which draws air in between the field coils, over and through the center of the armature, and then expels it from the motor, conducting away the heat that is necessarily produced. With this system of construction the service capacity of a particular size motor is greatly increased. The amount of heat a particular motor can dissipate is directly proportional to the armature speed.

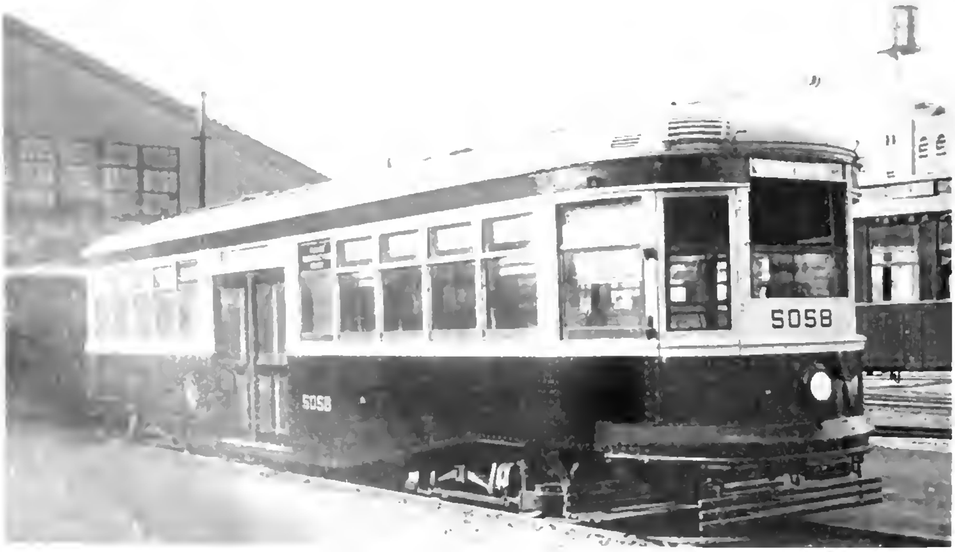
For slow speed work the service capacity is increased from 8 to 15 per cent by ventilation, while under other conditions, with high average armature speeds, the increase is 50 per cent or even higher in some cases.

The other improvements in construction of a modern motor are along the line of

Center Entrance Car, Washington Railways & Electric Company, Equipped with Four 32/38 H.P. Ventilated Motors (GE-200)



Center Entrance Interurban Car, Kansas City, Clay County & St. Joseph, Equipped with Four 100 H.P. 600/1200 Volt Ventilated Motors (GE-225) and Sprague G-E Type M Control



Center Entrance Car, Brooklyn Rapid Transit Company, Equipped with 45/55 H.P. Motors (GE-234) and Sprague G E Type M Control improvement in the individual parts. The field coils are a solid compact mass of ribbon copper insulated with tough heat-proof materials and held firmly in position to prevent movement in any direction. Armatures are designed so that coils are well supported and held firmly in position to permit high speeds without mechanical injury.

The brush-holders are supported by mica insulated studs which are further protected against insulation breakdowns by porcelain.

Lubrication has been very carefully studied and motors are now so arranged that the lubrication is wonderfully efficient. With modern bearings and oil reservoirs, waste oil does not penetrate every part of the motor, as was the case with many early designs. The waste chambers are so arranged that the oily waste is forced by gravity against the armature shaft and axle, insuring constant and ample lubrication.

A few years ago the majority of motors were built with split frames, but now ninety per cent of the railway motors are built with box frames.

Control

The function of a railway controller is to make and break a series of contacts handling heavy currents in a definite sequence, and to have the capacity to do the required work indefinitely with but very little attention and considerable abuse.

All present railway control apparatus for direct current work are based on a series-parallel scheme of connections and some combination of magnetic blowouts.

The number of operations that a car control must perform daily is remarkable. The work that is accomplished with the platform controller today is something wonderful. In crowded city streets, where travel is obstructed by vehicles, the controller is kept in almost constant movement, making and breaking large currents almost incessantly. There have been many improvements in the platform, or what is commonly known as the K controller. The latest controllers have individual magnetic blowouts for each contact and wooden covers.

The internal connections have also been rearranged so as to secure the minimum potential between adjacent contacts. In the early controllers the arc chute sides are subject to considerable burning. With the individual blowouts, the burning of arc chutes has practically been eliminated. The combination secured with the present form of K controllers is absolutely safe, reliable and dependable. This form of control is the most popular today and is used almost universally for motor equipments within the range of their capacity.

With car equipments where the total motive power exceeds two hundred horse power, remote control is usually preferred, the MK control being the most commonly used on account of its simplicity and compactness. The control equipment proper consists of the master controller and one box containing eight contactors, the reverser and overload relay. By using train line coupler sockets this equipment is used for train operation.

With several minor changes this equipment is suitable for 600-1200 volt operation. This same general form of apparatus is also suitable for 2400 volt equipments, the differences being mainly in the form of magnetic blowout, more insulation and greater clearances.

There is a large amount of field control being put in service. On the K controllers this is accomplished by extra fingers on the controller, and with M control one extra double circuit contactor is used for each motor required for the equipment.

THE ECONOMY OF SCRAPPING OBSOLETE TYPES OF MOTORS

By J. C. Thirlwall

Railway and Traction Engineering Department,
General Electric Company

It is shown in this article that the retention of obsolete motors on railway systems involves an annual repair expense which, in many cases, would pay for the replacement of the old motors by those of an up-to-date type. The analysis of the actual maintenance charges involved by older types of motors on a railroad having a typical equipment (old and new type motors) illustrates graphically the benefit which would follow the scrapping and replacement of many of the older forms of motors that are still, to a very great extent, maintained in active service. The superior maintenance economy of modern designs is clearly indicated by the figures submitted, and the practical nature of the article should make it of special interest and value to operating men.—Editor.

There are in service, today, on railroad systems in every part of this country, thousands of motors which, if not obselete, are obsolescent; that is, they are of so inferior a design or so over-loaded when used that it is impossible to obtain any great amount of mileage from them annually without an excessive number of failures, and consequent heavy repair bills. A very large proportion of these motors, of course, are mounted on service cars, sweepers, snowplows, etc., where the amount of work they are required to do is necessarily little. Others are beneath single truck cars of ancient vintage which may be held as reserves and used only on days when an unusual press of traffic demands more than the ordinary number of cars. On this type of equipment, where the mileage made per year is necessarily limited by the car itself rather than by the motors, it is questionable whether the replacement of the old motors by those of a more modern design could return a reasonable percentage on the investment. But a very large proportion of these oldest motors are mounted under cars, both passenger, work or supply, which operate regularly and run up a large mileage annually, [illegible] very high cost for motor repairs; [illegible] large proportion beneath cars [illegible] and suitable for regular service, [illegible] kept lying idle the greater [illegible] time due to the unreliability of [illegible] consumers instead of [illegible]

[illegible] equipments, very [illegible] be effected in many [illegible] of the old motors and [illegible] of modern design.

To determine [illegible] road whether a sufficient return [illegible] from the maintenance account [illegible] capitalizing the [illegible] equipments means that the expense chargeable to each of the different designs of motors in service on its lines must be segregated; and as few, if any, roads have an accounting system that does segregate such charges, a special investigation is usually necessary. On one large system such an investigation was recently made, and the steps of the process may prove of interest to others who may propose to make a similar investigation.

The first thing ascertained was the total mileage made by each class of motors, as all costs must be reduced to a mileage basis to be comparable. This road and many others keep a record of individual car mileage, which greatly simplifies the segregation of the motor mileage of the various types. Where such records do not exist, a close estimate can be made from the number of cars in service, the average number of hours per day they are run, and the average schedule speed of the lines on which they operate.

Systems of cost keeping vary widely. On the road in question, the inspection account included all inspection work done on any part of the equipment, bodies, trucks, motor, control or air brakes. The proportion of the total time devoted to the inspection of the motors had therefore to be approximated. Each shop foreman on the system was required to estimate the proportion of his inspectors' time devoted to motors of all classes, and then to estimate on the time necessary for a proper inspection of each class of motors handled in his shop. An average of these several estimates showed that the older motors without exception required more attention, from the fact that flashovers were more frequent and consequently more cleaning of commutators was necessary; the oiling systems were inferior and required more attention due to the use of oil cups with wicks that had to be regularly removed and cleaned; and brush-holders and yokes, in particular, required far more attention to maintain them in proper condition than on the newer types.

The average time for four-motor equipments per inspection was determined to be as follows:

WP-30-50	$1\frac{1}{2}$ hours
GE-800	$1\frac{1}{2}$ hours
GE-1000	$1\frac{1}{2}$ hours
GE-57	1 hour
GE-67	1 hour
GE-80	45 minutes
GE-203	30 minutes

The average hourly wage of the inspectors being known, the cost per inspection for each class was thereby established. The inspections on this road are on a daily basis, making about 300 inspections per year. The total annual cost divided by the motor mileage for the year gave the cost per motor mile.

The next step was to obtain the cost of repairs. These were divided as follows: Repairs to armatures; repairs to fields; repairs and renewals of gears, pinions and gear cases; repairs and renewals of brush-holders and yokes; repairs and renewals of bearings, both armature and axle, including rebabbitting; renewals of brushes; and general motor repairs and renewals, including all work done not covered by the foregoing. The cost of all materials issued by the storeroom during the year was obtained, and in the majority of cases the individual items, such as armature coils, new fields, brushes, commutators, motor shells, gears, pinions, gear cases, etc., had been issued under the motor group for which they were used. Items like lead wire, motor bolts, etc., that might be used in different classes were divided proportionately to the mileage made, and babbitt was divided according to the records of bearings rebabbitted.

The armature room records showed the labor costs for each individual armature rewound or repaired, and for field repairs in lots of 10 to 20 of each class. To the total repair costs thus obtained on armatures and fields, a charge had to be added to cover the cost of removing and replacing such defective parts. Careful estimates were made on this by a number of foremen, and their estimates averaged. The results were interesting. On a basis of 22 cents per hour per man, it took two men two hours to remove and replace a W.P. armature from the shell, at a total cost of 88 cents. To rewind one of these armatures cost for labor and material approximately \$60.00. A GE-80 armature required two and one-half hours for two men for removal and replacement, but the rewinding cost only \$22.00.

The time for removal and replacement of fields averaged about one and one-half hours for a bottom field, and two and one-half to three hours for a top field. These figures for both fields and armatures are fairly representative for any shops handling such removals over the pits.

The entire expense chargeable to fields and armatures was, next to that for inspection, the largest of the items making up the total cost of the motors. It averaged per 1000 motor miles as follows:

WP-30	\$6.50
WP-50	3.93
GE-800	3.51
GE-1000	1.10
GE-57	1.79
GE-67	.98
GE-80	.54

In general, these costs are all high, as compared with roads having a more modern and efficient inspection and maintenance system, but show relatively how much more expensive are the older types.

Bearings was the next largest item. There were comparatively few new shells used, the rebabbitting being the bulk of the expense. All worn bearings on the system are sent to a single shop where one man devotes his entire time to rebabbitting them. His wages for the year, plus an estimated cost for the removal of bearings from the shells, after assuming that bearings were renewed each time an armature came out for other defects, gave the labor cost. The cost of babbitt metal was calculated from the number of bearings rebabbitted and from the amount of babbitt used in each shell, the new babbitt issued by the storeroom being proportioned from that basis among the various motor types. Cost for bearings per 1000 motor miles varied from \$1.48 for the GE-1000 down to \$0.32 for the GE-80's.

Costs for brush-holders and yokes, for gears, pinions, gear cases, frames, leads, etc., were arrived at in a similar manner, actual figures being used wherever the records made it possible, and close estimates from several sources being used where the records did not exist.

The grand total of costs, on a comparative basis of cost per 1000 car miles, showed the following results:

WP-30	$17.35
WP-50	11.23
GE-800	11.91
GE-1000	3.41
GE-57	4.64
GE-67	3.40
GE-80	1.86

In other words, were motors no more efficient than the GE-80 substituted for the WP's or GE-800's, savings of from $9.37 to $15.49 could be made for every 1000 miles run per motor, and on a basis of 100 miles per day, which is what the GE-80's are making, the annual saving would be from $340.00 to $550.00 per motor per year. Of course, with a really modern motor, which the GE-80 is not, the difference in cost and the saving possible would be even greater. We estimate, for instance, that the cost per 1000 miles for the most modern G-E motors, of the same general size, after several years service, under the same maintenance conditions that prevail on the system referred to, would be but $9.55. On this basis a saving of about $500.00 annually per motor can be shown as against the WP-30; as the cost of replacement would be less than $400.00 per motor, the immense economy to the operating company of making such a substitution becomes immediately apparent.

THE STORAGE BATTERY CAR

By G. W. Remington

Railway and Traction Engineering Department, General Electric Company

The field for storage battery cars is more or less restricted, but there is a certain class of service for which such equipments are superior to other types of self-propelled cars. The rating of battery efficiency is one of the important subjects dealt with in this article; while motors, control, type of equipment and service requirements are also discussed, and the article is concluded with a bibliography of the storage battery car.—Editor.

No attempt will be made in this article to give a long historical review of the development of this type of self-propelled car. It is sufficient to say that since the year 1889, when such cars were first applied with some measure of success, there have been many improvements in its component parts.

The cost of operation was high and the [illegible] of operation low, and while the first [illegible] sarily put the storage battery car out of consideration in all cases, the [illegible] certainly will.

[illegible] therefore, been largely directed [illegible] a large daily mileage at a [illegible] mile; in other words, to reduce [illegible] hours input, to the batteries, per [illegible]. This has been accomplished by, first, decreasing the weight of the battery equipment; second, decreasing the weight of car bodies and trucks; third, increasing the efficiency of the batteries; fourth, increasing the efficiency of motors.

The prospective purchaser now finds himself able to buy cars at a reasonable first cost, which can be operated at from 13 to 17 cents per car mile, and from which he can secure a mileage of from 50 to 100 miles in a 12 hour day without recharging; the mileage obtained depending on the nature of the service.

There are probably some 275 storage battery cars in operation in this country today of which more than 70 per cent are in New York City operating on the line of the Third Avenue Railroad Company and the New York City Railways; where they are employed on various streets where trolleys, or other types of self-propelled cars, cannot for one reason or another be used.

Of the cars of the type in question in use outside of New York City some are run simply that franchises may be retained and some for the purpose of carrying passengers to newly opened land developments, etc. It may safely be said at the present state of development of the storage battery that this type of car cannot be considered in locations where the traffic is dense; when the service is severe as regards high schedules compared with trolley car schedules; or when long continuous grades are met.

There are, however, many conditions which are best met by self-propelled vehicles, and in this class the storage battery car owing to its cleanliness, quietness and simplicity of operation is a strong competitor.

Batteries

Battery efficiency is expressed in ampere-hour efficiency, by which is meant the ratio of ampere-hours output to ampere-hours input; and also in watthour efficiency, by which is meant the ratio of watthours output to watthours input.

These efficiencies vary widely, depending on the rate at which the battery is charged and discharged and the extent to which the discharge has been carried when the charge is begun.

If curves were plotted with ampere-hours output as ordinates and ampere-hours input as abscissae, the ratio would be over 90 per cent at the lower values and would drop off at an elbow, the normal rating being generally established at just about the elbow.

High rates of discharge lower the efficiency and, therefore, a service which includes heavy grades of considerable length or demands schedule speeds approaching those provided by trolley cars, puts a severe handicap on the storage battery car, and requires the battery to be "boosted" every 30 to 50 miles; furthermore, a service of this nature necessitates making the charge at an uneconomical rate in order that a satisfactory mileage may be shown at the end of the day.

In selecting the battery, consideration must therefore be given to the type which will best take care of heavy boosting for short periods during the day, and heavy discharges during the acceleration of the car, which occurs as frequently as every 50 seconds in ordinary city service as represented by 8 or 9 stops per mile.

While the ampere-hour efficiencies of two types of cells may compare favorably, the watthour efficiencies may not. Also the voltage of one may drop with discharge more rapidly than the other. It is usually desirable that the car make the same schedule speeds at all times during the day, and in selecting the type of battery and the number of cells to be installed it is, therefore, necessary to compare them, not on open circuit or full charge voltage, but at various stages of discharge and at various rates of discharge.

The following tables are abstracted from publications of various battery manufacturers:

EDISON STORAGE BATTERIES

Type of cell	A/4	A/6	A/8	A/10	A/12
Rated capacity ampere-hours output	150	225	300	375	450
Normal actual output (7 hour charge) ampere-hours	168	252	336	420	504
Maximum output on overcharge-ampere-hours	190	285	380	475	570
Rated capacity watthours output	180	270	360	450	540
Normal actual output (7 hour charge) watthours	202	302	403	504	605
Maximum output watthours	228	342	456	570	684
Normal rate of discharge amperes for 5 hours	30	45	60	76	90
Average voltage on normal discharge	1.2	1.2	1.2	1.2	1.2
Normal rate of charge amperes for 7 hours	30	45	60	75	90
Normal rate of charge volts for 7 hours	1.85	1.85	1.85	1.85	1.85
Maximum rate of "boosting charge" (for short time only) volts	2.21	2.21	2.21	2.21	2.21
Maximum rate of "boosting charge" (for short time only) amperes	180	225	300	350	400
Weight of each cell alone, lb.	13.5	19.2	27.5	34	41
Average weight per cell of battery, assembled in trays, lb.	15	21	30.3	37.5	45
Rated watthours output per lb, of cell	13.3	14.1	13.1	13.2	13.2

GOULD T. H. BATTERIES

No. of plates per cell	13	17	23	27	29
Rated capacity in amp-hr. output	165	220	303	358	385
Rated capacity in watthour output	322	429	592	698	751
Normal rate of discharge amp. for 5½ hr.	30	40	55	65	70
Average voltage on normal discharge	1.95	1.95	1.95	1.95	1.95
Average normal rate of charge amps. for 10 hr.	18	24	33	39	42
Average normal rate of charge volts for 10 hr.	2.4	2.4	2.4	2.4	2.4
Weight of each cell alone, lb.	30	39	52.5	61.5	66
Rated watthr. output per lb. of cell	10.7	11.0	11.3	11.3	11.4

THE ELECTRIC STORAGE BATTERY CO'S MV "HPCAP EXIDE"

Number of plates	11	17	23	29	33
Rated capacity in ampere-hours	137.5	220	302.5	385	440
Rated capacity in watthours	273	434	596	758	867
Normal rate of discharge amp. for 5 hours	27.5	44	60.5	77	88
Average voltage of discharge 5 hours rate	1.97	1.97	1.97	1.97	1.97
Average normal rate and approx. time for complete charge after rated capacity discharge	69 A 1 hr. 35 A 1 hr. 17 A 1 hr. 10 A 4 hr.	110 A 1 hr. 55 A 1 hr. 28 A 1 hr. 15 A 4 hr.	151 A 1 hr. 75 A 1 hr. 38 A 1 hr. 20 A 4 hr.	192 A 1 hr. 96 A 1 hr. 48 A 1 hr. 26 A 4 hr.	220 A 1 hr. 110 A 1 hr. 55 A 1 hr. 30 A 4 hr.
Average voltage normal charge at above rates	2.3	2.3	2.3	2.3	2.3
Weight of cell	31	47.5	64	81	92

Motors

The motors are designed with the idea of securing a high efficiency. Practically all of the magnetic frame carries flux, and the densities are low throughout in order that the current demand from the batteries may be small during acceleration and other torque overloads. The result is a rather heavy motor but one which requires less power from the batteries than would a lighter one.

The requirement of high efficiency (low losses) due to consideration of the batteries, results in motors which run at much lower temperatures than could be maintained if the effect on the insulation alone had to be considered.

[illegible] of rugged design and employ ball [illegible] further increase the efficiency [illegible] maintenance.

[illegible] of the GE-1022 and GE-1027 [illegible] motors are shown in Figs. 1 and 2. [illegible] be noted that the rating is [illegible] input basis, on the testing stand [illegible] in place and 60 deg. C. rise.

Voltages of 85 [illegible] been selected as standard for the [illegible] the same windings may be employed for use on voltages varying materially from [illegible], the only limit being excessive armature speeds, the commutation being satisfactory within the limits thus set.

Rolling Stock

Cars rarely exceed 20 m.p.h. free running speed in ordinary city service, and in consequence bodies and trucks can be built very light, resulting in cars which weigh, complete with battery and motor equipment, little if any more per passenger seat than ordinary trolley cars.

Fig. 3 shows the type in use on the Third Avenue Railroad, New York City. These cars seat 26 passengers and are equipped with 58 M/V 29 Hycap Exide cells, having a capacity of 67 amperes for 6 hours or 402 amp-hours at 114 volts and two of the GE-1022 motors, rated 30 amperes 85 volts, whose characteristic curves are shown.

The car journal boxes are fitted with ball bearings with ball end thrust.

The K-45 cylinder controller used in these cars is of the double end, series parallel type, with fields shunted on the last point.

The complete weight of car is made up as follows:

Body and trucks	9,044 lb.
Battery equipment complete	4,876 lb.
Motor and control equipment	1,980 lb.
Accessories	500 lb.
Total	16,400 lb.

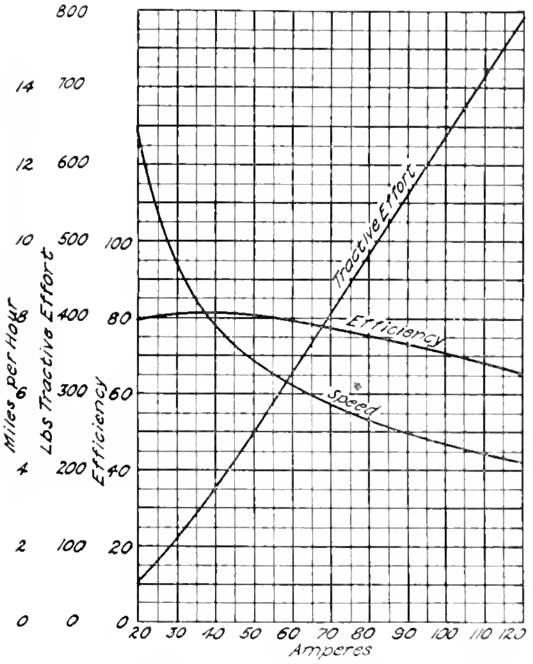


Fig. 1. Characteristic Curve of GE-1022 Motor on 85 Volts. Gear Reduction 6.21 to 1, Wheel Diameter 30 In.

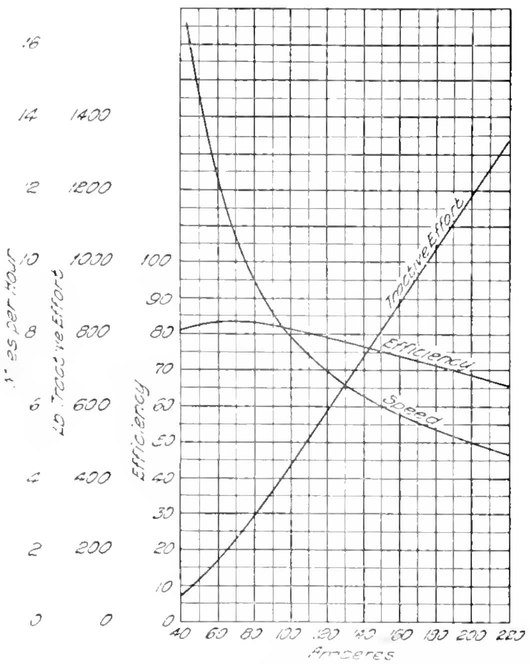


Fig. 2. Characteristic Curve of GE-1027 Motor on 85 Volts. Gear Reduction 6.2 to 1, Wheel Diameter 30 In.

Fig. 3. Storage Battery Car, Third Avenue Railway Company, New York

This is equal to 632 lb. per passenger seat, while the Third Avenue trolley cars seat 48 passengers and weigh 765 lb. per passenger seat. It must be remembered in comparing these weights, however, that the motor equipment of the trolley cars is much heavier and the service, schedule etc., is much more severe.

Illustrations are also shown of a car which has been in operation by the Lewisburg, Milton & Watsontown Passenger Railway Company since the summer of 1911 between Montandon and Mifflingburg, Pa.

This car is equipped with 88 M V-29 Hycap Exide cells, two GE-1027 motors and double end cylinder control, the complete weight being made up as follows:

Car body and trucks	19,700 lb.
Electrical equipment excluding [illegible] motors	8,800 lb.
[illegible] GE 1027 motors	2,070 lb.
[illegible]	1,500 lb.
[illegible]	130 lb.
	32,200 lb.

[illegible] passengers and [illegible] 805 lb. per seat [illegible] room for [illegible]

Fig. 6 [illegible] car, used by the New York Ra[illegible] ny. These cars, of which there [illegible] 15 at this time, unlike the Third Aven[illegible] are built largely of steel and are of the [illegible] entrance type, with the floor level, at the entrance, approximately 13½ in. above the stre[illegible]

These cars seat 31 passengers, and are equipped with 58 M V-29 Hycap Exide cells. The motor equipment consists of two GE-1040 motors, rated 30 amp. 85 v., and is designed specially for these cars and 23 in. diameter wheels.

The K-53 series-parallel, shunted field controller is also of a special design to permit its being installed under the end-seat of the car.

The complete weight of the car without passenger load is about 8 tons.

Two of the types manufactured by the Federal Storage Battery Car Company, of Silver Lake, N. J. are shown in Figs. 7 and 8.

This company employs exclusively the Edison battery, and advocates an interesting truck design, shown in Fig. 10, in which the wheels turn on non-revolving axles. A special design of low friction bearing is contained in the wheel hub, and claims are made of a considerable reduction of friction losses between the wheel flange and rail as well as of the reduction of friction on the tread of the wheel on curves. The friction of the motor axle bearings is also eliminated.

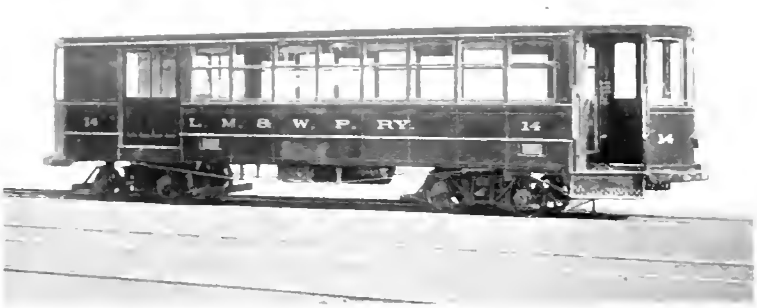


Fig. 4. Storage Battery Car on Lewisburg, Milton & Watsontown Passenger Railway

Fig. 5. Interior of Car Shown in Fig. 4

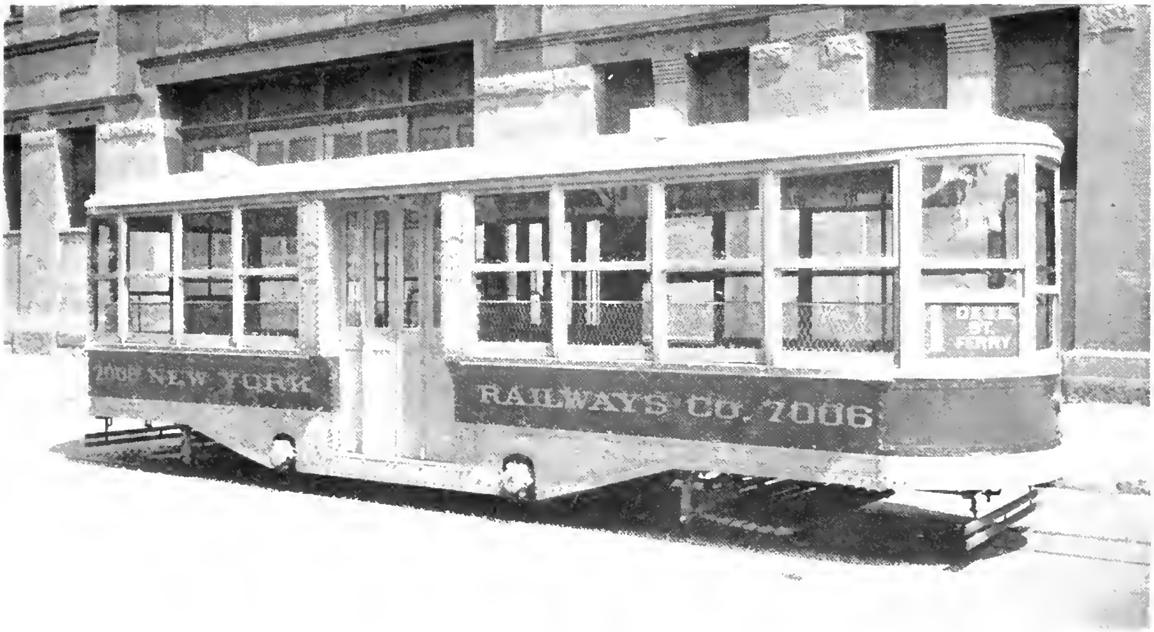


Fig 6 Center Entrance Storage Battery Car, New York Railways Company

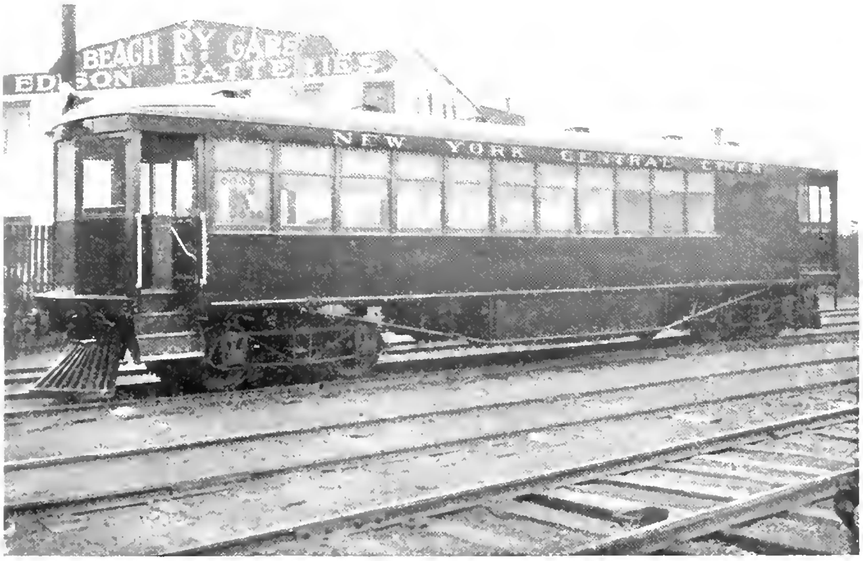


Fig 7. Storage Battery Car Operating on New York Central Lines

Control

Ordinary cylinder controllers are provided for two or four motor equipments for single car operation, or for two car operation with two motors on each car, or even for two car operation with four motors on each car.

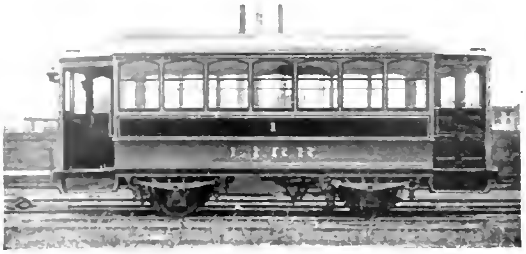


Fig. 8. Storage Battery Car on Long Island R.R.

although in the last case two motors would be connected permanently in series and an ordinary four motor controller employed.

Two car trains should preferably carry but two controllers, one on each car. The train as a whole can then be operated from either end; this arrangement avoids complication in the wiring such as the running of duplicate sets of cables, which are necessary when each car in the two car train is provided with two controllers.

If more than two motor cars are to constitute a train it is best to employ the ordinary Type MK control, two controllers being

Fig. 9. Truck for Storage Battery Car

installed on each car if desired, and the train being capable of operation from any controller.

Cost of Operation City Service

The following is assumed as representative:

Weight of car complete with average passenger load, 2[illegible],600 lb.
Average battery voltage, 114.
Battery rating, 795 watthr. or 402 amp-hr.
Watthr. efficiency, 70 per cent.
Motor equipment, 2-GE-1022's.
Stops per mile, 8.
Track, level.

With but 660 feet between stops the schedule which can be secured depends largely on the rate at which the car can be accelerated. If the batteries will deliver 90 amperes for the time the motors are in series, and 180 amperes during the time they are in parallel, that is to say, 90 amperes per motor continuously, while the motors are running on the resistance points of the controller, a rate of acceleration of 1.08 m.p.h. per second will be secured. Under this condition a theoretical schedule speed of 8.2 m.p.h. should be the result. This will require from the batteries an output of 6.27

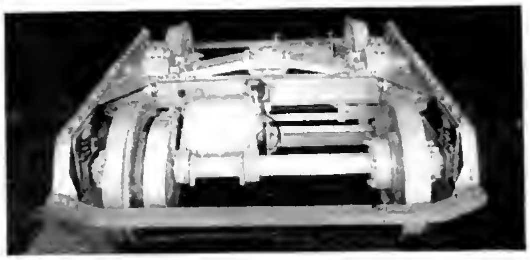


Fig. 10. Truck for Federal Storage Battery Car. The Axles do not Revolve on this Type of Truck

amp-hours per car mile and 715 watthours per car mile. The car can thus be expected to make 64 miles without either recharging or boosting, and as the schedule speed is 8.2 m.p.h. it would remain in service 7.8 hours leaving ample time for recharging.

If the batteries are recharged at a watthour efficiency of 70 per cent they will require 58 kw-hours which at 1½ c. per kw-hr. is equal to 1.36 cents per car mile for d-c. power delivered to the battery terminals.

In order to deliver to the battery the proper charging amperes, it is necessary to finish the charge at approximately 17 per cent higher voltage than the starting voltage. If this variation in voltage is secured by inserting resistance in the charging circuit, the above costs must be increased approximately 8 per cent.

If motor-generator sets, booster converters, split-pole converters or similar apparatus, which permits a variation of d-c. voltage, is employed, this loss in the rheostat is eliminated. The total operating cost per car mile is then:

Power	1.36 cents
Maintenance of car bodies, including painting	.81 cents
Maintenance of fenders, trucks, wheels, axles and brakes	.74 cents
Maintenance of controllers, gears, pinions, cables and motors	.39 cents
Maintenance of substations and car house	.12 cents
Car house foreman and employees	.34 cents
Heat and lights	.06 cents
Car shifting	.20 cents
Car cleaning	.29 cents
Maintaining batteries	4.00 cents
Platform expense, including inspectors, etc.	8.75 cents
Total	17.06 cents

The above figures include all labor and material chargeable to maintenance of cars but do not include the material chargeable to the operating account, salaries of clerks and officials, interest charges or taxes, or maintenance of track and road-bed.

For the convenience of those interested in the details of various installations, there will be found in the footnote reference to a number of articles which have appeared from time to time.

The general tone of these reviews is very optimistic and while, as originally stated, the field of successful commercial application is limited there appear to be many conditions which the storage battery car fulfills better than any other type of self-propelled vehicle.

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The Self-Propelled Car Here and Abroad—*Electric Railway Journal*, August 24, 1912.
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Further Data on Storage Battery Train—*Electric Railway Journal*, October 19, 1912.
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Heating Storage Battery Cars—*Electric Railway Journal*, February 3, 1912.
Accumulator Tramway Cars in New York—*Electric Railway Journal*, January 3, 1911.
Penna. Storage Battery Interurban Line—*Electric Railway Journal*, March 23, 1912.
A Storage Battery Car Company—*Electric Railway Journal*, April 27, 1912.
Three Car Storage Battery Train—*Electric Railway Journal*, September 28, 1912.
Construction of American and Prussian Accumulator Cars—*Electric Railway Journal*, February 22, 1913.
Construction of American and Prussian Accumulator Cars—*Electric Railway Journal*, March 1, 1913.
Long Run of Storage Battery Car—*Electric Railway Journal*, March 8, 1913.
Service and Inaugural Performances of Beach-Edison Storage Battery Car—*Electric Railway Journal*, April 26, 1913.
Electric Tractor for Switching Service in City Streets—*Electric Railway Journal*, April 26, 1913.
Equipment for the New Stepless Car of the New York Railways Co.—*Electric Railway Journal*, April 20, 1912.

DEVELOPMENT OF THE SPRAGUE G-E TYPE M MULTIPLE UNIT CONTROL

By F. E. Case

Engineer, Railway Equipment Department, General Electric Company

[illegible] development of the multiple unit control has been one of the most important problems in electric [illegible]. Mr. Case's account of some of the early work will be of much interest to students of railway [illegible], and an added interest is given to this article by the fact that the author has been closely [illegible] with the development of control equipments ever since the early days of electric railways.—Editor.

The first experimental equipment of Sprague-General Electric Type M control was made in the winter of 1897-8. This equipment was installed on the only large car owned by the Company at that time and given severe tests on the berme bank railway. As the system of control was of an entirely different type from anything previously made the pieces of apparatus, circuit connections, and general arrangement were naturally very crude as looked at from the present viewpoint.

The control consisted of a master controller and a number of magnetically operated switches, or contactors, actuated by it, the switches producing the requisite motor and resistance connections, the same as in our present control. The construction of these [illegible] was quite different from the present [illegible], however.

At that time there was no apparatus in [illegible] which could be adapted to the [illegible] and it was necessary to originate [illegible] parts. The magnetic blowout [illegible] course been developed and a form [illegible] used in cylinder controllers was [illegible] in the contactor. The actuating [illegible] and magnet construction required [illegible] amount of thought. The [illegible] of a cylinder with fingers, [illegible] in series-parallel controllers, [illegible] for partially rotating [illegible]. The equipment was [illegible] design, but one [illegible] the operativeness [illegible]

[illegible] that the new [illegible] of a satis- [illegible] if the details [illegible]

[illegible] original [illegible] with [illegible] 25 volt storage [illegible] operation of the control magnets. A [illegible] was placed in series with the storage battery and the two connected across the line. A relay was so connected that when the master controller was turned on and current was being taken from the storage battery, an additional resistance was connected in parallel with the first one and part of the control current was therefore taken from the line. The storage battery was provided in this original equipment, principally for the purpose of securing a reliable operation of the motors as generators in producing electrical braking. At that time the electric brake was being actively pushed and it was believed a satisfactory multiple unit control should provide for this feature. In order to ensure the operation of the control magnets under all conditions it was, of course, essential to have a continuous supply of electrical energy, which could not be obtained by depending upon the trolley. It soon developed, however, that the air brake would probably be used for all multiple unit service, and, in consequence, as the storage battery was not required, it was abandoned.

In the second experimental equipment which was tried on the berme bank the contactors were provided with a new form of contact arm, which produced a greater contact pressure, and the magnet was wound with a large number of turns of very fine wire to permit operation directly across the 600 volt circuit. While the new magnet operated satisfactorily, the heating was excessive, the winding was bulky and the size of the contactor very materially increased.

In order to obtain a more practicable operating magnet, a system of connections was devised in which there were two control circuits. In one, there were four contactor coils in series, and in the other on the first step of the control one contactor coil was placed in series with an external resistance equivalent to four coils. On the second step another coil was introduced in the circuit and an equal amount of external resistance removed. This operation was repeated until, in the final position of the master controller, five operating coils were left in series across 600 volts without any external resistance. This change in connections permitted such a reduction in the size of the operating coils that it was immediately adopted on the first equipment shipped from the works and the scheme has been utilized ever since.

For the first few years of manufacture a form of magnetic blowout, similar to that used in cylinder controllers, was used. In this type the arc was blown to one side of the contact through an aperture into a chute, which carried the gases away. The limitations in the amount of excess current which could be properly broken by this form of blowout was soon appreciated and a better form of blowout was devised. In this the pole pieces of the blowout magnet were located at each side of the contacts and separated from them by arc resisting material. Instead of blowing the arc to one side as formerly the arc was projected toward the front. The successful operation of this blowout immediately demonstrated its superiority and the efficiency of the contactor was greatly increased. Owing to the success of this blowout it was later adopted in cylinder controllers and is now used in the K-34, K-35, K-36, etc. Incidentally the change in direction of blowing out the arc made it possible to greatly reduce the width of the contactor.

Up to this time contactors had been supplied as separate units for mounting on wooden supports attached to the under side of the car. The housings, or boxes for the contactors, were made and installed at the time the equipments were mounted under the car and in consequence the construction man was obliged to do a considerable amount of work in properly mounting and protecting the apparatus.

The introduction of the new form of blowout, with the resulting reduction in the size of the contactors, permitted mounting the latter in metal boxes, lined with asbestos, which were made up at the factory. This adoption of metal boxes gave a much more finished appearance to the equipment, aside from providing a good protection to the contactor and reverser. Even with this improvement, however, it was necessary for the construction man, when installing the apparatus, to make all cable connections between contactors for both the power and control circuits.

The next development was to install the contactors at the factory in a single metal box provided with drop covers for permitting ready inspection. All of the wiring between contactor operating coils was done at the factory and a connection board was placed at one side of the box where the incoming control circuit multiple cable was attached. The main connections between the power side of the contactors were also installed at the factory.

These improvements, together with the grouping of the control circuit resistance units in the box with the contactors, made the installation of the control much easier than formerly. At the same time this change was put into effect the contactor box was provided with fittings to which metal conduit, for carrying the cables, could be attached. As a result of this latter change the car wiring, instead of being run in canvas hose or being taped and held up by cleats to the car floor, was encased in metal conduit throughout. Injury from water or abrasion became practically impossible, and a very much neater and more substantial installation resulted.

With all of the earlier equipments the motor circuit was completely opened in passing from series to parallel, as it was thought that the circuit connections and apparatus would be much simpler and less liable to disarrangement than with the method of shunting half of the motors, which was the practice with cylinder controllers. Tests were subsequently made which showed that a system of connections, known as the "bridging method," was entirely feasible. Strangely enough, this method had been tried experimentally more than ten years previously, and in fact a patent had been obtained, but the tests were not considered successful, owing principally to excessive arcing at the controller contacts during the passage from series to parallel, and the scheme had not been used. The broader experience of later years made it possible, however, to eliminate obstacles which had previously been thought insurmountable, and this method was generally adopted.

During the past year or two, in order to simplify the control by reducing the number of contactors, an arrangement of resistance and motor circuits, somewhat similar to that of the older cylinder controllers, has been used on small and medium size equipments. This control is of the non-automatic type and represents the simplest possible connections. In order to differentiate from the bridge or automatic type of control, which is for a heavier or more exacting service, this control has been designated the "MK."

The older equipments were provided with a copper ribbon magnetic blowout fuse for the protection of the motor circuit, and for several years this was considered adequate. An electrically controlled circuit breaker was finally added and this had the advantage of quicker operation at small overloads and the elimination of delays occasioned in replacing a blown fuse. With the "MK" control, the circuit breaker is dispensed with and an overload relay is employed, which opens the contactor operating circuit and permits the contactors to drop out when an overload occurs. This scheme is entirely feasible where the equipments are of moderate size and the amount of possible overload current is not of maximum value. It is not recommended for heavy work, as the separate circuit breaker has an additional factor of safety when the amount of current to be handled is excessive.

The latest form of MK control has but one box for containing the reverser, contactors, overload relay, etc. In fact, the only parts under the car are this one box and a set of RG rheostats. The concentration of the control parts in one box, the elimination of the separate circuit breaker, and the reduction in the number of contactors required for the simplified connections, has brought about a very considerable reduction in weight of the MK control.

REQUIREMENTS OF CONTROL ON MODERN STREET RAILWAYS

By Harold C. Pease

Assistant Engineer, Railway Equipment Department, General Electric Company

The author cites some of the difficulties of designing control equipments for modern cars, where it would seem space is being provided for everything but the control. The designing engineer has to use the utmost ingenuity to get the control equipment on some types of car at all. In addition to the structural difficulties, operating requirements are constantly becoming more severe.—Editor.

For many years the earlier types of control equipment successfully controlled the motive equipment of electric street railways. The earlier and simpler types met the demands of the low voltage lines, the small power of the motors and the light weight cars then in use. Their installation was not a difficult problem in spite of the smallness of the cars. The controllers, which directly handled the motor current, were placed on the platform beside the motorman. The cables and rheostats were placed under the car body, leaving plenty of room for the hand brakes, which were the only type then in use on street cars.

With the rapid increase in the line voltage and horse power of the motors, greater demands were continually being made on the control equipment, requiring better designs and greater capacities. This increase, caused by the demand for carrying more and more passengers, finally made it economical and advantageous to operate cars in trains. For this reason it became necessary to install the motor controller where more space was available. It was first placed under the car body along with the air brake apparatus, which, for the same reason, was also required. The master controller, required for operating the motor controller, replaced the latter beside the motorman. In general design it was similar to the motor controller of the manually operated type, but as it handled only the small current necessary for operating the motor controller, it was greatly reduced in size and capacity.

In the majority of cases of single car operation, where the motors are only moderate in size (less than 300 horse power total per car) the manually operated platform controllers are still being used. Their operation is entirely successful and satisfactory. With the modern designs now in general use, the failures of the former types have been entirely eliminated. In other cases the multiple unit type of controller is preferable, either because of the very large motors, which make the manually operated controller very cumbersome, or because the latter is too large to be installed in the motorman's cab.

With the advent of the modern types of cars, such as the so called "center entrance" and "stepless" cars, frequently equipped with multiple unit control, the available space under the car body is greatly reduced and in some instances entirely eliminated. In such cases the control apparatus is necessarily trimmed and squeezed until the "elastic limit" is reached, and further reduction in one place forces an increase in another. Reducing the space naturally increases the necessary insulation and hampers the inspection and renewal of parts. Air is the cheapest insulation and the substitution of other material is bound to materially increase the cost. To place parts requiring inspection so that even a slight effort is necessary on the part of the inspector, is to risk the inspection. As for the renewal of parts, which are removed only after dismantling the apparatus, no master mechanic fails to criticise the designer and manufacturer when insufficient space is provided.

The limit is apparently reached when no room under the car body is available for either the motor controller or rheostats, and when even the air brakes have to be materially changed to properly perform their functions. It may be necessary to divide the latter into two sets, operating independently. This permits a very low center platform, which allows the entrance and exit of the car to be accomplished with greater ease and comfort. There being no room for control apparatus under this platform, with the brakes completely occupying the small spaces between it and the trucks, the next best location of the motor controller and rheostats must be determined. There is no question about the location of the motors. No design has yet eliminated them from the trucks on passenger cars, nor the brakes from their general location under the car body; but the motor controller, being more easily provided for, has to be adaptable to several places. It has been designed to go on the platform, under the car body, near the roof, under the seats and in special cabinets. It has yet to be designed to go on top of the roof. Of all these places the one so far adopted for the center entrance cars, where it cannot go under the car floor, is behind the motorman. It is practically built to fit the car and is either designed to rest on the floor, possibly forming a seat for the motorman, or in a vertical cabinet. The latter construction takes less floor space but obstructs to some extent the view of the passengers and conductor.

It is possible to divide the motor control into several sections and shape them to fit the available spaces, but this prevents the use of standard designs and makes necessary new drawings, patterns and tools. Each additional division increases the number of supports, the inter-connections, the amount of cable and the work of installation. To lay out the equipment in the most advantageous and satisfactory location, choosing the best of the innumerable solutions, requires long consideration and a thorough examination of the detail drawings of the car and the making of necessary changes in them.

The results of this condition are far reaching. For the customer it means long delivery, special parts and usually the sacrifice of some operating advantages. For the manufacturer it means new drawings, new dies, tools, moulds, and patterns, additional stock of raw materials and parts, and new tests, with all the accompanying chance of errors and failures, necessary revisions and lack of time to prepare for manufacture.

How many times the engineer has forgotten the decimal point, how many times the customer has given information in error, how many times the factory has failed to place orders either for materials or parts, how many times the samples are rebuilt to correct mistakes of draftsman or mechanic, and how many times the assembled apparatus is reassembled to pass inspection, is not all known to one man, either customer or manufacturer. Such troubles as can be overcome by extra labor or overtime are covered up and forgotten; but, if the apparatus does not assemble properly, operate correctly, or when finished can not be installed successfully, then the mistake is uncovered and criticism surely follows.

Aside from the manufacturing and installation requirements of modern control equipments, there are many operating requirements with their problems, demanding the constant effort of the engineer to solve and to keep solved. It required the efforts of many men to originate the principles of all the operations performed today by street car controllers. From the single motor, to the double motor and four motor control; from the hand-operated to the power-operated; from non-automatic to the automatic; from the two running speeds to the four running speeds; from the single car to train operation; from the open door to the closed door automatic starting; from the hand brake to the automatic stopping; and from the low to high voltage, the development has progressed by many stages of advancement. The results have been accomplished after many false moves and failures. It has meant the knowledge, by the engineer, of all the previous phases before successfully producing each succeeding step. Without a full knowledge of previous failures one can not travel the mazed paths of the control field and be reasonably sure not to be tripped up by the pitfalls there abounding.

The subject of alternating current control has purposely been avoided, principally because its use on street cars is not at present increasing, and also because it has already been sufficiently perfected to await the further perfection of the a-c. motor.

Among the operating requirements mentioned above, four running speeds, closed door starting, and high voltage may not be generally understood. These are briefly described as follows:

Four Running Speeds

The usual series-parallel control gives one running speed in series and one in parallel. Two additional speeds may be obtained by changing the field strength of the motors on full series and on full parallel points. Full field strength is required during acceleration to maintain the torque of the motors. When the motors have reached normal speed with full field the strength of the latter may be reduced with a resulting increase in motor speed. This may be done in two ways, either by shunting part of the current around the fields or by tapping the field and reducing the number of turns.

Although the control giving two speeds with full field will give four speeds with field control, there are several advantages in using only three speeds, that is, eliminating the field control speed in series. The advantages are as follows:

1. No interlocking is necessary to prevent going into parallel with reduced field.

2. It permits the use of standard controllers with a current limit relay operating contactor to reduce the field strength. This relay operates at a predetermined minimum motor current when the control is on the parallel running notch.

3. It permits confining the high speed to interurban running by controlling the operation of the relay. The operation of the master controller is unchanged.

With platform motor controllers these advantages are of great importance, due to the lack of mechanical complication. On remote or train control the advantages of (1) and (3) are not so great, but (2) is a very decided advantage.

Closed Door Starting

The latest development in automatic control is the starting of the car or train by the closing of the last door. The idea of having the last door closed signal the motorman is not new, it having been in use on several roads for some time; but the addition of closing the control circuit and starting the car if the master controller is turned on, has only just recently been put in operation. The connections are very simple, there being merely a relay operated by the door circuits closing the control circuit when the door circuit is completed.

The advantages derived from this method of operation are:

1. The time saved by starting the train as soon as the last door closes.

2. Impossibility of starting the car until the doors are all closed.

These advantages are lessened to some extent by the liability of failure, always possible with any automatic feature of operation. Cross connections or short circuits might start the train before all the doors were closed. The failure of any one of the numerous contacts would prevent the starting and operation of the train unless some means were provided to cut out this method of operation.

This method of operation is frequently extended to include the feature of holding doors closed until the train stops. This is accomplished by automatic means controlled by the speed of the car and is practically independent of the control of the motors.

High Voltage

Some years ago it was deemed advisable to confine the range of voltage over which d-c. railway motors could be most satisfactorily operated from 550 to 750. The controllers, therefore, were designed for this maximum voltage. With the recent change in motor construction, permitting two to three times this operating voltage, new controllers had to be designed to handle the high voltage.

Manually operated controllers were modified by increasing the creepage, insulation, and current rupturing capacities. They have been successfully built and operated up to 1500 volts. This is the highest voltage on which this type of controller has so far been called upon to operate.

Multiple unit control could be designed to be operated by the high voltage current, but the most efficient and satisfactory arrangement is to use some form of voltage transformer supplying the desired low voltage current for the control circuit. This voltage should be the same as the previous low voltage standard—750 maximum. It is then possible to use in the control circuit all the standard 750 volt parts. The parts for the motor circuit must necessarily be designed for the high voltage.

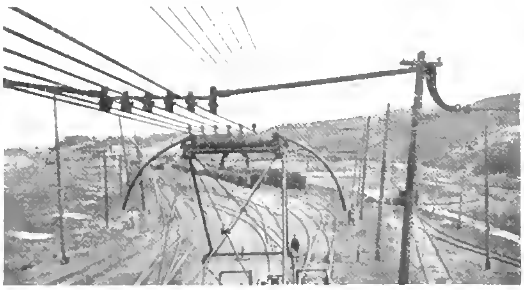
There are several methods for obtaining this voltage for the control circuit. The best one is to use either a motor-generator set or a dynamotor. The dynamotor is smaller, lighter, and cheaper than the motor-generator set and is quite generally used. The latter, however, has one or two advantages, such as the absolute independence of the high and low voltage circuits, and no necessary relation between the two voltage values.

The dynamotor has two armature windings and commutators on one drum, with the field between them. The control current is taken midway between the armatures and is returned to the ground side of the dynamotor. This insures that the maximum potential on the control circuit, under normal conditions, will be approximately one-half the line voltage, and the potential to grounded parts no greater than when operated directly on a line voltage of one-half the amount.

The operation on high voltage is generally combined with operation on low voltage. The high voltage may be used on the interurban lines where the city lines have been standardized at a value between 550 and 750. It is, therefore, desirable for the interurban cars to operate on both voltages. The usual arrangement is to have the high voltage double the low voltage, that is, between 1200 and 1500. This allows full speed operation on both voltages with four motor equipments. The equipment is much simpler and lighter if only half speed is obtainable on the lower voltage, as it is otherwise necessary to commutate the motors and rheostats. In some cases, however, the advantage of full speed on the city lines warrants the extra complications.

The problem of the auxiliary circuits for high voltage lines, other than control, has not been mentioned. The light, headlight, and compressor circuits may all be arranged for high voltage, and even for two voltage operation by commutation. In every case the possibility of reducing the size of the motor-generator set for energizing some or all of these circuits directly from trolley, forms a chance for engineering decision.

From the points already mentioned it is obvious that at the present time more possibilities present themselves for control equipment then ever before. Each one of the numerous circuits, each operation of the many parts, and every function of each part must be duly considered and a thorough analysis of each proposition carefully made before the most desirable and satisfactory control equipment can be furnished to fulfill the given requirements.



CONTROL EQUIPMENT FOR DIRECT CURRENT LOCOMOTIVES ON INTERURBAN RAILWAYS

By R. Stearns

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General Electric Company

In this very comprehensive article, the author divides interurban electric locomotives into three classes, according to weight, namely, 20 to 40 tons, 40 to 60 tons, and 60 to 100 tons, and describes the principal pieces of control apparatus used in each. The control diagrams and curves are of a most complete nature and these, together with the splendid collection of detailed illustrations, make this article a very valuable contribution to our Railway Number.—Editor.

It is customary to rate the hauling capacity of a locomotive with respect to the weight on the drivers. The motive power of an electric locomotive while figured for a cycle of service, must be designed with sufficient capacity to operate safely up to the slipping point of the drivers during acceleration. A smooth acceleration is essential to the highest efficiency of operation. The electrical equipment for controlling the motors must provide as many additive increments of impressed voltage at the motors as are necessary to permit a high average torque during acceleration, without causing the wheels to slip. The number of increments increases in proportion to the power to be divided during starting or, in other words, to the weight on the drivers. The number of points in the control system, intended to vary the applied voltage and the transition between motor groupings, that is, between motors connected in series, series-parallel or parallel, which is also a means of varying the applied voltage, are the important factors to consider when designing, in order to provide [illegible] for the engineer to take full advantage [illegible] maximum capacity of his loco[illegible] continuously as possible while [illegible]

D[illegible] electric locomotives for interurban [illegible] service are limited in weight [illegible] so that they range from 20 up [illegible] and sometimes up to 100 tons. So [illegible] motor control is concerned, the equip[illegible] for the various sizes of locomotives may [illegible] divided into three classes, without reference to the motor groupings. These three [illegible] are as follows: First control for locomotives between 20 and 40 tons; second, locomotives between 40 and 60 tons, and third, locomotives between 60 and 100 tons. It is intended to describe in this article, the chief pieces of apparatus used with these three classes of locomotives and to outline the salient features of the schemes of connection.

The following list of equipment covers the main varieties of apparatus in service using 600, 1200, 1500 or 2400 d-c. trolley potentials or a combination of 600 and 1200.

List of Equipment

1. Current collecting devices.
2. Lightning arrester.
3. Fuse boxes and fuses.
4. Protective relays.
5. Main switch.
6. Auxiliary switches and fuses.
7. Auxiliary equipment.
8. Meters.
9. Controllers.
10. Train lines.
11. Contactors and interlocks.
12. Reverser.
13. Motor cutout switches.
14. Commutating switch.
15. Rheostats.
16. Insulation.
17. Wire and cable.

Four types of current collecting devices are used: the standard pole with harp and wheel, pivoted in a roller bearing base; the sliding bow; the roller pantograph and the third rail shoe. Where the service runs endure for considerable periods in one direction, the pole trolley is cheap and satisfactory. If the service requires frequent changes in direction of operation, then either the sliding bow or the roller pantograph is more desirable. The bow is used for slow speed yard switching work and the roller pantograph for a combination of low and high speeds. Any one of these types of trolleys can be used at high as well as low voltages. Both over running and under running third rail shoes are used. Mr. Stewart's article in this issue outlines more in detail this type of apparatus.

Lightning Arrester

For protection against lightning, two types of arresters are used: the magnetic blowout type, of which there are two forms, the one equipped with an electro-magnetic blowout, and the other provided with a permanent magnetic blowout, and the aluminum arrester. The use of either form with the magnetic blowout is recommended for 600 volt trolley service. The arrester with a permanent magnetic blowout may be also used on circuits up to 1800 volts. The aluminum arrester is designed for service up to 2400 volts. In choosing between the different types of arresters, two things are to be considered; the degree of protection desired and the amount of inspection which will be given. Ordinarily the magnetic blowout type of arrester gives sufficient protection. The arrester with a permanent magnetic blowout while more efficient than those equipped with electro-magnetic blowouts, is somewhat more expensive. Little inspection is required of either of these. Where severe lightning conditions prevail, the aluminum cell arrester should be used. It is necessary to frequently inspect the aluminum cell arrester and where it is used it is assumed that the conditions warrant close inspection.

The lightning arrester should be tapped into the trolley lead of the locomotive next to the main fuse, and both arrester and fuse should be located as near the trolley as possible. A choke coil is placed ahead of the power circuits. The lead running from the trolley to the arrester should be located at least 12 inches from the power circuits extending beyond the choke coil and sharp turns should be avoided. In cases of high voltage where the blowout coils of the main fuse offer considerable impedance, this fuse is located below the lightning arrester in the power circuit and a separate fuse without appreciable impedance is installed as part of the arrester equipment.

Fuse Boxes and Fuses

In the case of car equipments it is the practice to provide fuse protection against short circuits, and a quick operating circuit breaker for protection against overloads. For a locomotive, it is only necessary to provide the short circuit protection, since the capacity of the electrical equipment is proportioned to the weight on drivers and the slipping point of the wheels is the overload limit.

Maximum protection is obtained by placing fuses as close to the power supply as possible. With an overhead trolley, the fuse is usually placed on the roof. With third rail collectors, a fuse is placed as near each individual shoe as possible. It is only necessary to provide a trolley fuse for series-parallel control, whether individual pairs of motors are connected either permanently in series or in parallel. Since the fuse provides against short circuit, ample protection for wiring and apparatus is obtained with the single fuse. With three speed control where the motors are operated all four in series, in series-parallel and all four in parallel, the circuits are more complicated, and it seems desirable to have a fuse in each of the four motor circuits in addition to the trolley fuse. The fuse provides in this case an automatic cutout which locates any trouble quickly.

On an electric locomotive operated from a third rail, four sets of third rail collectors are used; two of these on either side of the locomotive are in circuit at one time. It is necessary to provide fuse capacity for operating with either one of the sets of third rail shoes making contact with the third rail, since at

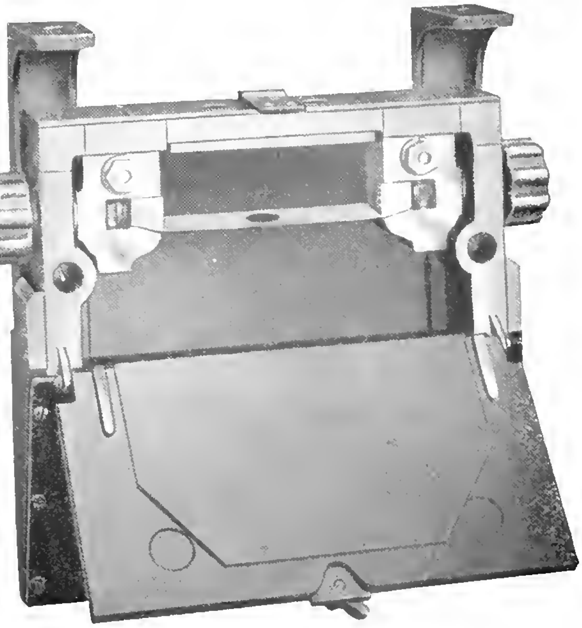


Fig. 1. 600-Volt Fuse Box, Open, with Fuse

starting only one set may be in contact, and in cases of emergency one set may be damaged. During ordinary operation with both sets in contact, the fuse capacity, in series

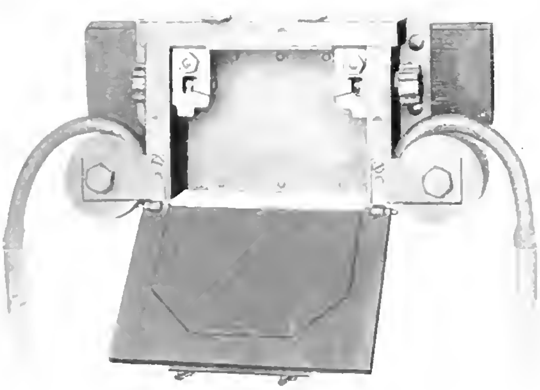


Fig. 2. 1200-Volt Fuse Box, Open, with Fuse Removed

with the power circuit, is higher than in the case of an overhead trolley. It is accordingly desirable with a third rail system to provide additional fuses for the motor circuits with both two and three speed control.

Figs. 1, 2 and 3 show respectively fuse boxes for 500 amps. and 600 volts; 800 amps. and 1200 volts; and 600 amps. and 2400 volts. These views are illustrative of the types used for these voltages. In each case the fuse box is equipped with a hinged cover to facilitate fuse renewals. An effective magnetic blowout, energized by the current through the fuse, causes the two ends of the

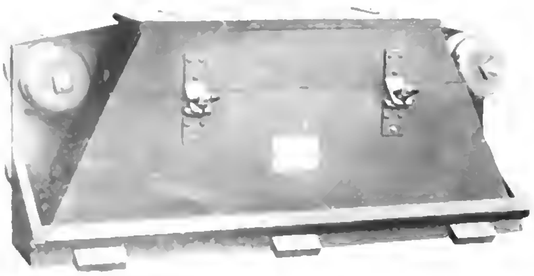


Fig. [illegible] Volt Fuse Box Closed

thin fuse to be [illegible] angles to their normal position, thus [illegible]ching as well as blowing the arc metal [illegible]ure.

The fuse itself con[illegible] a thin metal ribbon having a hole in the center to localize the heating. The cross section of this fuse is chosen with ample capacity to carry normal current, but the fuse will melt and open the circuit at a predetermined excess in current. The fuse is securely clamped in place by wedges controlled by screws equipped with suitable handles.

A fuse is rated at one-half the current it requires to volatilize in 30 seconds. In choosing a fuse for locomotive service, it is necessary to provide enough capacity for normal operation without undue oxidation which would reduce the blowing point. It is recommended that the fuse be selected with respect to the slipping point of the wheels. In the case where motor fuses are used, a rating should be taken equal to the current at about 25 per cent coefficient of adhesion. The fuse for trolley, third rail or bus line should be selected at 20 per cent

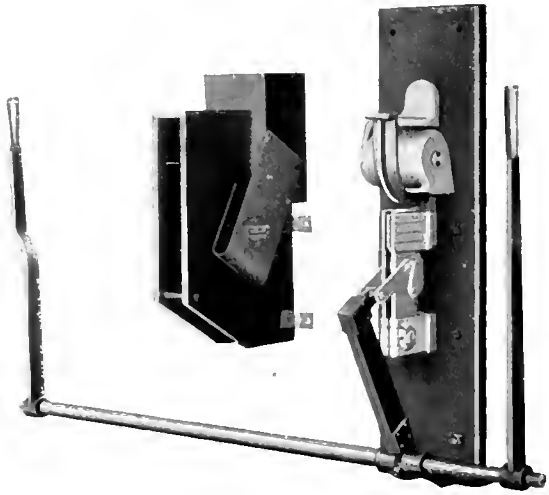


Fig. 4. Hand-Operated Main Switch, 600 Volts, Arc Chute Removed

coefficient of adhesion. Since the highest currents obtain usually during acceleration on the first few points of the controller with the motors connected in series, the duty on the trolley fuse is not so severe as on the motor fuses and the rating may be lower. However, where the service involves hauling long trains with high train frictions, it may be necessary to continue to accelerate even into the parallel connections of the motors close to the slipping point of the wheels. In such service the motor and trolley fuses should be chosen at the same ratio. For the individual third rail shoe fuses 20 per cent should give ample capacity, since in normal operation two shoes are in contact and supply current through two fuses at one time.

Protective Relays

Frequently combination locomotives used for both hauling and carrying heavy loads have varying weights on drivers so that the slipping point of the wheels cannot be depended upon as a current limit. In this service current limit relays have been used to open the line contactors in case the current in the motors exceeds a predetermined value.

In a service with both 600 and 1200 volt trolley current, a protective relay is used to prevent closing the circuit from the high voltage trolley when the motor and auxiliary circuit connections are set for 600 volt operation. This is accomplished through the means of a relay coil wound so that it will pick up its contacts at a predetermined value, which is chosen slightly above the normal lower voltage operation. When this coil picks up, it prevents closing the main circuit until the commutating switch, which changes the connections for either trolley voltage, is placed in the correct position.

Main Switch

The main switch on a locomotive has two functions, it serves as a disconnecting switch,

Fig. 5. Hand-Operated Main Switch, 1200 Volts

for cutting the motor power supply when testing the solenoid circuits, and it can be opened in emergencies under conditions far exceeding full load. It has been mentioned above that the fuses of two sets of third rail collectors supply current in multiple during normal operation, and that the fuses cannot be selected with respect to their combined capacity, since it is desirable in emergencies to operate from one set, and in some cases to

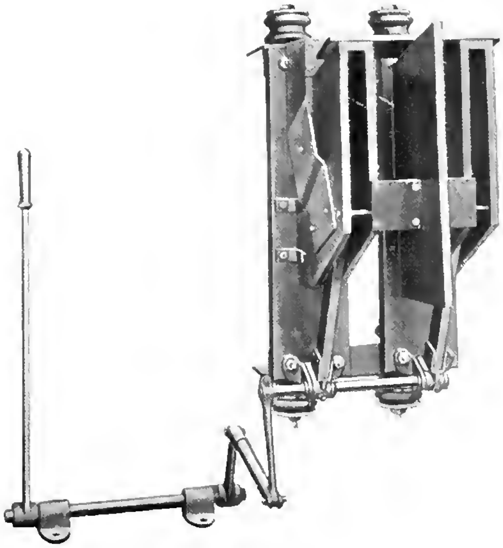


Fig. 6. Hand-Operated Main Switch, 2400 Volts

start the locomotive with only one set in contact. Because of this, particularly in the case of low voltage operation, the current limitation of the fuses is placed at a comparatively high value and it is possible to get a short circuit with considerable resistance in series, which may not blow the fuses immediately. By making the main switch multi-pole, and running a lead from each of the third rail shoe fuses to a separate blade, the main switch may be made not only to open the circuit to the motors, but also to open the connection between fuses, so that power is not fed through the short circuit with the fuses in multiple. One fuse may then be crowded to the blowing point by opening the switch.

Figs. 4, 5 and 6 show respectively, main switches for 1800 amperes and 600 volts; 800 amperes and 1200 volts and 400 amperes and 2400 volts.

Fig. 4 shows the switch with the arc chute removed. It may be noted that a powerful magnetic blowout energized by the current through the switch, is used to assist in directing and rupturing the arc. The arc chute is similar to that used on the standard contactors and the switch is of the standard knife blade type. The switch may be operated from an accessible point in the cab by means of lever handles.

Auxiliary Switches and Fuses

Besides the traction motor circuits it is necessary to supply power to the cab lights,

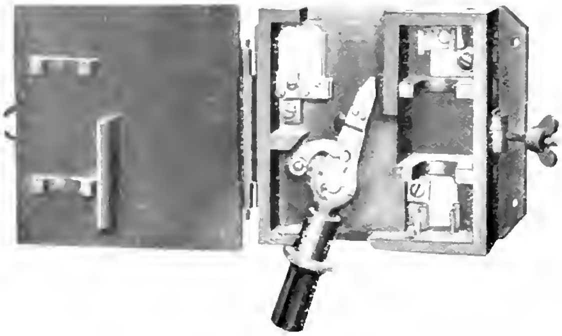


Fig. 7. Combination Switch and Fuse for 600-Volt Auxiliary Circuits, Fuse Removed

gauge lights, headlights, compressor, blower, motor-generator set, heaters and the circuits furnishing auxiliary power to the controllers. Each of these circuits is protected by a combination switch and fuse similar to that shown in Fig. 7, which is the 50 ampere size. The positive lead should be connected to the upper terminal of the switch and the negative lead to the upper fuse terminal; then the fuse is dead when the switch is opened to make renewals.

Auxiliary Equipment

With reference to the auxiliary circuits just mentioned it seems pertinent to call attention to laws now existing in some states with respect to headlights. There is a requirement calling for an abnormal amount of unreflected candle-power. With the larger manufacturing concerns of electrical apparatus the development in headlights for electric railway service has been toward gaining a high efficiency light, burning a small amount of current with high reflected candle-power.

The luminous arc light of two amperes and of four amperes has given satisfactory service for some time for varying trolley potential conditions. Where a constant potential is available, as in the case of high voltage with a motor-generator set furnishing power to the auxiliary circuits, a headlight using an incandescent lamp is most satisfactory. In this case, the unreflected candle-power is at a minimum and the reflected candle-power at a maximum. The energy required is low and full advantage is taken of all light by concentrating the filament at the focus of a parabolic reflector.

Blowers, driven by series motors, are used to ventilate and cool the traction motors in many cases on locomotives in switching and interurban service. The air is usually taken from the inside of the cab. The cab is equipped with louvres to assist in a free supply of air.

The solenoid operating and other auxiliary circuits, in the case of each class of locomotive described in this article, whether the traction motor circuit is high voltage or not, is at 600 volts or less. With a 600 volt trolley, these circuits can be taken directly from the main power supply. With higher voltages either a dynamotor or motor-generator set is used to step down the trolley potential. In the case of the motor-generator set constant voltage is available by using a regulator on the generator field; the ratio of potentials between trolley input and generator output may be anything desired; and a separation between the high voltage side of the set and the low voltage is possible.

Meters

An ammeter located at the engineer's position in each end of the locomotive, is the only meter required for ordinary service.

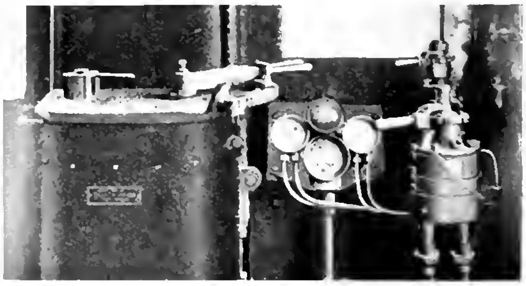


Fig. 8. Illuminated Meter and Air Gauge Panel

Fig. 8 shows the arrangement of ammeter and air gauges with respect to a lamp which is used for illumination. In order that the engineer may glance at his ammeter without being troubled by reflected light, the ammeter case has a dull finish throughout and the scale is black with white markings.

The meter is connected in series with the grounded side of the motor and its case is grounded. The ammeter reads the current of one motor, or one pair of motors, when two are permanently connected together. This enables the engineer to fix a current value at which he can accelerate whether in series, series-parallel or parallel. This value would change if the meter was located in the main trolley or grounded circuits so as to read all four motors.

The same type of ammeter can be used on all sizes of locomotives since a shunt is used to care for the varying capacities. The ammeter is calibrated with the dial at an angle of 60 degrees to the horizontal and with allowance for the length and size of the leads running from the shunt to the meters.

The ammeter scale is laid out for a maximum deflection corresponding to 40 per cent coefficient of adhesion of the locomotive. This places the average readings of 15 to 25 per cent coefficient during acceleration at points in the scale which are readily readable. With the limit at 40 per cent the meter cannot be damaged by any common overload.

Controllers and Train Line

The functions of the master controller, which receives its energizing current either at line potential, or in the case of trolley voltages above 600, from a dynamotor or motor-generator set, are to regulate the applied voltage at the traction motor terminals through the means of switches, called contactors, and to change the direction of rotation of the motors.

The engineer, by the use of a main handle controlling a cylinder covered with contact segments, that in turn engage with a row of fingers, may energize a multi-conductor cable running the length of the locomotive or train of locomotives. The solenoids of the contactors are connected to this train cable so that as different wires are energized by the controller, the motor circuits are closed through the different combinations of resistance points and motor groupings. A reverse handle, directly connected to another cylinder similarly operates connections which reverse the motor fields.

The main handle can not be turned "on" when the reverse handle is in the "off" position. In this way the engineer may lock his controller by removing the small reverse handle. Furthermore the reverse handle cannot be turned except when the main handle is in the "off" position. This prevents any attempt to reverse with power through the traction motors.

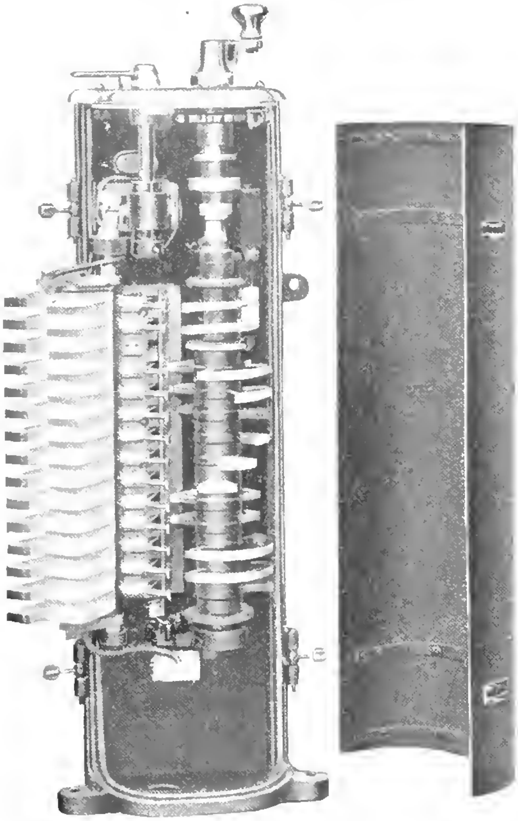


Fig. 9. C 90 Controller 7-5 Points

TABLE I

Type of controller	C 74	C 90	C 83	C 93	C 79
Class of locomotive	20–40 tons	40–60 tons	40–60 tons	60–100 tons	60–100 tons
No. of points Series, series-parallel or series-parallel, parallel	6–4	7–5		10–7	
No. of points Series, series-parallel, parallel,			7–6–5		9–8–7
No. of points in train line	10	12	16	16	16

Figs. 9 and 10 show the C 90 and C 93 controllers.

A master controller is located at each end of a locomotive and by means of the train line which runs through the train of locomotives as described above, any number of locomotives within the capacity of the controller, may be operated in parallel from either end of any locomotive when the latter are coupled in a sequence. The capacity of the controller is usually figured for not more than three locomotives in multiple; the combined tractive effort in this case being the maximum desired for ordinary service.

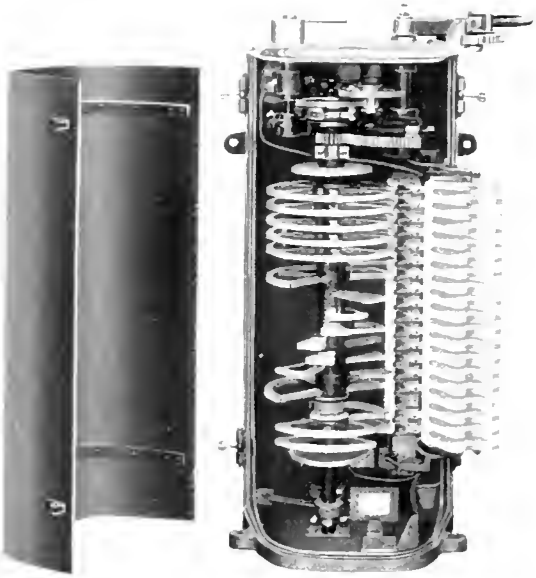


Fig. 10. C 93 Controller 10-7 Points

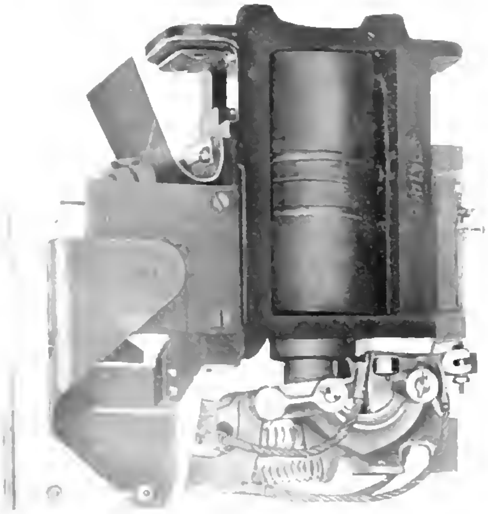


Fig. 11. Low Voltage Contactor

Table I gives a list of the standard types of controllers, with the number of operating points and the number of points in the train line, which have been developed for the different sizes of locomotives.

Contactors and Interlocks

The contactors for the different classes of locomotives are selected with respect to their current capacity and the voltage of the motors. With trolley potentials of 600 and 1200 volts, the same contactor is used, more breaks in series being allowed in the latter case. The incoming, or positive terminal, is isolated by an insulating compound, and the frame of the contactor supports the negative terminal. With potentials above 1200 volts both the positive and negative terminals of the contactor are insulated so that the frame carrying the operating solenoid may be grounded.

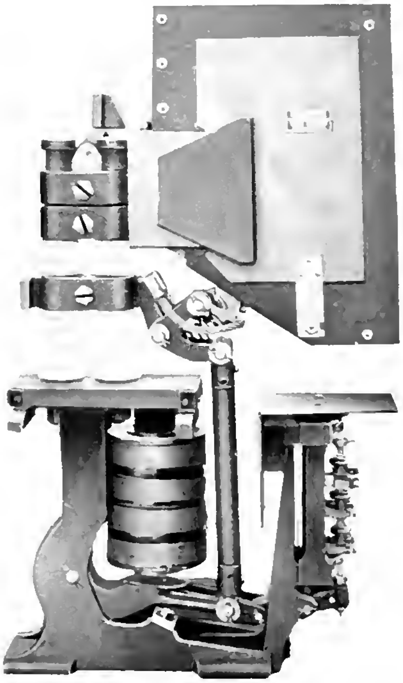


Fig. 12. High-Voltage Contactor

Figs. 11 and 12 show examples of these types. The contactor in Fig. 11 has a capacity of 800 amperes and when the frame is properly insulated from ground may be used on either 600 or 1200 volts. The contactor in

Fig. 12 has a capacity of 350 amperes at 2400 volts.

The actuating solenoids of a contactor are designed to close the main contacts at voltages as low as half the normal trolley potential. Sufficient radiating surface is provided so that the solenoids will not overheat when the locomotive is operating continuously at normal trolley potential.

The arc chute surrounding the main contacts is made as narrow as possible and is equipped with a powerful magnetic field set up by a solenoid in series with the positive terminal. At the time of rupturing the arc, when the operating solenoid is de-energized, the magnetic field causes the arc to move from the contact tips to burning horns, thus lessening the burning at the tips. As the arc moves on the cool metal of the horns, the amount of conducting copper vapor is reduced. The horns are shaped so as to stretch the arc and draw it away from the restricted part of the arc chute near the contacts. Care is given to shape the pole pieces so as to gain the best direction and concentration of the magnetic field; not only with the view of rupturing the arc but of keeping the arc away from the sides of the chute. The contactor is made accessible for renewals of the wearing parts without disturbing adjacent contactors when installed.

Electrical interlocks in series with the solenoid circuits are placed on contactors, as shown in the illustrations, in order to time the closing of different contactors with respect to each other. The interlocks have removable phosphor bronze wearing plates for the contacts and are designed to close with a wiping motion. They close and open in fixed relation to the closing and opening of the main contacts.

Reversers

The reversing of the motors is accomplished in two ways; by means of a set of contactors where each pair of contacts is equipped with its individual magnetic blowout and by a reverser where the main contacts are grouped together for simplicity in operation and are not so equipped.

The reverser is being used in many cases on locomotives of the smallest class, from 20 to 40 tons, and on locomotives operating at high trolley potentials where the fields of the motors are placed on the grounded side. It is necessary in the latter case, to have contacts which are held closed mechanically, to prevent the accidental opening of the field circuit by a broken or open circuited solenoid wire. For the heavier locomotives, it is necessary to use contactors, although slightly more expensive, in order to gain the advantage in capacity which the construction affords, and profit by the increased breaks in series.

Motor Cutout Switches

With series-parallel control, three schemes for cutting out damaged motors are in common use. With each scheme it is necessary to cut out two motors, although only one motor may be damaged, in order to balance the control connections for operating the remaining motors. Where a pair of motors is permanently grouped in parallel and a reverser is used, the damaged motor is cut out by a knife blade switch located on the reverser, and the corresponding motor of the second group is also cut out. This permits series-parallel operation through all the points of the controller with two motors. Where contactors are used, multi-pole knife blade switches are placed so as to cut out the group of motors in which the damaged motor is located. The controller circuits are commutated by these switches so that the remaining pair of motors will operate through the series points of the controller, and retain

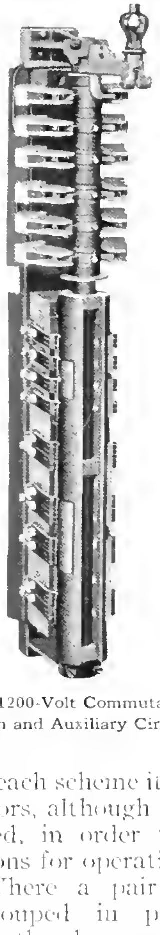


Fig. 13. 600 1200-Volt Commutating Switch for Main and Auxiliary Circuits

the full series connection through all the points in parallel. With the control connections as used with the C 93 controller, the motor cutout switch, which is a part of the series-parallel switch, cuts out a group of motors. The control circuits are commutated, at the same time the motor group is disconnected, so that the power circuits are

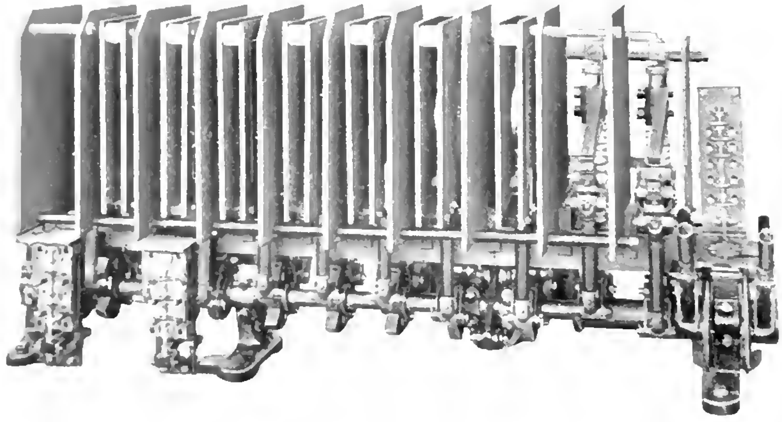


Fig. 14. 2400-Volt Series-Parallel Switch

not completed when the controller handle is turned on, until the first point parallel is reached. Resistance is then cut out throughout the parallel points on the controller. The additional low transfer points which are dotted on Fig. 24, are useful, when a pair of motors is cut out, in starting a locomotive from rest with the remaining motors.

With series, series-parallel and parallel control, the motor cutout switches disconnect a single motor, see Fig. 21, and a pair of motors, see Fig. 23, and commutate the control circuits so the operation is with the last two motor groupings only. There is no connection in series and the first point is in series-parallel with one-half the motors doing [illegible]. When the controller handle has finally reached the full parallel positions, the three motors or three pairs of motors are in circuit. When starting, with the motors connected in the intermediate series-parallel grouping, the external resistance of two pairs of motors is in circuit in place of the external resistance of one pair of motors which is the connection in normal operation.

When two or more locomotives are operated in parallel, and it has been found necessary to cut out a damaged motor, the connections, which prevent operation on the series points of the controller and place the starting point at the first parallel position, are preferable in order to gain a better division of the motor load between locomotives.

Commutating Switches

Fig. 13 illustrates the construction of the commutating switch used with equipments which operate up to the full speed of the motors at both 600 and 1200 volts. The lower fingers and segments, series-parallel the individual groups of motors and sets of external resistances. The upper fingers equipped with magnetic blowouts, commutate the control and other auxiliary circuits with respect to the power supply whether from a trolley or a dynamotor or motor-generator set. Heaters and other similar circuits are series-paralleled. Blowouts are provided so that the engineer may turn the switch without reference to whether the auxiliary circuits carry load or not. It is only necessary for him to see that the main handle of the controller is in the "off" position, thus disconnecting the traction motors.

The switch is designed without a cover for location inside a locomotive end cab. The handle projects through the bulk-head and is easily accessible while the switch itself is isolated. In changing the position of the switch from 600 to 1200 volt operation, the handle may be thrown directly from one position to the other, but with the reverse operation, throwing from 1200 to 600 volts, where there is a possibility of making low voltage connections while the high voltage trolley is in circuit, a button in the handle must be pushed in order to disengage a latch before the transfer can be completed. This latch provides a check for the engineer which has been found sufficient to insure correct operation. It is intended that a marking post be placed on the 600 volt section of the line near the dead trolley section, to indicate the point where the commutating switch should be thrown. This transfer is to be made without reference to the direction in which the locomotive is running. As has been stated previously, a protective relay can be used as an auxiliary protection.

In the case where the motors are operated full speed on 1200 volts, and half speed on

600 volts, it is not necessary to commutate either the rheostat or the main motor circuits. In this case the protective relay equipment is designed to take care of the commutation of the auxiliary circuits as well as to give protection.

Fig. 14 shows a type of commutating switch used in 2400-volt service to transfer the motor connections between the series and parallel groupings. The two handles at the right of the illustration are used individually to cut out a pair of motors and constitute the motor cutout switch feature as previously explained.

Rheostats

The rheostat used as external resistance to the main motors is of the cast iron type with grids mounted together on a frame. The grids are insulated from the supporting rods, and from each other where necessary, with mica. The cast iron has a relatively low temperature coefficient insuring a comparatively uniform resistance value during normal operation. Fig. 15 shows a locomotive rheostat with grids that are readily removable after loosening, but not disconnecting, the through bolts. The same type of grid rheostat, varying with capacity, is used up to 2400 volts. In all cases it is intended that the box be mounted on suitable insulators adapted to the trolley voltage.

The rheostats should be installed with the view of gaining the best possible natural circulation. It is unnecessary to artificially blow the rheostats, except in cases where a poorly ventilated position has been provided. Blowing the rheostats artificially does not give the proper returns unless the operation is more continuous than is usual with locomotives of these classes.

In figuring rheostat capacity the operation during cold weather with long trains where the starting friction is high is the limiting feature to keep in mind. The rheostats must carry current up to the slipping point of the wheels at 30 per cent coefficient of adhesion for reasonable periods depending upon the service.

There are also the rheostats used in circuits of smaller capacity. The type required in series with the operating coils of contactors is made up in a cylindrical form having a fired mica body over a metal sleeve. A wire possessing a low temperature coefficient is the resistance element and is wound around the form. After winding, the tube is dipped into an insulating compound and then baked, making the tube practically moisture-proof. The resistance wire terminates at metal bushings which permit the use of the tube in standard fuse clips mounted on an insulated base. When so mounted the tube is open to easy inspection and replacement.

The ohmic resistance of the contactor rheostat tubes is chosen so that these units and the contactor coils may be connected into circuit interchangeably. The number of contactor switches closing on the different controller points vary, so that, in order to maintain the proper ampere-turns in the coils, which are grouped in series, a substitute resistance of approximately the same ohmic value as the coils is necessary.

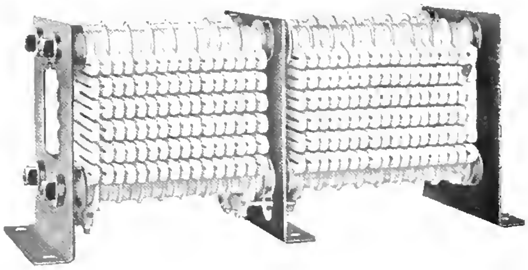


Fig. 15. Rheostat

A type of rheostat of slightly larger capacity and with better insulation than the tube used in conjunction with the contactor coils is required in some of the auxiliary circuits. This unit consists of a bare, non-corrosive wire of low temperature coefficient wound on grooved porcelain insulating supports. The porcelain supports in turn are mounted on rust-proof sheet metal punchings arranged for assembling on frames By insulating the frames from ground and between groups, this unit may be used at voltages up to 2400. The frames are installed in a grounded iron box.

Electrical Connections

The simplified diagrams, see Table II, show the control connections used with the traction motors of the different classes of locomotives under consideration:

TABLE II

Illustration	Controller	Class of Locomotive	Trolley Voltage
Fig. 16	C 74	20– 40 tons	600
Fig. 17	C 74	20– 40 tons	1200/1500
Fig. 18	C 90	40– 60 tons	600
Fig. 19	C 90	40– 60 tons	1200/1500
Fig. 20	C 93	60–100 tons	2400
Fig. 21	C 83	40– 60 tons	600
Fig. 23	C 79	60–100 tons	600

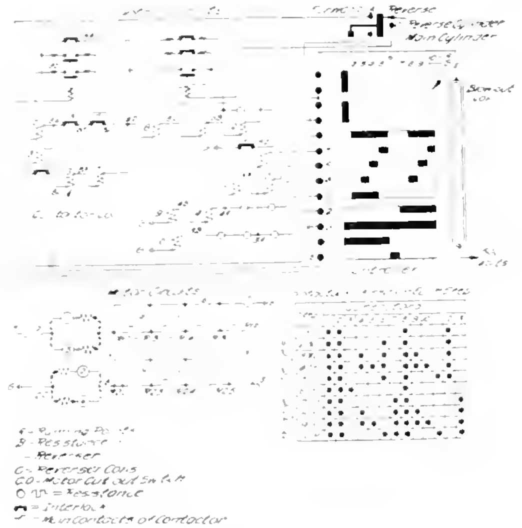


Fig. 16. Simplified Connections with C 74 Controller, 600 Volt Trolley

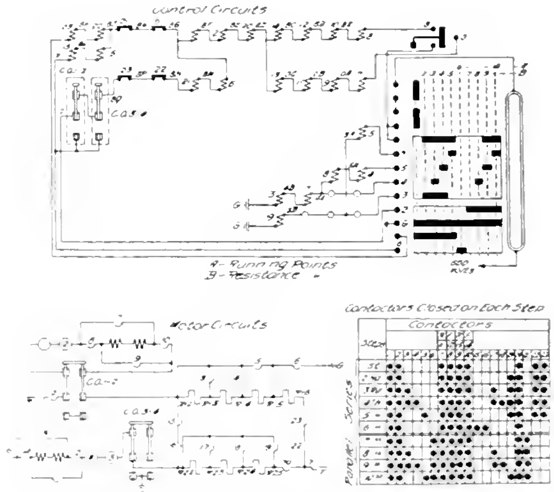


Fig. 17. Simplified Connections with C 74 Controller 1200 Volt Trolley

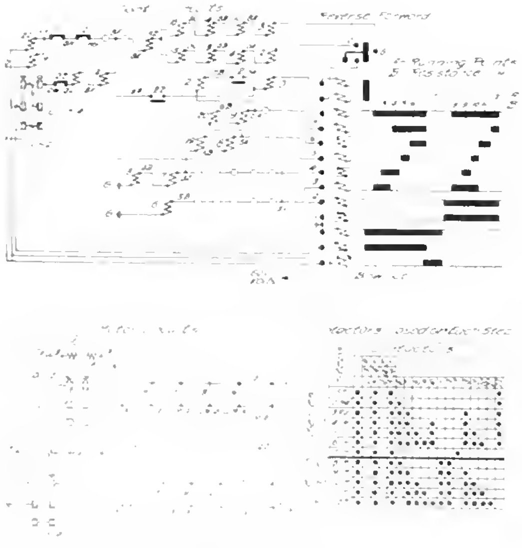


Fig. 18. Simplified Connections with C 90 Controller, 600 Volt Trolley

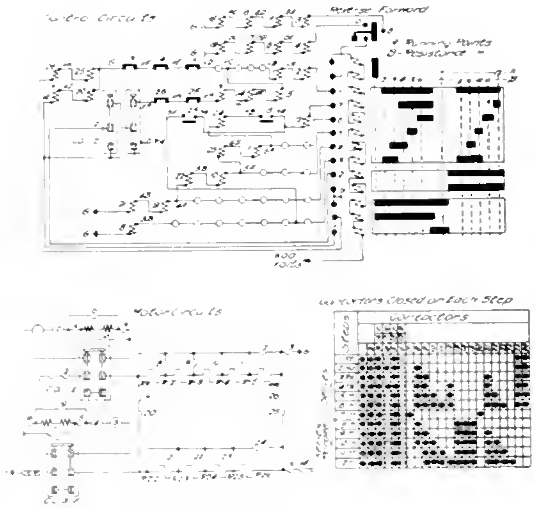
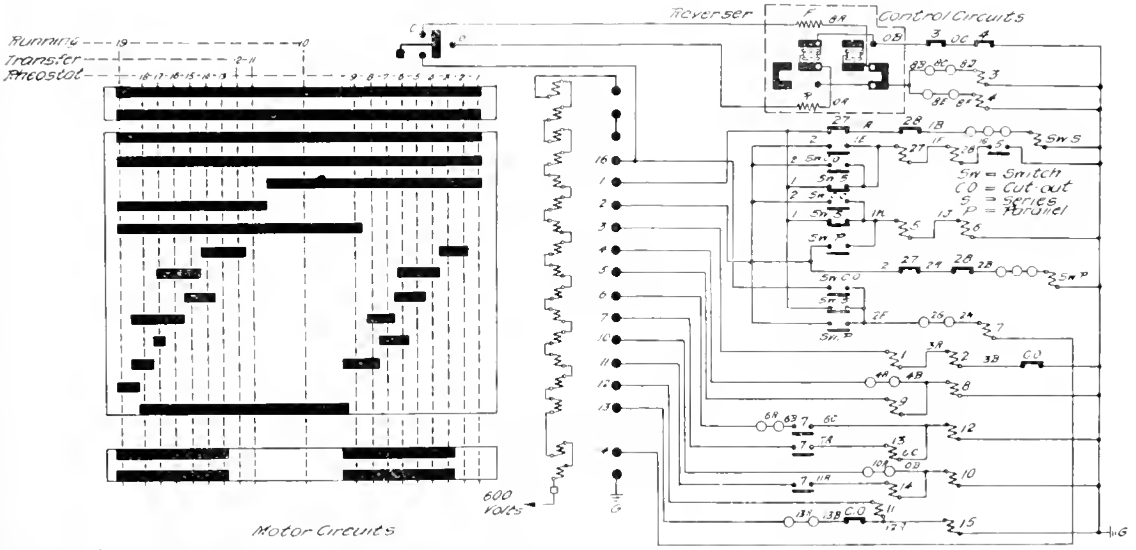


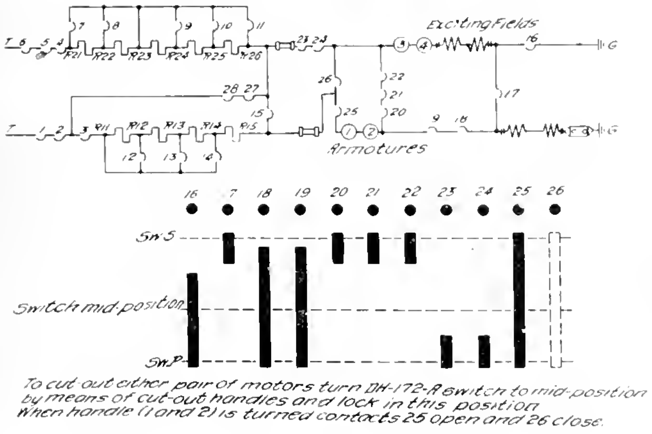
Fig. 19. Simplified Connections with C 90 Controller, 1200 Volt Trolley

The accompaying diagrams show the electrical circuits both with respect to the master controller and the motors. Any locomotive which must operate at two trolley potentials, involves the use of a commutating switch similar to Fig. 13. The basic connections for this and other modifications, however, may be taken from these diagrams.

Figs. 23, 24, 25 and 26 show respectively, typical speed tractive-effort curves for locomotives using the C 90, C 93, C 83 and C 79 controllers.

From these characteristic curves of standard motors, plotted to a constant trolley voltage; a fixed gear ratio and wheel diameter, the variations in speed, torque and amperes during a typical acceleration, may be noted. The curves show how the increments in torque, in passing from one point to another, vary with respect to any desired accelerating current and they show this variation with respect to the slipping point of the wheels. It is a matter of experience that the increments in torque in going from one point to another as the impressed voltage is increased should not exceed 10,000 lb. per locomotive. This takes into consideration the possibility of using one or more locomotives





Contactors Closed on Each Step

Steps		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Series	1st			●	●	●	●											⊗			⊗	⊗	⊗			⊗		●	●
	2nd			●	●	●	●		●									⊗			⊗	⊗	⊗			⊗		●	●
	3rd			●	●	●	●	●	●									⊗			⊗	⊗	⊗			⊗		●	●
	4th			●	●	●	●	●	●	●								⊗			⊗	⊗	⊗			⊗		●	●
	5 "			●	●	●	●	●	●	●			●					⊗			⊗	⊗	⊗			⊗		●	●
	6 "			●	●	●	●	●	●	●	●		●					⊗			⊗	⊗	⊗			⊗		●	●
	7 "			●	●	●	●	●			●		●	●				⊗			⊗	⊗	⊗			⊗		●	●
	8 "			●	●	●	●	●			●		●	●	●			⊗			⊗	⊗	⊗			⊗		●	●
	9 "	●	●	●	●	●	●	●			●				●			⊗			⊗	⊗	⊗			⊗		●	●
	10 "	●	●	●	●	●	●									●		⊗			⊗	⊗	⊗			⊗		●	●
Switch Transfer	1st Posit.	●	●	●	●											●		⊗			⊗	⊗	⊗			⊗			
	2nd "	●	●	●	●											●			⊗	⊗						⊗			
	3rd "	●	●	●	●											●	⊗		⊗	⊗						⊗			
	4th "	●	●	●	●											●	⊗		⊗	⊗				⊗	⊗	⊗			
Trans.	11th	●	●	●	●	●	●									●	⊗		⊗	⊗				⊗	⊗	⊗			
	12 "	●	●	●	●	●	●		●							●	⊗		⊗	⊗				⊗	⊗	⊗			
Parallel	13 "	●	●	●	●	●	●	●	●							●	⊗		⊗	⊗				⊗	⊗	⊗			
	14 "	●	●	●	●	●	●	●	●				●			●	⊗		⊗	⊗				⊗	⊗	⊗			
	15 "	●	●	●	●	●	●	●	●	●			●			●	⊗		⊗	⊗				⊗	⊗	⊗			
	16 "	●	●	●	●	●	●	●	●	●			●	●		●	⊗		⊗	⊗				⊗	⊗	⊗			
	17 "	●	●	●	●	●	●	●	●	●	●		●	●		●	⊗		⊗	⊗				⊗	⊗	⊗			
	18 "	●	●	●	●	●	●	●			●		●	●	●	●	⊗		⊗	⊗				⊗	⊗	⊗			
	19 "	●	●	●	●	●	●	●				●				●	⊗		⊗	⊗				⊗	⊗	⊗		●	●

⊗ = DH-172-A Switch

Fig. 20 Simplified Connections with C 93 Controller, 2400 Volt Trolley coupled together and operated as a unit. Furthermore, the first point of the controller, when making the start, should give less than 10,000 lb. tractive effort. While it would be possible to handle the locomotive satis-

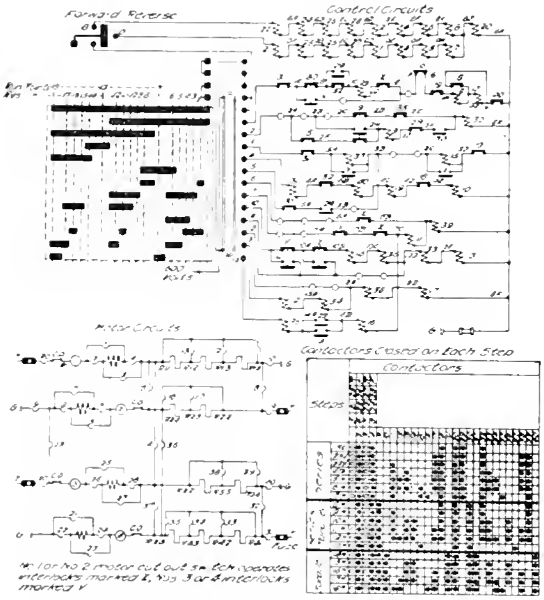


Fig. 21. Simplified Connections with C 83 Controller, 600 Volt Trolley

factorily, running light, with a higher torque on the first point, it would be undesirable because it necessitates throwing the controller "on" and "off" frequently. When a locomotive is starting a long train, it is desirable to take up the slack slowly in order not to jerk the last cars in the train. Experience shows that the best results are obtained when the starting torque is less than 10,000 lb.

In choosing the various amounts of external resistance, the points in parallel serve as a basis, since with these points properly proportioned, it is comparatively simple to make connections using the same resistance, to give a good acceleration in the series groupings. The points of the control are therefore based on the motor requirements in parallel operation. In case of two speed control, it is necessary to provide an additional resistance step, for the first point, to give the low starting torque required for switching or for starting long trains. For three speed control, it is unnecessary to provide extra external resistance for the starting point, since the first point is already brought to a low value by the reduction in voltage due to the extra motor grouping.

The transfer between different motor groupings, that is, between series, series-parallel, parallel, etc., is effected in two ways; one where power is applied continuously to all the motors and resistance is balanced against the motors at the time of transfer, as shown in Fig. 16, and where one group of motors is short circuited in making the transfer as shown in Fig. 20. The former is known as the bridge connection and if the transfer is made at a predetermined current, there is no appreciable reduction in torque. In the latter case the torque during transfer falls to approximately one-half value as the motors are short circuited. In order to smooth out the acceleration in this case, an extra resistance point is provided in parallel. As the locomotive falls in torque during the transfer, it may recover to this extra resistance value without affecting the acceleration materially.

Practice has shown that the transfer is seldom made in the case of bridge control on a locomotive, at the predetermined current value and as any variation causes a change in torque, there is no great advantage in the bridge control over the other type. The connection where the motors are short circuited, is simpler and allows more flexibility in selecting the rheostats and providing maximum capacity in them.

It has been found advantageous to combine the bridge connection and the short-circuited motor connection, in case of three speed operation as shown in Figs. 21 and 22. The transfer from series to series-parallel is made by short circuiting one-half the motors; the transfer between series-parallel and parallel by the standard bridge connection.

In establishing the number of points in parallel, it is necessary to first determine the correct total external resistance required in series with an individual motor during parallel operation at the time of transfer. We can assume that the locomotive should accelerate at approximately 20 per cent coefficient of adhesion. It is desirable then to figure the transfer current somewhere between 20 and 25 per cent so that at the time of maximum acceleration, the torque increment is a minimum. Since with the bridge control, the current in the external resistance must equal the current through the motors at the time of transfer, we can determine this total resistance for any trolley voltage. The speed

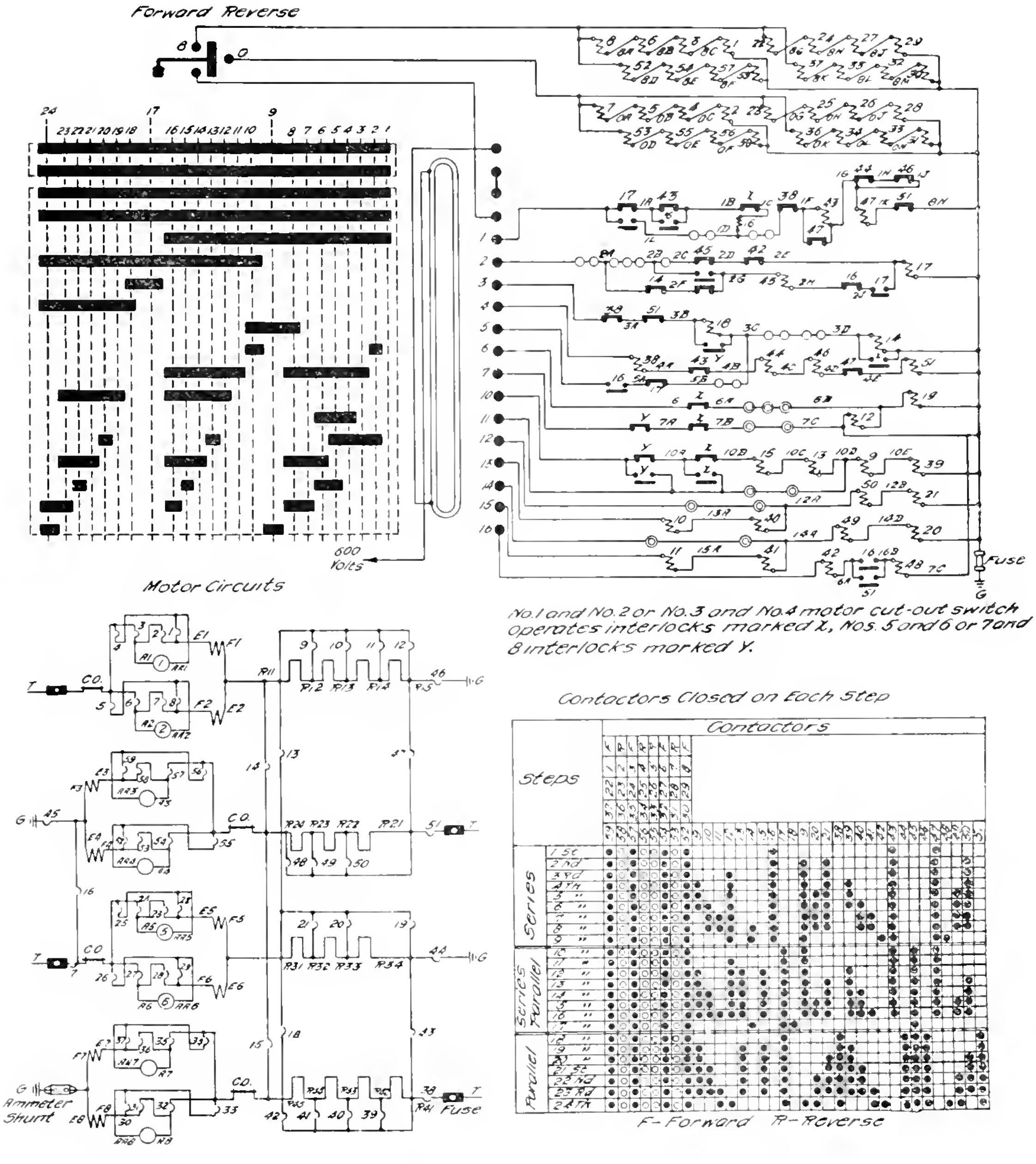


Fig. 22. Simplified Connections with C 79 Controller, 600 Volt Trolley

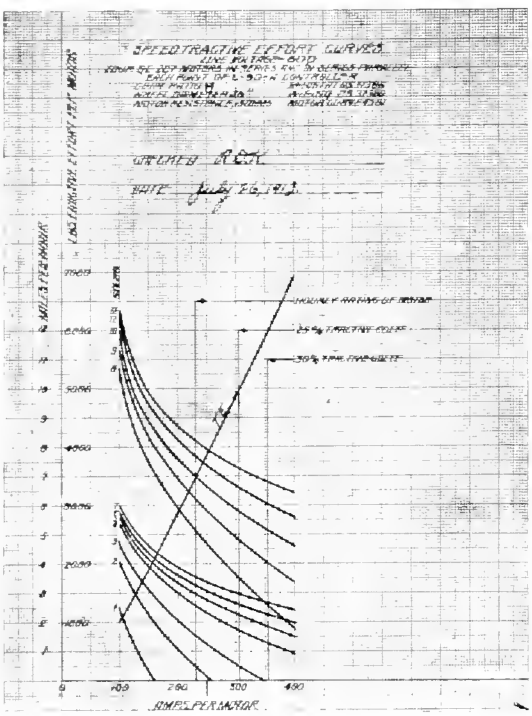


Fig. 23. Typical Speed Tractive Effort Curves for Each Point with C 90 Controller

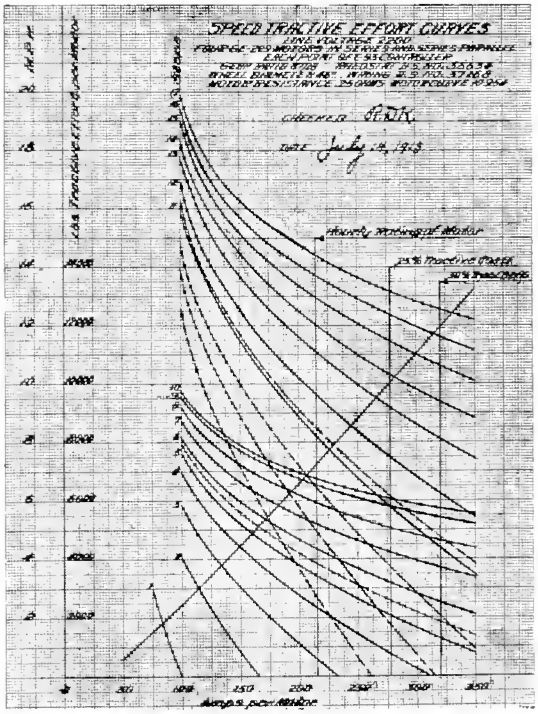


Fig. 24. Typical Speed Tractive Effort Curves for Each Point with C 93 Controller

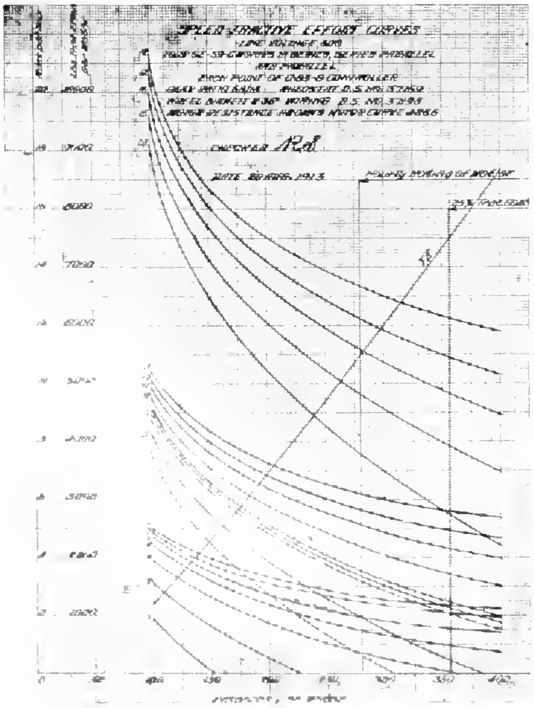


Fig. [illegible] Typical Speed Tractive Effort Curves for Each Point with C 83 Controller

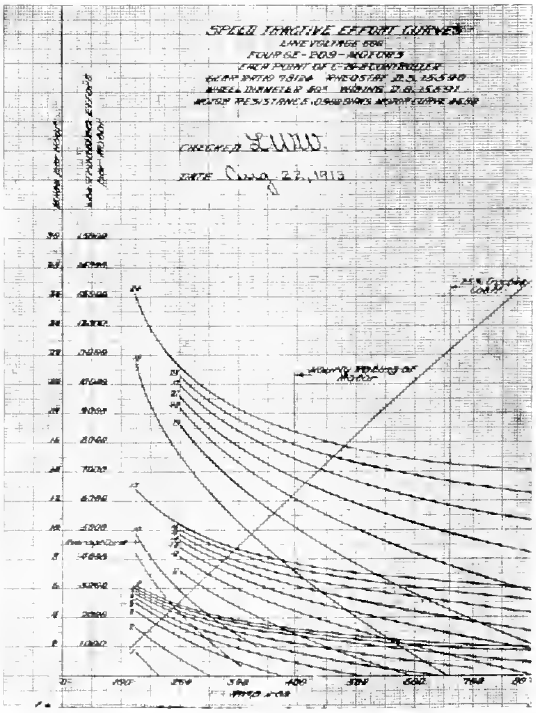


Fig. 26. Typical Speed Tractive-Effort Curves for Each Point with C 79 Controller

tractive-effort curve may be drawn, see Fig. 25, point 14, for this resistance value at constant line potential. The points of this curve are based upon the theory that the speed of the locomotive for any current value in the motors, is proportional to the counter e.m.f. of the motor. With this first resistance value established and the speed tractive-effort curve of any particular motor plotted for a given gear ratio, wheel diameter, etc., the intermediate points may be chosen graphically to give the desired increments of tractive effort between points. It is desirable that these increments do not exceed 10,000 lb. when the peak points approach currents corresponding to 30 per cent coefficient of adhesion.

The dotted lines on the speed tractive-effort curves show either transitional points or where the motor resistances are different between motors in order to secure the desired increment in torque. The numbers at the left of each curve indicate the effective points corresponding to the points on the controller dial.

To one interested in the detailed functions of the electrical connections, a study of the characteristic curves and simplified diagrams will give a better understanding of the points, which the writer wishes to bring out, in reference to contactor-breaks in series for different voltages; number of contactors; changes in torque during acceleration; selection of resistance values for points in parallel and methods of transfer, which come under this heading for interurban locomotives. The typical characteristic motor curves show particularly the current values with respect to the slipping point of the drivers and how nearly the controlling equipment meets the essential requirement of a smooth acceleration throughout all the steps of increased voltage as applied to the traction motor terminals.

FORCES IN ELECTRIC LOCOMOTIVES INFLUENCING WHEEL FLANGE AND TRACK WEAR

By A. F. Batchelder

Engineer, Railway Locomotive Department, General Electric Company

So far as we know, this is the first time that this important subject has been dealt with in this definite manner. Mr. Batchelder is an authority on locomotive design, and we believe the results he gives and his brief, direct method of determining his values will be of much use to those wishing to learn something definite about this much discussed and very important subject.—Editor.

One of the many advantages incident to the electric locomotive is the fact that it is possible to use its entire weight for traction purposes and thus effect a saving in the total train weight. It is also possible to construct the running gear so that it can operate around curves of very short radius without the use of special guiding trucks not supplied with power.

In the lighter locomotives this can be accomplished with satisfactory results by constructing a running gear similar to the ordinary double truck interurban car and applying a motor to each of the four axles.

In the heavier locomotives of the four axle type, more consideration must be given to the design of the running gear in order to eliminate, as far as possible, the wear of its parts and of the track. The wear of the wheel flanges and of the inside of the track rail are among the important points to consider. Both of these are effected by the same conditions and a remedy for one is also a remedy for the other.

With slow speed heavy locomotives that are well constructed, the tendency to flange and rail wear is most pronounced when operating on curves.

It is the purpose of this article to make clear how, by constructing a four axle locomotive with two trucks connected together by a hinge joint, the forces which tend to effect the wear of the wheel flanges and the inside of the track rail are lessened, as compared with other four axle locomotives with two trucks connected by the body through the center pins, or with four axle locomotives constructed with a rigid frame. In making these comparisons, the end play of the axles is not taken into consideration; but this, no doubt, can be arranged to lessen the forces to some extent in the rigid type.

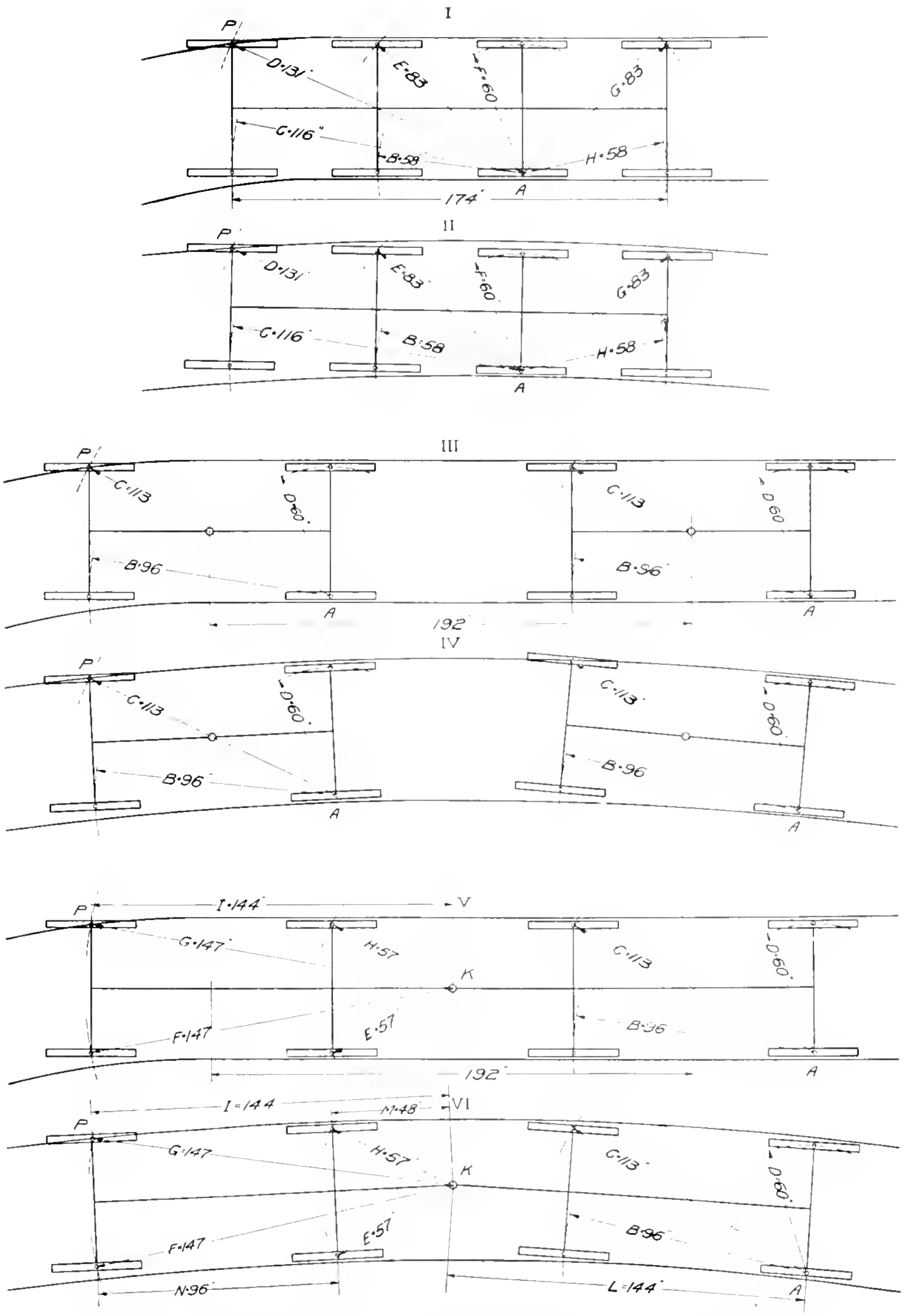
When a locomotive enters a curve from a tangent track or is rounding a curve the change of direction of motion is accompanied by a continual slipping of the wheels across the rails. The force to slip the wheels is applied at the flange of the leading outer wheel of each independent truck, if not otherwise guided. The force required to slip the wheels is dependent upon the coefficient of friction between the tread of the wheels and the rail head, and as this value changes with the conditions of the surfaces, absolute values cannot be used. Therefore, 25 per cent of the weight at the wheel tread will be assumed for this value; and for the purpose of dealing with concrete values, a locomotive weighing 60 tons and having four axles and 15,000 lb. per wheel will be used for the purpose of illustration. Diagrams of each of the different locomotives have also been prepared to show the relative dimensions and the values of the forces on entering a curve, and also when operating on a curve.

Diagram I illustrates a rigid four axle locomotive entering a curve. The inner wheel of the third axle can be considered as the pivot point A, and all the other wheels must be slipped about this as a center with the force applied at the outer leading wheel flange P. This force is equal to the sum of the distances of all the wheels from the pivot, multiplied by the weight per wheel and by the coefficient of friction, and divided by the horizontal distance from the pivot point to the leading axle center, and can be expressed

Force at P

$$= \frac{(B+C+D+E+F+G+H) \times 15{,}000 \times 0.25}{C}$$

$= 19{,}040$ lb.



Figs. 1–6. Diagrams of Various Truck Arrangements, Showing Points of Application of the Forces Developed in Taking Curves

Diagram II illustrates the rigid four axle locomotive operating on a curve. In this case the pivot A and the point of applied force P and the values of the force are the same as in Diagram I.

Diagram III illustrates the two-truck four-axle locomotive entering a curve. In this case the inner rear wheel of the front truck serves as a pivot point A and the force necessary to slip the front truck around is applied at the outer leading wheel flange P. This force is equal to the sum of the distances of all the wheels of the front truck from the pivot point, multiplied by the weight per wheel and the coefficient of friction, and divided by the horizontal distance from the [illegible] to the leading axle center of the [illegible] and can be expressed

$$\text{[illegible]}\ P = \frac{B+C+D \times 15{,}000 \times 0.25}{l}$$

$$= 10{,}507 \text{ lb.}$$

Diagram IV illustrates the two-truck, four-axle locomotive operating on a curve. In this case both the front truck and the rear truck have the same relative pivot points A, points of applied force P, and force values as the front truck in Diagram III. The force values are equal to 10,507 lb. for each truck.

Diagram V illustrates the articulated two-truck four-axle locomotive entering a curve. In this case the joint K between the trucks serves as the pivot point for the front truck, and the force necessary to slip the front truck around is applied at the outer wheel flange P. This force is equal to the sum of the distances of all the wheels of the front truck from the pivot point, multiplied by the weight per wheel and by the coefficient of friction, and divided by the horizontal distance between the pivot point and the leading axle center of the front truck and can be expressed:

$$\text{Force at } P = \frac{E+F+G+H}{l} = 10{,}625 \text{ lb.}$$

Diagram VI illustrates the articulated two-truck four-axle locomotive operating on a curve. In this case the inner rear wheel of the rear truck is the pivot point for the rear truck, and the force necessary to slip the truck around is applied to the joint K between the two trucks. This force is equal to the sum of the distances of all the wheels of the rear truck from the pivot point, multiplied by the weight per wheel and by the coefficient of friction, and divided by the distance from the pivot to a line parallel to the axles through the joint K between the trucks, and can be expressed

$$\text{Force at } K = \frac{(B+C+D)\ 15{,}000 \times 0.25}{L}$$

$$= 7000 \text{ lb.}$$

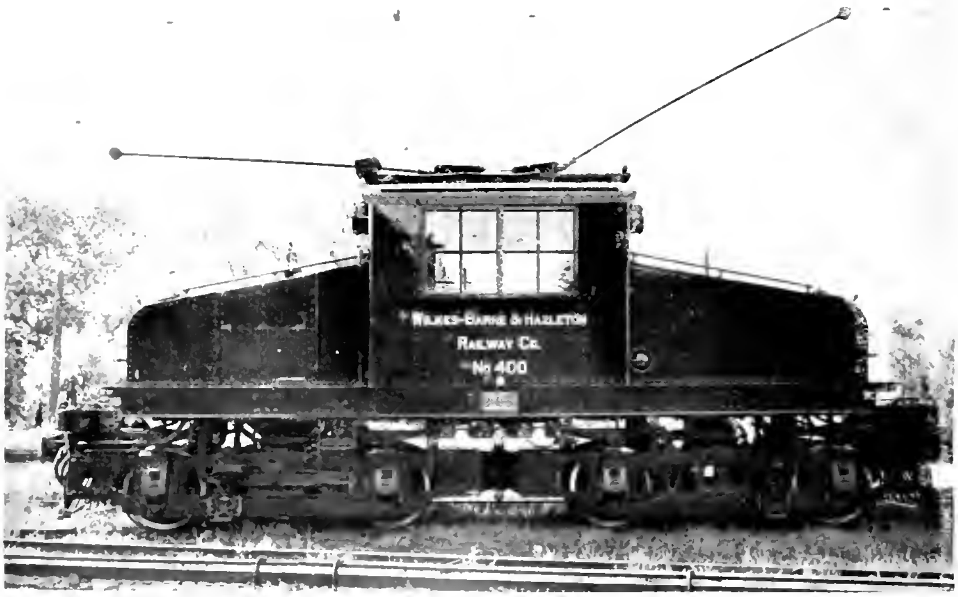


Fig. 7. A 60 Ton Articulated Truck Locomotive

The reaction against this force tends to slip the rear wheels of the front truck outward, and the leading wheels of the front truck inward; the resultant of this reaction at the leading outer wheel is equal to the force at the joint K multiplied by the distance from the joint to the rear axle of the front truck; and divided by the distance between the axle centers of the front truck, and can be expressed

Resultant reaction at P

$$=\frac{\text{force at } K\times M}{N}=3500 \text{ lb.}$$

The pivot point K and the point of applied force P of the front truck are the same as in Diagram V, but the force value is changed by the resultant reaction at P, which is in the opposite direction; therefore,

Resultant force at the outer leading wheel flange P is

$$10625-3500=7125 \text{ lb.}$$

It will be seen by these values that, with the four-axle rigid locomotive, greater relative wear due to this influence should be expected at the point of entering the curve and also on curves throughout their entire length.

With the four-axle locomotive having two independent trucks connected together by the body through center pins, much less wear should be expected, notwithstanding that the force is applied in two places, that is, on the outer leading wheel of each truck; while with the four-axle locomotive with articulated truck very little wear should be expected on the curves throughout their entire length as the force to slip the wheels is less and is applied only at the outer leading wheel of the front truck. Although at the point of entering the curve the force is slightly greater than with the independent trucks, the average wear due to this influence should be much less than with either of the other types.

Fig. 7 is from a photograph of a 60-ton two-truck, articulated, four-axle locomotive of the same dimensions as illustrated by Diagrams IV and V. This locomotive was built by the General Electric Company, for the Wilkes-Barre & Hazleton Railway Company, and is in regular operation hauling freight trains over their interurban lines.

THE COST OF OPERATING ELECTRIC SWITCHING LOCOMOTIVES

By S. T. Dodd

Railway and Traction Engineering Department, General Electric Company

The relative cost of operating steam and electric switching locomotives has been attracting considerable attention in recent years. The author has collected the most important data available and, after making a careful analysis of these, has given a summary of his investigations. The results are very satisfactory from the electric locomotive standpoint. The fact that the author himself has been responsible for carrying out some of the tests cited will add weight to the conclusions arrived at.—Editor.

The question of the comparative cost of operating steam and electric locomotives, in similar service, is one which is frequently raised. In particular, the cost of such locomotives in switching service has so often been presented to the writer that he has felt it would be of general interest to tabulate the fundamental data; and, after giving references to those tests which have been published and assuming the conditions of a particular case, to work out the results and then show the comparative costs of operation of a steam locomotive and an electric locomotive of the same capacity performing the same service. The conditions which have been assumed in the present article are the following:

The service to be purely switching work, such as would be encountered in railway terminals or in industrial yards.

The weight of the locomotive to be 50 tons, all on drivers; the same weight being assumed for both steam and electric locomotives. It is probable that a steam locomotive of this weight would have additional weight on the leading trucks and tender, which would increase the tonnage moved and the consequent cost of operation above the figures which we are presenting; but we have assumed for our case that all of the weight of the steam locomotive is on the drivers.

References

A number of investigations and tests have been made bearing on various phases of this subject, and as a consequence the fundamental data which must be referred to are scattered in a number of articles in various publications. For the sake of brevity and for convenience in reference, the writer has tabulated below the principal tests to which he will refer, and has given a brief reference to the publications in which they will be found and to the ground covered by each.

"N.Y.C. Tests." A paper by W. J. Wilgus, entitled "Electrification of the Suburban Zone of the N.Y.C. & H.R.R.R. Co.," published in the A.S.C.E. Transactions, Vol. 61, gives a tabulation of the results of steam and electric locomotive performance in doing switching and hauling work around the New York terminals, and tabulates such figures as the tonnage handled per hour, amount of coal per ton mile used by steam locomotives, and the watts per ton mile used by electric locomotives.

"New Haven Tests." Mr. W. S. Murray under the heading "Electrification Analyzed. Its Practical Application to Trunk Line Roads," published in the proceedings of the A.I.E.E., April 7, 1911, has given an analysis of the costs of handling freight and passenger service by steam and electricity on the N.Y., N.H. & H.R.R.

"Pittsburg Tests." A paper by D. C. Hershberger upon "The Service Required of Switching Locomotives in Industrial Yards." Elec. Journal, October 11, 1912, gives the results of tests on steam switching engines in the yards of the Westinghouse Electric and Manufacturing Company at East Pittsburg and an analysis of these results.

"Fort Dodge Tests" Under the heading "Freight Train Tests on an Electric Interurban Railway," published in the proceedings of the A.I.E.E., May 17, 1912, the writer has discussed the service of an electric locomotive handling freight and doing switching service on the Fort Dodge, Des Moines and Southern R.R.

"M.M. Assn. Tests." In the Proceedings of the Railway Master Mechanics Association for 1905 is published the report of a committee appointed to investigate the distribution of time of a steam locomotive in service. These tests cover a period of one month and give the time during which the locomotive was in service and the time consumed by various delays incident to operation.

"Trunk Line Electrification." A paper under the above heading by C. P. Kahler, published in the proceedings of the A.I.E.E., May 20, 1913, gives a number of records of the expenses and distribution of time of steam locomotives on western roads.

Some other sources have been drawn on for data, and are referred to in the body of the article. The following table gives a comparison of the weights of the locomotives to which the various tests refer.

	Weight	
	On Drivers	Total
"N.Y.C. Tests" steam switching engine	152,500	244,000
"N.Y.C. Tests" steam road engine	156,000	342,500
"Pittsburg Tests" steam switching engine	92,000	105,400
"N.Y.C. Tests" electric engine	139,000	189,000
"Fort Dodge Tests" electric engine	82,000	82,000

Mileage in Service

In order to make an estimate of the service capacity of our assumed locomotives, the following figures are obtained from the tests to which we have referred.

	Average Speed	
	Steam	Electric
"N.Y.C. Tests" switching Grand Central	6 m.p.h.	5.56 m.p.h.
"N.Y.C. Tests" switching Harlem Division	5.55	7.3
"N.Y.C. Tests" switching average	5.77	6.43
"Pittsburg Tests" switching	2.6	
"Fort Dodge Tests" switching		2.9

The "N.Y.C. Tests" were made on comparatively heavy locomotives in fairly extensive yards, and therefore the hourly mileage is greater than would be made by a locomotive in the service which we have assumed It seems fair to estimate a service of 3 miles per hour in our case.

Time Lost for Coal and Water

The "M.M. Assn. Tests" above referred to give figures from which an estimate can be made of the time spent by a steam locomotive in taking on coal and water, cleaning fires, etc. Quoting from this report, we have the following figures:

Total time of test	714 hr. 42 min.	100 per cent
Waiting to get over ash pits	52 hr. 51 min.	
Cleaning fires	12 hr. 6 min.	
Taking on coal and water	31 hr. 5 min.	
Delayed at ash pit	2 hr. 8 min.	
Coal and water on road	24 hr. 30 min.	
Cleaning fires on road	7 hr. 33 min.	
Delays due to coal and water	130 hr. 13 min.	18.2 per cent

It seems fair to assume, from the above, that 15 per cent of the time of a steam locomotive is consumed by taking coal and water and cleaning engine fires. Out of a 10 hour day, this would leave 8½ hours for service. The daily mileage made by the two locomotives for similar service would therefore be

Electric loco., 10 hours at 3 m.p.h.—30 miles.
Steam loco., 8½ hours at 3 m.p.h.—25.5 miles.

Time in Shop

A certain allowance must be made for overhauling and repairing both steam and electric locomotives. The repairing of electric locomotives is, without question, a far simpler matter than that of steam locomotives. In general, an electric locomotive can be maintained in operating condition by periodic inspections involving the cleaning and renewal of contactor tips, the inspection of brushholders, etc., and the occasional taking out of a pair of wheels or a set of bearings. The repairing of a steam locomotive is a more serious affair and involves turning cylinders, renewing crown sheets, replacing tubes and other work which involves a considerable detention of the locomotive in the shops. Kahler in his article "Trunk Line Electrification," after an analysis of the time spent in the shop and on the road, gives the following table as his estimate of the distribution of time in switching service.

	Steam Loco.		Electric Loco.	
	Per Cent Time	Days of Year	Per Cent Time	Days of Year
In shops	37.5	137	27.3	99
In service	62.5	228	72.7	266
Total	100	365	100	365

If we accept these figures as indicating approximately the number of days in service in the two cases, and keeping in view the daily mileage already assumed, we have the following:

Electric loco., total yearly mileage . . 7980.
Steam loco., total yearly mileage . . . 5800.

Wages

The steam locomotive will require an engineer and fireman, and we have charged wages of two men against the steam locomotive at $5.50 per day. The electric locomotive not being in trunk line service can be handled by one engineer. The switching and coupling, which is the only additional service around the locomotive, will naturally be handled by the regular train crew, and we have not included wages of train crew in our comparative costs. We have charged wages against the electric locomotive at $3.50 per day.

Tonnage Handled

The following data can be tabulated as the results of the various tests to which we have referred.

	Steam	Electric
"N.Y.C. Tests"		
Ton miles per hr. trailing	501	445
Ton miles per hr. engine	929	585
Ton miles per hr. total	1430	1030
Percentage trailing to total	35%	46%
"Pittsburg Tests"		
Ton miles per hr. trailing	331	
Ton miles per hr. engine	138	
Ton miles per hr. total	469	
Percentage trailing to total	71%	
"Fort Dodge Tests"		
Ton miles per hr. trailing		511
Ton miles per hr. engine		119
Ton miles per hr. total		630
Percentage trailing to total		81%

Apparently, in the "N.Y.C. Tests" there were a greater percentage of light engine runs than are indicated by the other tests, and it would seem that a fair assumption of the tonnage handled by a switching locomotive, such as we have in mind, would be the following:

Ton miles per hr. trailing	450
Ton miles per hr. engine	150
Ton miles per hr. total	600
Percentage trailing to total	75%

Cost of Coal and Power

The amount of coal used by a switching locomotive is rather difficult to calculate. In through freight or passenger service, the results of calculations, based on the calorific value of the coal, agree fairly well with the results of tests of the amount of coal used; but in switching service, the losses at standstill and starting are such a large proportion of the whole, that the amount of coal used is far in excess of what would be used to handle the same tonnage in through service. A convenient table of coal per ton mile is presented in a book entitled, "Electric Traction for Railway Trains," by E. P. Burch, on page 82. This table shows the coal used per ton mile for various roads and various services. It runs from 0.06 lb. for freight trains on the Penn. R.R. to 0.89 lb. for mountain freight service on the Great Northern. Compared with these, we have from our references, the following data:

POUNDS OF COAL PER TON MILE

"New Haven Tests" freight	0.169 lb.
"New Haven Tests" pass. express	0.194 lb.
"New Haven Tests" pass. local	0.335 lb.
"N.Y.C. Tests" Mott Haven, road service	0.35 lb.
"N.Y.C. Tests" Harlem Div., road service	0.6 lb.
"N.Y.C. Tests" Grand Central, switching	1.19 lb.
"N.Y.C. Tests" Harlem Div., switching	2.42 lb.

For electric service, the watthours per ton mile have been checked both by calculations and tests for various weights of trains and character of service. This figure will run from 10 watthours per ton mile for steady speeds at low train friction to 100 watthours per ton mile at high train friction, or with frequent accelerations. Referring to our references, we have the following data:

WATTHOURS PER TON MILE

"N.Y.C. Tests" Mott Haven road service	33.9 W.H. per Tn. Mile
"N.Y.C. Tests" Harlem Div., road service	55.8 W.H. per Tn. Mile
"Fort Dodge Tests" freight road service	27.5 W.H. per Tn. Mile
"N.Y.C. Tests" Grand Central switching	121 W.H. per Tn. Mile
"N.Y.C. Tests" Harlem Div., switching	136 W.H. per Tn. Mile
"Fort Dodge Tests" freight switching	81.6 W.H. per Tn. Mile

In view of the figures given above for coal and current consumption, it seems that a fair figure to assume for the service which we have in view will be the following:

Steam loco. switching, 1.5 lb. coal per ton mile.
Elec. Loco. switching, 100 watthours per ton mile.

On the basis of service of 600 ton miles per hour, this is equivalent to 900 lb. of coal per hour, or 60 kw-hr. per hour, and, assuming the cost of coal at $3.00 per ton and electric current at $1\frac{1}{2}$ c. per kw-hr. at the locomotive, we get the following costs:

Steam loco., cost of coal per day . . $11.50.
Elec. loco., cost of current per day . . $9.00.

Oil, Waste, and Supplies

The records of locomotive reports on a number of steam roads in the United States show that the cost of oil, waste and supplies averages about 4 per cent of the fuel costs. A good deal less than this should be enough to cover the same items for the electric locomotive. We have accordingly made an addition of 5 per cent of the fuel cost for supplies on the steam locomotive and one-half of that amount for supplies on the electric locomotive.

Maintenance and Repairs

The *Railway and Engineering Review* has made some valuable compilations of the Interstate Commerce Commission's reports for a number of years, bearing on the subject of maintenance of equipment. The tables published in the issues of January 4th and August 2nd, 1913, show that on thirty roads in the United States the cost of maintenance per locomotive mile for the year 1912 runs from a minimum of 8.156 cts. per mile on the Chicago & North-Western to a maximum of 14.896 cts. per mile on the Santa Fe, with an average of 10.78 cts. per mile.

Kahler in "Trunk Line Electrification" presents some cost data upon a western road showing costs running from 6.95 cts. for Atlantic type passenger engines making 60,500 miles per year to 19.21 cts. for Consolidation helper engines making 14,500 miles. The maximum and minimum total yearly costs are $5550 for Pacific passenger engines weighing 192 tons and $1950 for ten wheel switcher engines weighing 110 tons.

For comparison with the above figures we have available the following data upon the cost of maintenance of electric locomotives in trunk line service.

N.Y.C. & H.R.R.R. electric locomotives maintenance less than 4 cts. per locomotive mile (Quereau, Railway Age Gazette, June 13, 1913).

Penn. R.R. electric locomotives maintenance 5.19 cts. per locomotive mile (Gibbs, Elec. Ry. Journal, March 23, 1911).

Penn. R.R. electric locomotives maintenance 6.62 cts. per locomotive mile (Elec. Ry. Journal, March 15, 1913).

Mr. Gibbs in quoting the figures given above compares this record of 5.19 cts. for the electric locomotives with a cost of 8.83 cts. for steam locomotives on the N.J. Div. of the P.R.R. and of 11.9 cts. for the average of steam locomotives on all of the divisions of the P.R.R.

These records show that apparently the electric locomotives have a maintenance cost of something less than one-half that of the steam locomotives. The records, however, are not taken upon locomotives in the same service and the service is not that which we are considering in our typical case.

For additional data the writer has collected the repair records of an industrial plant where a number of locomotives are used in purely yard switching service. This record extends over the years when the change was being made from steam operation to electric operation, and may illustrate more nearly than any of the above the cost of repairs in switching service. Unfortunately, no record has been kept of the tonnage or yearly mileage of the locomotives, but the record seems extensive enough to cover a fair average of the yearly costs.

Record of Repairs of Switching Locomotives

	LOCOS. IN SERVICE		YEARLY REPAIRS PER LOCO.	
	Steam	Electric	Steam	Electric
1905	2	2	503	344
1906	2	4	1681	371
1907	2	6	552	442
1908	2	7	507	133
* 1909	2	7	....	174
1910	1	7	....	352
1911		7	....	131
Average			811	278

* One month estimated.

Upon the basis of the yearly mileage which we have already decided upon for our typical service, that is, 5800 miles for the steam locomotive and 7980 miles for the electric locomotive, the costs given are equivalent to 11 cts. per mile for the steam locomotive and 3.5 cts. per mile for the electric locomotive. As these records seem to be most nearly comparable with our assumed service, it would seem fair to use 15 cts. per mile for steam and 4 cts. per mile for the electric locomotives to cover repairs in switching service

SUMMARY

The summation of our investigation is presented in the following table:

Cost of Electric and Steam Locomotive Switching

	Electric	Steam
Miles per hour	3	3
Hours per day	10	$8\frac{1}{2}$
Miles per day	30	25.5
Days per year	266	228
Miles per year	7980	5800
Ton miles per hour	600	600
Ton miles per day	6000	5100
Power and coal per ton mile	100 watts	$1\frac{1}{2}$ lb.
Cost of power and coal	$1\frac{1}{2}$ cts.	$3.00
Cost per day	$9.00	$11.50
COST PER MILE		
Wages	11.6 cts.	21.5 cts.
Power and fuel	30 cts.	45.5 cts.
Oil, waste and supplies	1.1 cts.	2.2 cts.
Maintenance and repairs	4 cts.	15.0 cts.
Total	46.7 cts.	84.2 cts.
Cost per day	$14.01	$21.47
Cost per year	$3740.00	$4895.00
Cost per 1000 loco. mi.	$467.00	$842.00

It is not intended that the totals presented in this table are to be used arbitrarily for any case that may present itself, but rather that the method of calculation should be used as a guide in discussing similar problems. The final results will, in any particular case, be so far affected by such fundamental conditions as the cost of coal, wages, power supply, amount of traffic and other conditions, that the total results cannot be accepted as any criterion of another problem; but the fundamental data has been collected in the hopes that it may be of use in working out similar problems.

RAILWAY ROTARY CONVERTER AND MOTOR-GENERATOR SUBSTATIONS

By A. R. Smith

Construction Engineering Department, General Electric Company

In view of the small amount of attention that in many cases is given to the buildings which house substation apparatus, the author presents a few general specifications for the design and construction of indoor and outdoor substations (including portable substations), and a comparison is made between the merits and costs of indoor and outdoor types. Figures are also given which show the approximate costs of buildings for different voltages and styles of construction. Recommendations are made respecting the location and installation of apparatus, and the provision of proper lighting, heating and ventilation.—Editor.

Railway converter substations may be divided into three general classes as regards the general design and arrangement of apparatus. These classes are city substations, interurban substations and portable substations.

No attempt will be made here to describe the design of city substations, because each substation presents a problem in itself. For example, the type of building will depend upon the nature of the contiguous buildings, the character of architecture used in the vicinity, the size of the building lot, the limited choice of locations for windows and entrances for apparatus and lines, the value of the land, etc. The arrangement of apparatus is likewise affected by similar local conditions.

On the other hand, interurban substations and portable substations can be standardized in so far as the general features are concerned, and these standards applied to individual cases with minor modifications.

Interurban Substations

In the past too little attention has been given to the proper design of the building which houses the substation apparatus. Inasmuch as the building is erected solely for the protection of the apparatus and, in the great majority of cases, is never used for any other purpose, every consideration should be given to the following important features of design:

First. The arrangement of the apparatus should be such as will economize space, because, if more space is allowed around the apparatus than is necessary when making repairs, it not only increases the cost of the building and wiring but is sometimes a detriment to operation.

Second. The building should be fireproof throughout and every arrangement should be made to protect one piece of apparatus from another, and to protect all of it from communication with external fire. In stations of the type described herein the transformers and oil switches are isolated from the converters and switchboard by a fire wall.

Third. Every provision should be made for the possible extension of the station, even though it appears that no future extensions will be necessary at the time the design is made. This refers to a symmetrical arrangement of apparatus on the unit system and the proper construction of the roof framing to make such extensions feasible.

Fourth. The building should be simple and substantial, with just sufficient paneling on the exterior to relieve the monotony of a plain wall. A good looking building can be built at the same cost as a poorly designed building, if sufficient attention is given to this subject.

Fifth. Good lighting and ventilation is of the utmost importance.

Portable Substations

Steel cars are now invariably used for portable substations and are recommended in all cases. The important factors in the design of a portable substation are as follows:

First. It should be fireproof throughout.

Second. The size of the car should be limited to the clearance dimensions of the local road on which it will be operated, and to the clearance of the steam roads over which the car will travel to its destination.

Third. The car design should be in accordance with the Interstate Commerce Commission's rules and the Master Car Builder's standards.

Fourth. Good ventilation is essential for both the apparatus and the operator.

Fifth. All apparatus should be securely anchored to the car floor and framing, so that

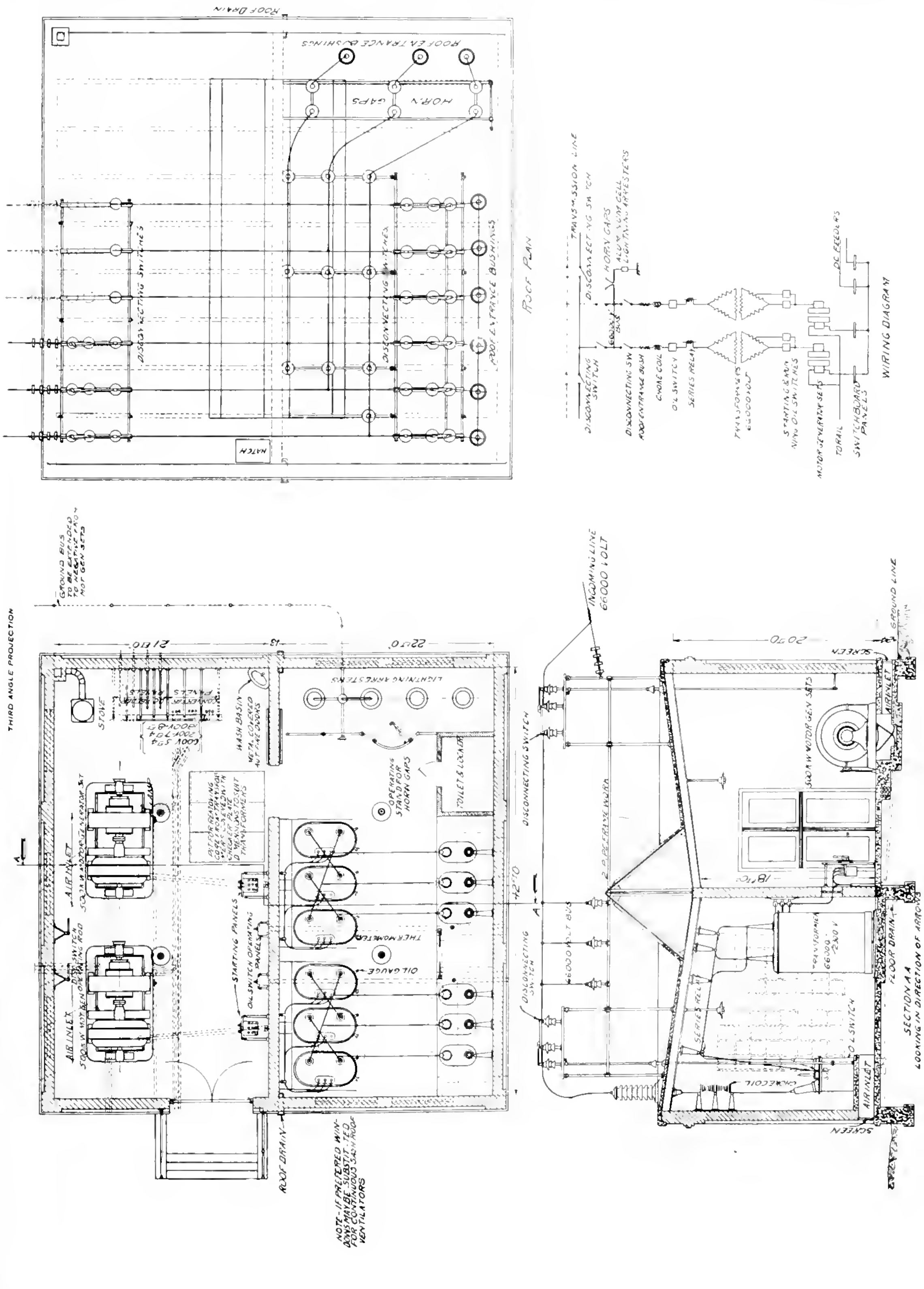


Fig. 1. Motor-Generator Substation with 66,000 Volt Incoming Lines

it will not shift or topple over unless it should meet with a destructive accident.

Sixth. Rotary converter and motor-generator sets should be arranged so that the shafts can be levelled when the car is standing on a grade or on an uneven track.

Seventh. All doors, windows, hatches, etc., should be made tight against all kinds of weather conditions.

In mild climates there is no serious objection to putting transformers, oil switches, and lightning arresters out of doors. In extremely cold climates where excessive snow falls are numerous, or in extremely hot climates, it is an open question if the amount of money saved in the initial cost is worth while. If oil-cooled transformers are used they have to be excited when standing idle to keep the oil from freezing when the temperature is down below 0 deg. F. Non freezing oil (that is, oil which freezes at a very low temperature) should be used in the oil switches when installed in cold climates. If water-cooled transformers are used, some means have to be provided for circulating water through the coils to keep the temperature of the idle transformers above 0 deg. F. The heat of the sun in warm climates materially reduces the capacity of the transformers and lightning arresters, unless they are shielded. Apparatus located out of doors will not receive as careful attention from the operators when the weather is severe, and consequently the liability of failure is greater.

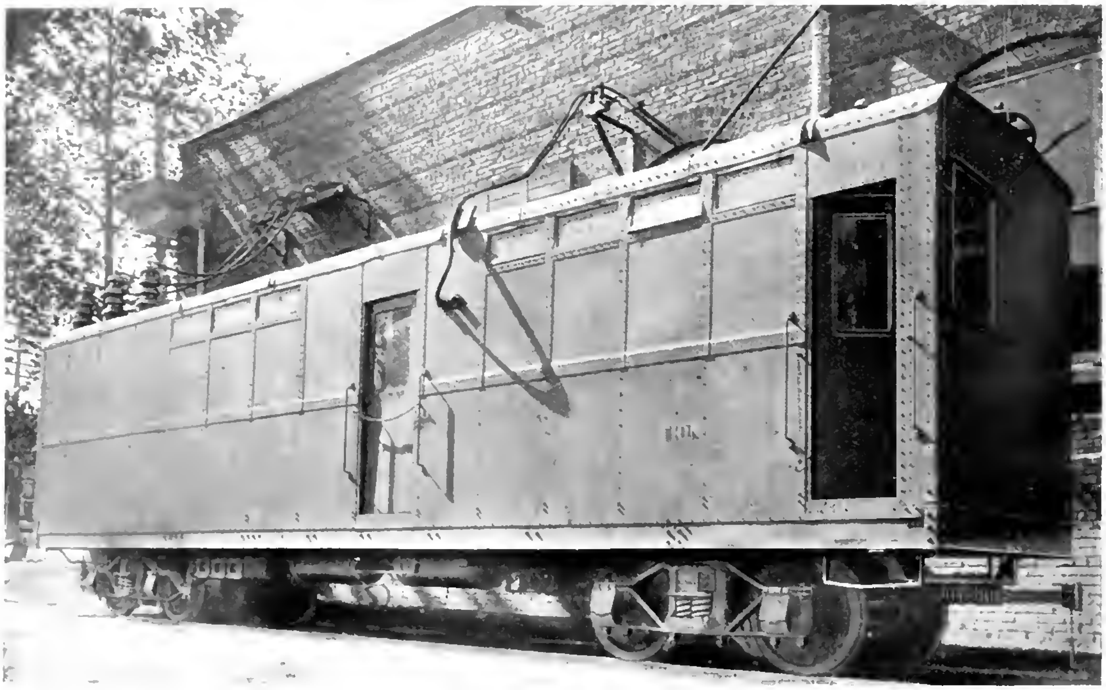


Fig. 2. Self propelled Portable Substation Built for the Georgia Railway & Electric Co. 6600 and 22,000 Volt A-C., 600 Volt D-C., 500 Kw.

Indoor *versus* Outdoor Substations

There has been a great deal of discussion as to the relative merits and costs of indoor and outdoor substation equipments. This applies more particularly to transformer substations, but the problem is now being seriously considered for converter substations. There is hardly an argument in favor of the outdoor substation except the reduction in the initial cost. Whether or not the outdoor substation is cheaper depends largely on the system of connections used, and numerous comparative estimates show that in some cases there is really no saving in the outdoor arrangement. On the other hand, certain installations will show a considerable saving.

Designs are shown herein for both the indoor and the outdoor stations for 66,000 volts. The cost of the building, including the roof bushings, for the 66,000 volt indoor station is $7565.00. The cost of the building for the outdoor station, including the necessary poles, the additional cost of outdoor bushings on the apparatus, the non-freezing oil in the oil switches, and the current transformers for the operation of the oil switches, is $7061.00. It will thus be seen that in this particular case there is a saving of $500.00 or only about 7 per cent on the cost of the building for the indoor design, or about 2 per cent on the total cost.

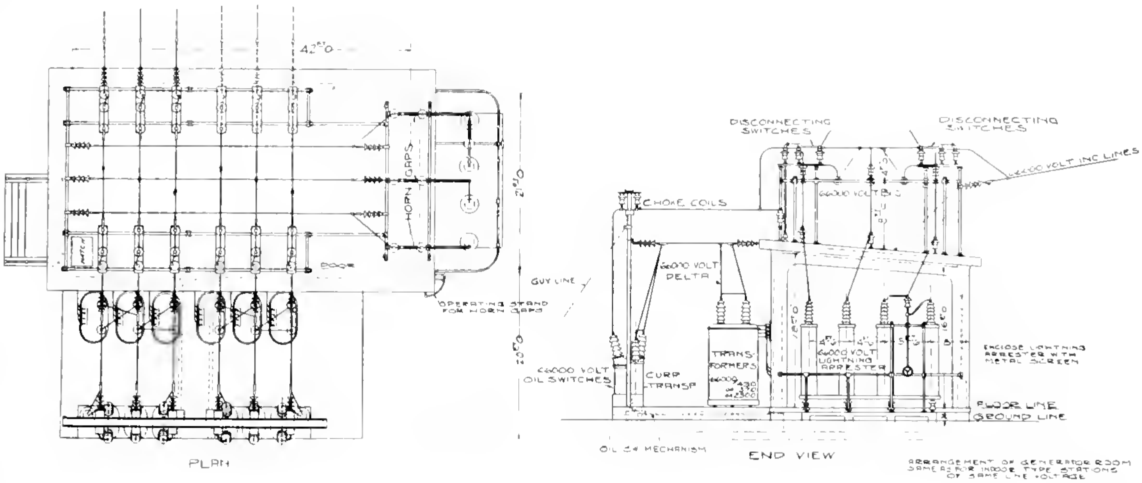


Fig. 3. Outdoor Substations with Same Equipment as Shown in Fig. 1

Building Construction and Costs

In the following tabulation is given the costs of the building complete, without plumbing, for the various voltages and for different types of construction. These costs will represent a fair average condition. In some localities where labor and material is high, the costs will be greater, and in localities where labor and material is exceptionally cheap, the costs should be less. Costs are given for tile buildings with stucco finish, and these costs will vary, depending on whether the tile is readily available or not; that is, in some places a tile building may actually cost more than a brick building.

Costs are given for buildings with a continuous metal sash monitor and without windows; without the monitor, and with metal sash windows; and also without the monitor and with wooden sash windows. The metal sash construction is, of course, preferable to the wooden sash.

These costs are based on the designs accompanying this article and provide for reenforced concrete roof with 5 ply felt, tar, and gravel; 13 inch walls of common red brick laid in

Voltage	Monitor Roof Brick Walls	Monitor Roof Tile Walls	Steel Sash Brick Walls	Steel Sash Tile Walls	Wooden Sash Brick Walls	Wooden Sash Tile Walls
			INDOOR DESIGN			
66,000	$6800.00	$6600.00	$6515.00	$6315.00	$6245.00	$6045.00
33,000	5900.00	5750.00	5635.00	5485.00	5415.00	5265.00
11,000	5650.00	5500.00	5345.00	5195 00	5125.00	4975.00
			OUTDOOR DESIGN			
66,000	. . . . .	. . . . .	$4500.00	$4400.00	$4285.00	$4185.00
33,000	. . . . .	. . . . . .	4500.00	4400.00	4285.00	4185.00

cement mortar; concrete floors; metal protected wood doors; all pits, foundations, steel work, and pipe framing, but not the plumbing or conduits.

Rotary Converters and Motor-Generator Sets

Rotary converters or motor-generator sets should be located over a pit in the floor, for several reasons. In these stations the pits serve as ventilators for the lower half of the machines, as practically all of the cold air is carried from the outside directly to the pit. The pit also acts as a drain for all conduits leading into it and makes the lower parts of the machine more accessible for repairs, besides providing space for the terminal connections of all the machine cables.

For machines of 750 kw. and smaller, which are usually shipped completely assembled, it is desirable to level the converter unit or motor-generator set for the proper end-play action before grouting. In the case of larger machines, where the base has to be set first, the machine should be made perfectly level for good end-play action.

The method of starting rotary converters has become so well standardized that there is no need for a description of the starting connections; however, the correct sequence of starting operations is not always correctly followed. The operations should be as follows:

1. Close high tension oil switch.
2. Close starting switch to one-third voltage.
3. When machine is up to speed, close field switch in the upper position, and observe voltmeter for correct polarity. If polarity is reversed, throw the field switch to lower position for a moment and again to the upper position and repeat this operation, if necessary, until correct polarity is obtained.
4. Throw starting switch quickly to two-thirds voltage.
5. Throw main starting switch quickly to full voltage position.
6. Close equalizer switch.
7. Close positive circuit breaker.
8. Regulate voltage to approximately that of the machines in operation.
9. Close [illegible] main switch.
10. Regulate field rheostats for the proper division of loads between machines, and to obtain correct direct current voltage.

The above operations apply to six-phase converters and are based on the assumption that all switches of any idle machine are open. This practice should always be followed: that is, when a machine is shut down every switch should be opened and ready for the starting operation. It is quite customary for some operators to start by first closing the low tension starting switch and then the oil switch. Such an operation throws the transformers on the line with heavy starting current on the secondary, whereas in the method above prescribed the transformers are first excited and then the load thrown on the secondary. A method frequently used for correcting the polarity of the converter is to open and close the oil switch after the converter is once started, to slip a pole. This method is not as reliable, and it simply overworks the entire equipment. Another erroneous method of starting is to put the converter on full voltage before correcting the polarity. The machine will come up to speed when on the fractional voltage tap and the field can be much more easily reversed when running at the low voltage than when running on full voltage. It is sometimes found that the operator tries to close the main starting switch instantly following the downward throw of the low voltage starting switch. The resulting rush of current, which is equivalent to practically jumping from one-third to full voltage, will frequently open the oil switch.

The converters used in portable substations are similar to the standard converters with the following exceptions:

The base casting is made extra heavy so as to make it possible to allow the base to rest on four points and thereby permit the levelling of the shaft with jack bolts so that the end play will be operative regardless of the grade of the track on which the car rests. The equalizer switch and the field switch are also shifted from the standard position because of the limiting width of the car.

Transformers

Transformer tanks will sometimes leak oil and there is a possibility of a breakdown in the transformer which will puncture the transformer casing. It is therefore desirable, and Fire Underwriters sometimes insist that a curb be provided around the transformers or the floor graded to a pit or sump so as to confine the oil in case of a bad leak. It is very desirable, and sometimes demanded by the Fire Underwriters, to pipe up the oil drain valves so that in case the oil in a single transformer takes fire it can be quickly emptied. The trouble from this source is decidedly uncommon, but the cost of piping up the transformers is so small that

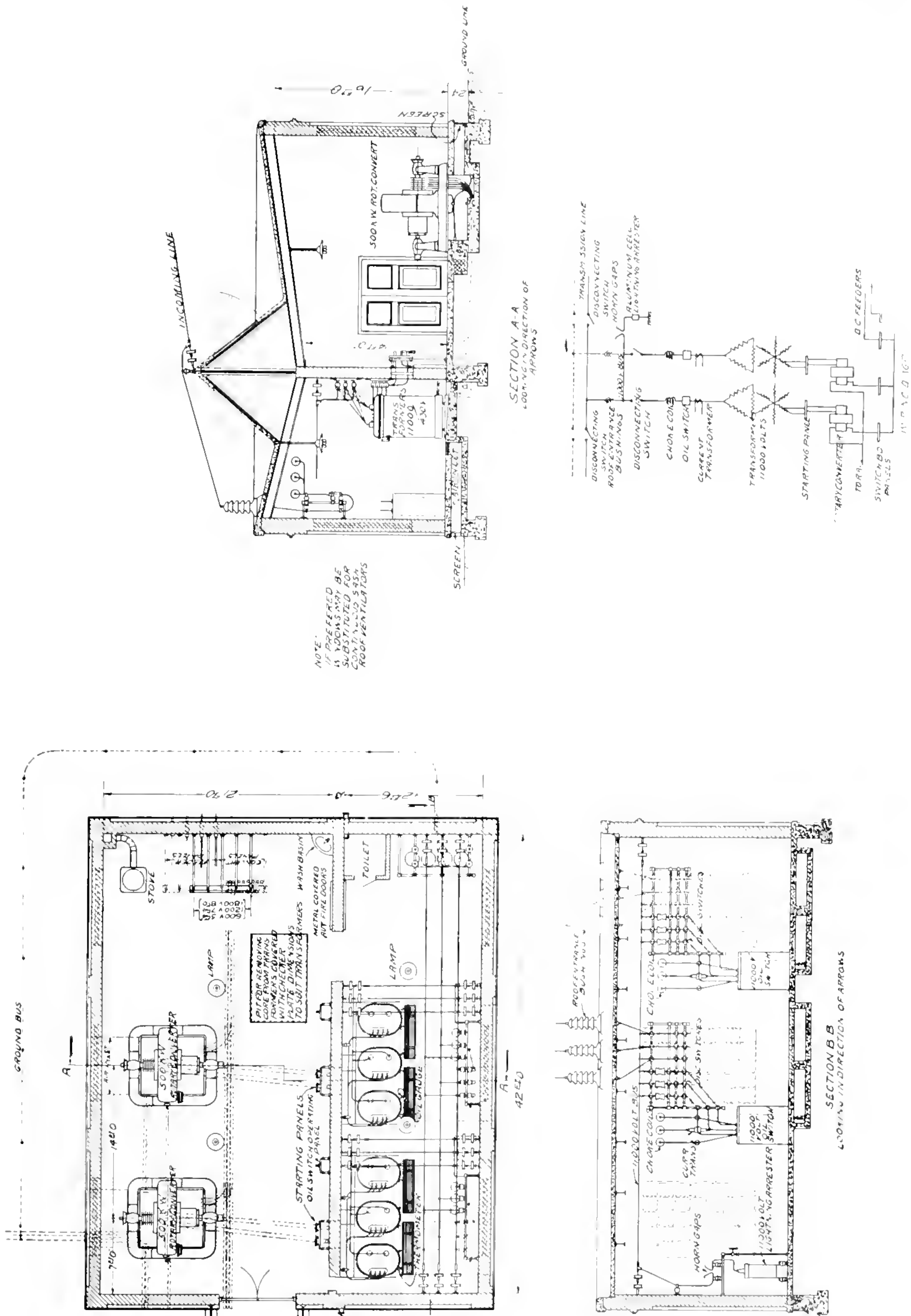


Fig. 4. Rotary Converter Substation with 11,000 Volt Incoming Lines

it is a good investment. In stations containing a large number of transformers this drain header should be run to a reservoir for saving the oil, but in substations of the calibre now being described the drain header can be run to the outside of the building, as the fire will not follow the oil through a long run of pipe, and the chances of ever having to empty a transformer are so remote that the oil could more economically be wasted than to pay the fixed charges on the cost of a reservoir for saving it.

The transformers should preferably be kept in a separate room from the converters, and this is recommended by the Fire Underwriters. The additional cost of a wall for dividing the building into two rooms is offset by the saving in the roof steel due to the decreased span.

If the transformers are set permanently on small rollers, they can be moved from their permanent positions to the pit for inspection without the use of jacks. In the case of small units, a transformer may be handled by one workman. It is best to leave the supports on which these rollers rest about two inches above the floor level, so that planks can be laid under the rollers when the transformer is being transported to the pit.

Oil Switches and Switchboards

The oil switches should be hand-operated so as to avoid the necessity of installing control battery and other auxiliary equipment. Oil switches for 11,000 volt systems are mounted in brick cells. For higher voltages the oil switches are set above the floor level so that the exposed high tension terminals are well out of reach, and this high setting also facilitates the removal of the tanks and the emptying of the oil. It is not practical to attempt to house these large switches in cells, and, from the experience which has been had on switches of this type, the cell construction has not been found necessary. Ordinarily there is no need of piping up the oil switch tanks for the removal of oil.

The alternating current starting panel for either converters or motor-generator sets and the high tension oil switch hand operating mechanisms are located in the converter room near the converters; thus reducing to a minimum the length of the low tension leads, and at the same time greatly adding to the convenience of operation. For example, all the operations necessary when starting up a converter are accomplished right at the machine, and the attendant does not go to the switchboard until the machine is to be paralleled on the direct current side. Furthermore, the high tension oil switch is convenient in case the starting switch should stick when closing, or other troubles occur.

The direct current switchboard panels should, of course, be made to form a common switchboard to facilitate parallel operation and reduce the length of the positive bus. The location of this switchboard should be such that the direct current voltmeter is visible to the operator when standing at any converter. In view of the large amount of exposed positive conductors on the back of the switchboard, and the possibility of a man getting a wrench between the pipe supports and positive copper, or getting one hand on the pipe supports and the other hand on the copper, it is extremely important that all the framework of the switchboard be insulated from the ground. This is cheaply accomplished by setting the switchboard on a wooden sill and securing the tie rods to a wooden cleat on the wall, or using insulated couplings in the pipe tie rods.

The high tension disconnecting switches for 33,000 volts and 66,000 volts are operated from a single pipe mechanism arranged for three poles extended through the roof of the building. The switches are of such a type that should the charging current of a transformer or a line be interrupted, or should they be opened under a light load, the arc will do no damage to any of the station apparatus aside from what might be expected from the rupturing of an arc on an air break switch. Switches arranged for operation in this manner eliminate the wooden pole commonly used. The wooden poles for high voltages are awkward and undesirable when used out of doors in wet weather.

Switchboard panels used in portable substations are very similar to those used in the permanent substations, but they are usually somewhat lower on account of the small available head room in the car. A view of a 66,000 volt oil switch with hand operating mechanism and protecting screen, together with the series ammeter and relay as mounted in a portable substation car, is shown in Fig. 6.

Lightning Arresters

The perfect protection offered by aluminum cell lightning arresters on high voltage circuits has led to the general adoption of this type of arrester, but an arrester of this

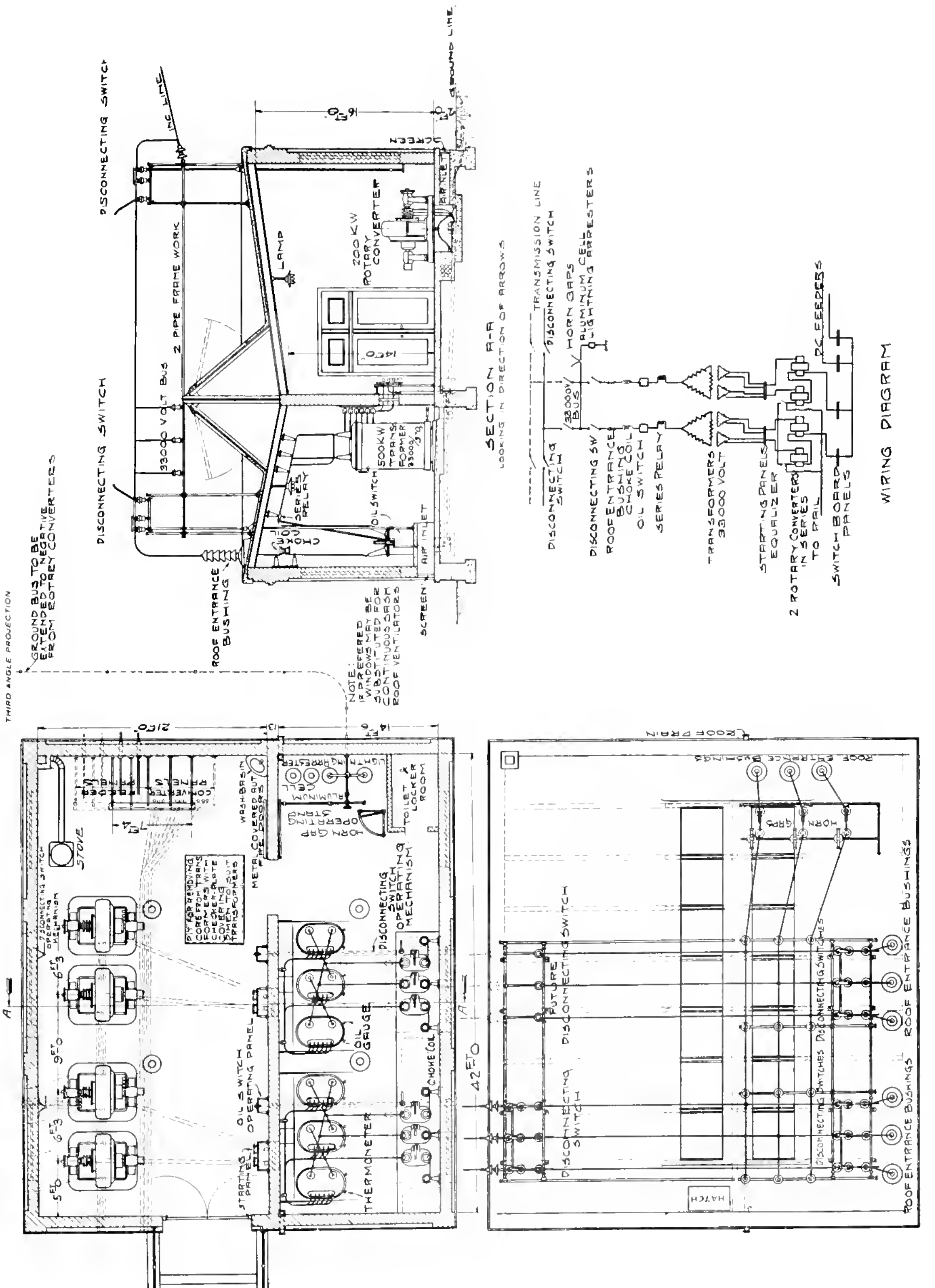


Fig. 5. Rotary Converter Substation with 33,000 Volt Incoming Lines and Arranged for Operating Two Converters in Series

type requires daily charging and is therefore not very desirable for portable substation work where the station is not in continuous service. In such cases the multi-gap arrester, while not as efficient as regards protection, is more practical. Multi-gap arresters up to 33,000 volts can be mounted in cars. Ordinarily a portable substation

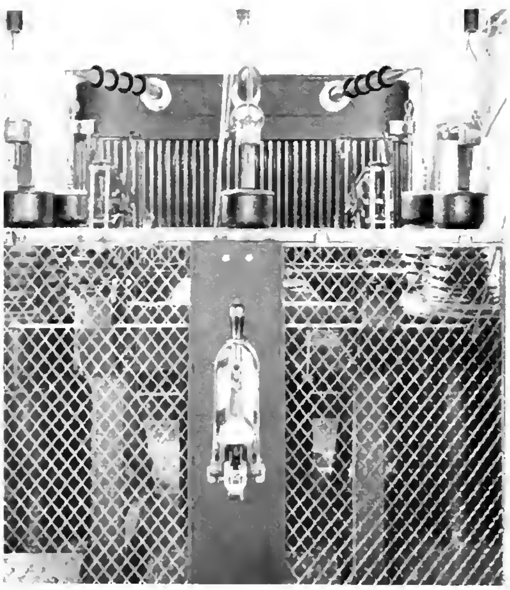


Fig. 6. View of 66,000 Volt Oil Switch, Transformer and Protecting Screen in Portable Substation

is located near a permanent substation, and the aluminum cell lightning arresters in the permanent substation should afford ample protection for the apparatus in the portable substation.

For 11,000 volt circuits the arc on the horn-gaps of an aluminum cell lightning arrester is not of sufficient magnitude to warrant putting the horns out of doors. On high voltage arresters the height required for the arc in case of a heavy lightning discharge makes it advisable to locate the horn-gaps out of doors. With the horn-gaps on the roof and [illegible] indoors, the operating mechanism [illegible] carried to the outside through a pipe [illegible] roof. The operating pipe is flashed [illegible] of an inverted [illegible] metal cone which [illegible] the pipe bushing. It is sometimes [illegible] to have the horn-gaps in a position visible to the operator when standing near the tanks, so that observation can be made of the nature of the arc when charging the arrester. To accomplish this the operating mechanism can be carried down the outside of the building, in which case more time is required for charging because of the extra steps taken to get from the horn-gap mechanism to the transfer switch when interchanging the ground tank with one of the phase tanks. Arrangements could be made, however, to extend the transfer device operating mechanism through the outside wall.

Miscellaneous Station Equipment

A telephone should be provided in each station, and preferably connected to a private line, so that the power house or dispatcher's office can be reached without delay in case of trouble. When cessation of power occurs the regular telephone service is besieged by the general public, often seriously interfering with the communication between operators.

The substation should be provided with an air compressor for cleaning the machines, high tension insulators, etc. This compressor can be of the portable type where the compressor and storage tank are mounted on a truck. The pressure should be from 40 to 60 lb., and the set should have a capacity of approximately 15 or 25 cubic feet per minute. A stationary type air compressor may be used to advantage by running a few air pipes to several points from which a short hose line can be used.

The station should contain a small oil filter which will also act as an oil storage, a can for dirty waste, and one for clean waste. There should also be provided a metal locker for each of the substation attendants and a suitable metal locker for supplies, such as insulators, brushes, terminals, lamps, wire, etc. A set of tools charged to the operators should also be maintained, and it is very desirable to provide a work bench. Fire extinguishers and pails of sand should be kept in readiness.

Roof Bushings

There exists a certain amount of unfounded prejudice against roof bushings, probably the result of experience with earlier forms of bushings which were not wholly satisfactory. Up to 66,000 volts a wall entrance bushing consisting entirely of porcelain has been found perfectly safe, and is considerably cheaper than a bushing of the vertical type. However, they must be protected from the weather, and the cost of building a substantial protecting hood usually more than offsets the extra cost of roof entrance bushings. For potentials in excess of 66,000 volts, the use of insulating oils or compounds has to be resorted to. This construction requires a vertical bushing, and the most accessible place for such a bushing is in the roof. It is better, of course, in such cases to avoid the use of parapets on the building so that snow and ice will not bank up around the bushing. There is, apparently, little or no objection to the use of outdoor insulators on oil switches and transformers, and there is no reason why this same type of bushing should not be used as an entrance bushing for the building.

tension lines at a much higher elevation, and there is consequently less danger from outsiders meddling with them. In case the road over which the portable substation car will travel has low bridges or tunnels, the roof bushings must, of course, be removed from their sockets. This is not, however, a difficult or long operation.

Crane

Besides the saving in the first cost of installation resulting from the use of a crane, it is also extremely valuable to facilitate repairs

Fig. 7. Portable Substation Built for the Oregon Elec. Ry. Co., 60,000 Volt Incoming Line, 1200 Volt 500 Kw. Converter

It will be noted in the arrangement shown in these stations that the roof bushing might be considered a part of the transformer and converter unit, as the entire power fed into the substation is not dependent upon a single set of roof bushings.

The roof bushing has a distinct advantage over the wall bushing in that it is possible to arrange the interior wiring to the best advantage, whereas with a wall bushing the lines have all got to be carried to one wall, and in some cases this wall is not on the same side of the building as the transmission lines, thereby requiring additional dead end poles to double the line back over the station.

The roof bushing has done a great deal to simplify the inside wiring of portable substations. Furthermore, it puts the high

in case of an emergency. However, the extra cost of a crane is not generally considered necessary in a station housing less than 1500 kw. of apparatus. In stations of larger capacity a crane is recommended.

Cranes of 10-ton capacity or smaller can generally be hand operated, as they are not used frequently enough to warrant the added expense of electric drive.

Provision should be made for the removal of any transformer core from its tank for inspection. To do this without increasing the height of the building, a pit is made in the floor and the roof beam above this pit should be made of sufficient strength to carry the weight of a single transformer. The transformer can then be lifted by means of a chain fall of suitable capacity, permanently attached to the roof beam.

Wiring

The wiring may be classified as follows:

1. Extra high tension, 22,000 volts to 66,000 volts.
2. High tension, 2300 volts to 13,000 volts.
3. Low tension, 1200 volts to 1800 volts
4. Low tension, 370 volts to 600 volts.

Extra high tension wiring should be located well out of reach of the attendants or visitors, and should consist of solid bare copper wire not smaller than No. 1 B.&S. Copper tubing $\frac{3}{4}$ in. in diameter with a $\frac{1}{32}$ in. thick wall makes a better appearance, but in these stations will cost more because the number of insulators saved, due to the longer span possible between insulators with copper tubing, is not sufficient to pay for the extra cost of the material, fittings, and labor.

The high tension wiring covered by class No. 2 should consist of single conductor solid copper wire, insulated for full working potential, and covered with a flameproof braid or tape. These conductors should be supported on insulators good for the working potential. The reason for insulating 13,000 volt circuits and not insulating higher voltages is that circuits of these lower voltages are invariably carried near to the floor, and the attendant is not so liable to be cautious when working around the lower voltages. It is obvious, therefore, that the insulation is largely a protection against loss of life, but it also affords an additional protection against the breakage of the insulator.

Class No. 3 for 1200 volt to 1800 volt direct current, or 2300 volt cables run in ducts, should consist of stranded conductors insulated with varnished cambric and covered with a weatherproof braid, unless such conductors are run on exposed insulators, in which case they should be provided with a fire resisting covering. Where cables are run in ducts, the ducts should be drained to a pit; otherwise the cables are likely to lay in water which may accumulate from the condensation in the conduits, from the washing of floors, or the conduits may become filled with water during the construction of the building. It is never safe to assume that a conduit is dry unless it is drained to a pit. Should any water leak through the conduits and run out into the pit no harm will result, as a cable insulated as specified above would have to be submerged in water some time before there would be any liability of a breakdown.

Low tension cables for 370 to 600 volts can be run in ducts or on insulators and provided with asbestos tape insulation with a very small amount of varnished cambric. The duct lines, of course, will have to be drained in the same manner as described above.

All transformer tanks, converter or motor-generator frames, oil switch cans, and other metal parts which are likely to be alive through faulty insulation, and which the operator has every reason to believe are dead, should be thoroughly grounded. Furthermore, this ground connection should be carried directly to the ground bus instead of first passing by the lightning arrester ground wire to the ground rods. Otherwise, there might be a difference in potential between these grounds and the earth at the instant of a lightning discharge. It is not necessary to install a separate ground from that for the lightning arresters, provided the ground connection is thoroughly reliable. The method of making the ground is shown in Fig. 4 and consists of driving a number of solid iron rods some eight feet long and three-quarters of an inch in diameter into the ground, locating them some six feet away from the building and connecting them all by a copper ribbon or cable not smaller than No. 1/0 B.&S. or its equivalent. The lightning arrester ground can then be connected to one end of this bus and the negative feeders and ground connections for the apparatus to the other end.

For station work, lead covered cables, and particularly single conductor lead covered cables, are to be avoided wherever possible. It is not intended to intimate that lead covered cables are not reliable, but they are not as reliable as conductors carried on insulators, and all station wiring should be made just as safe as is possible. It is true that the use of lead covered cable improves the appearance of the station, but the open wiring makes it possible to trace out all connections and greatly facilitates the locating of trouble.

Lighting

The building should be perfectly lighted in all parts by day to facilitate repairs, which are usually made in the day time, and so that all corners, pits, etc., can be readily observed and kept clean. On the other hand, excessive window area makes the building cold in winter. The use of ribbed glass is very desirable, as it eliminates the glare of the sun and makes it much easier to read instruments, gauges, etc.

Artificial illumination should preferably be obtained by the use of tungsten lamps in large units with suitable diffusers. In the case of 600 volt direct current stations a cluster of small lamps can be substituted and thereby avoid the use of a special lighting transformer. This same arrangement of lighting may also be used on 1200 volt direct current stations, but the use of a transformer connected to the low tension side of either bank of converter transformers is far more desirable. The amount of lighting necessary in stations of this type, when based on the efficiency of the tungsten lamp, is approximately 0.75 watt per square foot of floor area. This amount of light will make it possible to read all switchboard meters and instruments, transformer oil gauges and thermometers, and to readily observe the oil in the machine bearings.

Heating

In most localities it is a question if the station should be heated in addition to the heat supplied by the losses in the machines, and while it is a very simple matter to estimate if any additional heating is necessary, the problem is usually solved by operating the station through the first winter and then installing a stove if found necessary.

Fig. 8 indicates when additional heating is necessary according to the size of units installed and the capacity factor of the station. These curves, of course, apply to the design shown in this article, but will not differ materially if the station volume per kilowatt of installed apparatus is approximately the same. The curves are based on maintaining a temperature in the operating room of 65 deg. F.; the outside temperatures varying from 10 deg. below zero to 20 deg. above zero.

Ventilation

Little or no attention has been given to the necessity of good ventilation in transformer and converter substations, notwithstanding the fact that good ventilation but very slightly increases the cost of the building, while it materially increases the output and life of the apparatus. Good ventilation will contribute to higher efficiency in transforming and converting apparatus, because it is possible to operate at a higher load factor and it should improve the efficiency and alertness of the operators.

The ventilation essential in each particular station really requires individual consideration. However, the accompanying curves should be of considerable assistance in determining the amount of ventilating or window opening in most cases; they are, however, intended to apply to the particular designs illustrated in this article. Should there be any doubt as to the correct amount of ventilation necessary, it is better to err on the side of too much rather than too little.

The old method of using windows only and keeping them open during the warm weather is objectionable in many localities, because of the deposit of dust on the moving apparatus. Furthermore, the noise emitted from the machines is far more audible to the nearby neighbors, and in some cases this has become a decided nuisance.

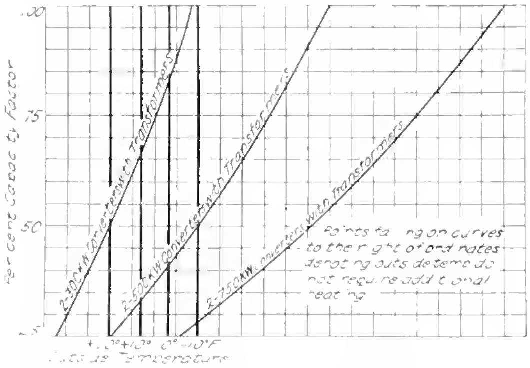


Fig. 8. Curves Showing Necessity of Heating Substations, with Different Capacity Factors and Prevailing Temperatures

The method of taking the air in at the base of the machines or transformers and allowing it to pass out through the roof by means of monitor construction or metal ventilators is the ideal system of ventilation, and this ventilation is possible during all kinds of weather conditions. The general tendency of the operators is to keep the room in which they spend most of their time cool, and frequently the ventilation of transformer rooms is entirely neglected.

The velocity of the warm air rising from the machines or transformers depends on the difference in temperature between the heated air and the incoming air, and the height of the openings for the exit of air above the floor. It is therefore obvious that the exit openings should be as high above the floor as possible, and, in case windows are used, the top sash should be lowered to obtain the best results.

The curve, Fig. 9, shows the theoretical square feet of openings for the exit of warm air necessary per kw. loss in the station. Fig. 10 shows how these curves are applied to a station of the design shown herewith. A 50 per cent allowance is made for the friction through the entrance and exit. By first deciding on the maximum permissible difference in temperature between the outside and the inside air, the amount of exit opening necessary per 100 kw. installed can be read directly from these curves.

The object of the curves is to establish some definite basis for ventilating substations,

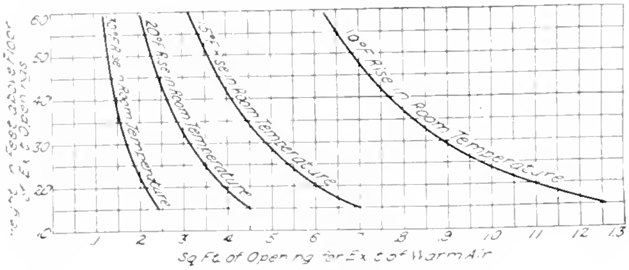


Fig. 9. Theoretical Amount of Air Exit Opening in Sq. Ft. Necessary Per Kw. Loss in Apparatus

as heretofore, to the best of the writer's knowledge, practically no attention has been given to this subject when designing the buildings.

OPERATION

Substations are operated in two or three shifts; a substation of the type described requiring but one operator to a shift. In many stations young men are taken and trained for the work without any previous experience, and with very good results. The position affords ample time for study and opportunity for advancement.

Temporary wiring or repairs of any importance should be under the direct supervision of the engineer in charge of the system. Work of this nature left to the operator is frequently done in an unskillful way, and sometimes causes trouble. Repeated changes and repairs made in a slipshod manner soon spoil the appearance of a station.

A daily log of the principal meter readings and other important facts in connection with the operation of the station should be kept on printed forms provided for the purpose. In many cases the greater part of the records thus kept are of no particular value as far as the cost accounting system is concerned, but they require the operator to observe the instruments at stated periods, hold his attention more closely to the operating conditions, and in general have a good moral effect.

The station and all of the apparatus should be kept perfectly clean; oil stains should be prevented or removed, and there should be no accumulation of waste or refuse. This work can readily be insisted upon in a substation where there is plenty of time for the operator to do it.

The general appearance of a station can be greatly improved by properly laying out the ground surrounding the building into lawns, paths and flower beds. Many operators have a liking for gardening and it is only necessary to provide them with sufficient seeds, plants, etc. The expense involved is very slight and it helps to keep up the operator's interest in his station.

Portable Substations

Judging from the many portable substations, built in recent years, their advantages are, presumably, well understood. Practically all of the orders now received for portable substations call for steel cars. The extra cost of a steel car over that of a wooden car is about 10 per cent of the complete outfit, and the extra weight of the steel car equipment is a like percentage. The equipment of a portable substation is practically the same as that of a permanent substation, with the omission of the lightning arresters. Oil-cooled transformers of the three-phase type are now invariably used, as the three-phase design saves considerable space, and the use of oil-cooled transformers eliminates the complication of a blower and air chamber.

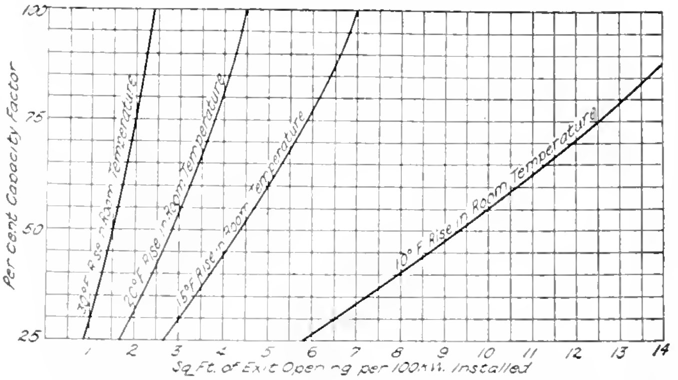


Fig. 10. Amount of Air Exit Opening in Sq. Ft. Necessary Per 100 Kw. Installed for Varying Capacity Factors. (By capacity factor is meant average daily load divided by total installed converter capacity)

The car clearance available over steam roads and local roads naturally limits the size of the car, but a car 40 feet long, of a size equivalent to the common furniture car, will house an equipment for 500 kw. 1200 volts direct current and 66,000 volts alternating current. Cars of smaller sizes are used for

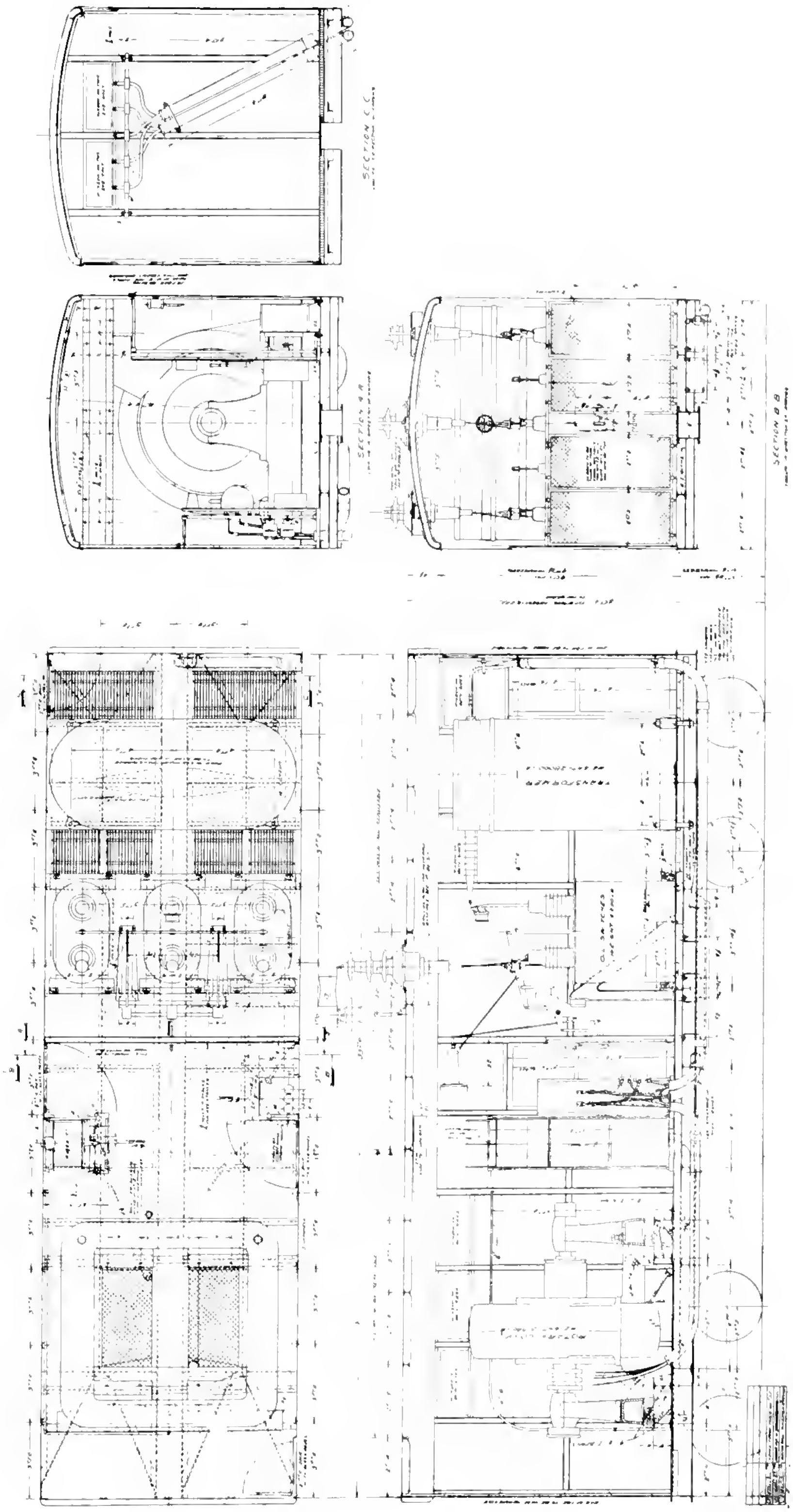


Fig. 11. 66,000 Volt 500 Kw. Portable Substation. Exterior view shown in Fig. 7. Oil switch shown in Fig. 6

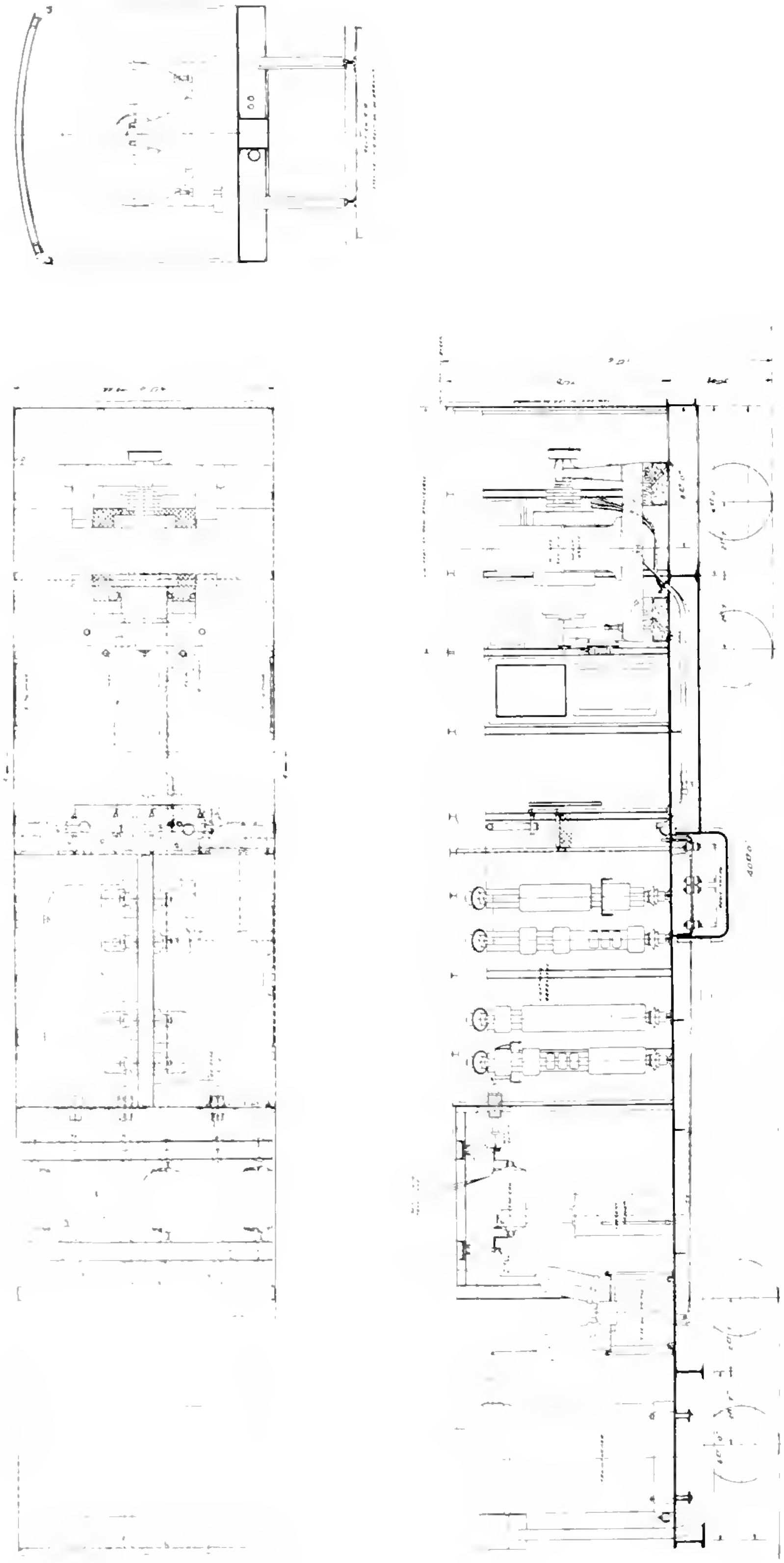


Fig. 12. 33,000 Volt 300 Kw. Semi-Outdoor Portable Substation. Note Transformer and Oil Switch are not covered with cab

smaller equipments and lower voltages. Motor-generator sets of the two-unit or three-unit type can also be installed.

Car Body Construction

No wood or combustible material is used in the construction of the car except the wooden supports for bracing the apparatus, and the window sashes. The external appearance of the car has been greatly improved over that of the wooden cars, as will be observed by referring to Fig. 2. The doors are of the swinging type covered with sheet metal, and the windows, which serve also as ventilators, are of the pivoted sash type. The latter can be closed tightly in case of a driving rain. Under the converter and around the base of the transformer the floor is made up of gratings with removable covers, so that the cold air can sweep up alongside of the apparatus and pass out of the windows, which are at the extreme top of the car. The object of the covers over the gratings is to protect the interior of the car from wheel wash while in transit.

Each car contains four doors, one at either end, and one at either side of the operating space in the center. The doors at the center permit a draft through the center of the car, thus making it as comfortable as possible for the operator.

The floor framing is made sufficiently strong to carry the full weight of the apparatus without placing any dependence upon the sides of the car. The center girder, which is usually of the box type, is carried continuously from one coupler to the other, so that when the car is in a train the stress will not be transmitted to the remainder of the framing. The steel framing is especially designed in each case with the necessary struts for anchoring the transformer and converter. The floor consists of one-fourth inch steel plate with countersunk rivets on the top.

Car Equipment

As cars must be shipped over steam railroad lines to their destination, they are provided with MCB equipment throughout, including air brakes acting on all wheels. A hand brake shaft is usually provided at one end, operating the brakes on one truck only. If the car is required to pass around curves of very short radius, a special construction of the brake rigging to permit the trucks to swivel may be required, differing from the usual steam railroad brake rigging. Draft gear is of the MCB standard type with MCB standard couplers and hand levers at the side of the car. Bodies should have the usual steps, ladders, etc.

The trucks are usually of the diamond frame arch bar type equipped with 33 inch wheels mounted on MCB standard steel axles with cast iron journal boxes.

OPERATION AND MAINTENANCE OF SUBSTATION APPARATUS

By T. F. Barton

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Several articles dealing with this subject have been published, but few of them have embodied the [illegible] treatment given it in this article. In the introduction, the author describes the more important [illegible] motor-generator and rotary converter operation, and the relations which the auxiliary equipment [illegible] to them. The various features of the generating units involving voltage regulation, and the operations to be performed in starting up from both the alternating-current and direct-current ends, are next taken up. The effect of brush position upon the operation of machines of both types is carefully explained, and directions are given as to the proper setting for both single and parallel operation. The remainder of the article is devoted to the maintenance of the apparatus and covers the testing, inspection, and care of the various parts of the machines. Such points as the fitting, chipping, pressure, lubrication, and staggering of brushes, the clamping of commutators, and the attention which should be given commutator and collector ring surfaces are taken up in detail.—Editor.

General

The railway substation transforms the high-tension, a-c. power into d-c. power at 600, 1200, or even 2400 volts at points best suited for supplying power to the railway system. This conversion of power is accomplished by either a motor-generator set or a rotary converter. The motor of the motor-generator set may be wound for the voltage of the incoming high-tension line, or may be used in connection with transformers. The rotary converter is always used in connection with transformers, except in very rare cases where the converter is installed in the generating station and the generator is wound for the voltage of the converter.

The substation equipment, aside from the converting apparatus, is about the same when using a rotary converter or a motor-generator set. When a-c. starting only is required, a starting compensator is used in case of the synchronous motor-generator set, a compensator or starting resistance in the rotor circuit in case of an induction motor-generator set, and starting taps on the transformer in case of the converter. The starting compensator is usually connected to a starting bus from which all machines are started. Good practice calls for one spare compensator. In the case of the converter, each machine has its own starting equipment. Machines up to and including 300 kw. are started from a [illegible] tap on the transformer with [illegible] connected in series. The starting [illegible] obtained from two of the three [illegible] form a bank connected open-delta.

The [illegible] with converters are arranged [illegible] cent taps on the high-tension [illegible] to obtain the [illegible] voltage [illegible] The transformers require [illegible] if they are [illegible] but [illegible] cooled or water [illegible] must be [illegible] the air or [illegible] turned on when [illegible] formers are in service. The blowers for air-blast transformers should have their driving motors connected across the rings of the converter, so that the blower comes up to speed with the converter.

When several banks of transformers are supplied with air from a common pit, fed by two or more blowers, the pit may or may not be sectionalized. The blowers should be arranged with automatic dampers which close when the blowers are not in service, and thus prevent a leakage of air from the air pit.

The characteristics of the rotary converter and the motor-generator set are somewhat different on both the a-c. and d-c. ends. The motor of the synchronous motor-generator set can be used for power-factor correction, while the rotary converter can be used but little, if any, for this purpose. The voltage on the d-c. end of the synchronous converter with fixed field rheostats and load is dependent principally on the a-c. voltage applied and, to a lesser extent, on the frequency. Higher frequency has the effect of increased field excitation while lower frequency has the effect of diminished excitation. The d-c. voltage of a motor-generator set with fixed field rheostat setting and load is altered by change of frequency only. With fixed a-c. supply the inherent voltage regulation of the synchronous converter is better than that of the generator of the motor-generator set. Especially is this true at loads above normal. This falling off of voltage on the motor-generator set acts as an automatic protector, relieving the strains on the machine at times of heavy overload and short-circuit. The character of load has much to do with the best amount of compounding to use on a converter. If the swings of load are large and of short duration, it is best to use very little compounding. The armature of the converter, having a relative position to the field depending on the power-factor, the duty on the machine becomes very severe if, in addition to carrying heavy swings of load, the armature has to change its electrical position with respect to the field.

The a-c. resistance line drop on all synchronous machines should be as small as practicable. On the converter this drop at full-load should not exceed about ten per cent.

Pulsation on synchronous apparatus is due to three primary causes:

(A) Irregular angular velocity of prime mover.

(B) Excessive line drop on a-c. end.

(C) Operation in parallel with units that have a period of oscillation within about 15 per cent of the free period of the machine, provided the conditions given under (A) or (B) or both are also encountered.

In general, under any of the above conditions, the stability of the converter or the synchronous motor is better with lagging current than with leading. Pulsation can be overcome, in many instances, in one machine by operating it in parallel with another machine that has a free period not corresponding to the period of the first. In such a case the pulsating machine, instead of drawing all of its corrective current from the line, draws it from the other machine, and the oscillations are broken up and eliminated.

Variable Ratio Converters

The d-c. voltage on commutating and non-commutating pole rotary converters depends on the value of the a-c. voltage impressed. That is to say, the ratio is constant for any given load. When high-tension power is purchased by a railway company in addition to the power it generates, it is sometimes desirable to consume a constant amount of the purchased power. This can be accomplished by using a converter of variable ratio between a-c. and d-c. volts; or by a constant ratio converter in connection with an induction regulator. Either type machine can be operated from the lines of the power-supplying company, and when running in parallel on the d-c. end with machines operating from the railway company's lines will by means of an automatic device set to maintain constant current accomplish the desired result.

There are two types of variable ratio machines; the regulating pole and the series-booster. The regulating pole changes the d-c. volts for constant a-c. volts by change of "field form" with consequent corrective harmonics; and the series-booster by adding to or subtracting from the impressed line voltage the voltage of the booster—the booster coming between the line and the rotary armature.

Starting of Motor-Generators

There are two common methods of starting up and phasing in a motor-generator set when the motor is of the synchronous type.

From D-C. End

The generator of the set is started as a d-c. motor. After the set comes to synchronous speed the field circuit of the motor is closed, its voltage adjusted to normal, and the motor phased in by means of synchronizing lamps or synchronism indicator. Railway generators are usually compound wound, so an arrangement is usually made for either short circuiting or reversing the series field at the time of starting. If there is no such arrangement, and there is more than one unit in the substation, the closing of the equalizer switch on two or more units will insure stability during starting.

From A-C. End

The motor is started as an induction motor at reduced voltage from a compensator and, when the set reaches about synchronous speed, the field is closed at about one-half its normal value. The motor is then thrown from the starting voltage of the compensator to the line. The time element of the switches must be considered, as an appreciable time lag in closing the line switch, with the field on, would jar the machine more than throwing on normal voltage with the machine running at about synchronous speed without field.

The induction motor-generator set is usually started from the a-c. end, for the motor being designed as an induction machine will not draw an excessive starting current from the line.

Starting of Rotary Converter

There are two common ways of starting up the rotary converter.

From D-C. End

The converter is started from the d-c. end as a motor, brought up to speed, and phased in on the a-c. end by means of lamps or synchronism indicator. This method requires considerable time, and care on the part of the operator, especially if the d-c. voltage is fluctuating.

From A-C. End

The converter is started as an induction motor using ½ voltage taps, if the machine is of 300 kw. or less capacity, and employing $^1{}_3$ and $^2{}_3$ voltage taps if it is greater than 300 kw.

Before starting, the shunt field break-up switch must be opened to prevent high-voltage strains on the field from induced voltage, and the switch to the shunt around the series field should preferably be opened to prevent heavy short-circuit currents, due to induced voltage. The current in the series field is not harmful, except in reducing the starting torque of the converter.

If the converter is a commutating pole machine the brushes should be raised, as very severe sparking at the brushes would result from leaving them on the commutator. These machines are equipped with two pilot brushes which remain on the commutator during the starting for excitation and voltmeter connection.

After making sure that all is clear at the machine, the operator connects the transformers to the high-tension line and plugs the d-c. voltmeter to the machine. The starting switch is then closed, and the machine comes up to synchronism. As the machine approaches synchronous speed, the d-c. voltmeter will oscillate above and below the zero on its scale. By watching the voltmeter and knowing the usual action of the machine, the operator can close the field switch so as to get the desired polarity. Slow-speed machines with heavy armatures usually make two to three slow beats. The switch should usually be closed on the second beat, just before the voltmeter indicates a maximum swing. This is done to care for the time lag in building up the excitation in the main field. It is also easier to draw the armature "ahead" into position, than to draw it "back" into position.

On high-speed machines with light armatures, the beats are usually of less amplitude, and the operator must be quick to close the field switch at the proper time. Should the operator fail in this, and the machine settles to the reverse polarity, and the double-throw break-up switch must be thrown to the reverse position in order to slip the armature one pole.

Another method of changing the polarity is to open and close the high-tension switch. This permits the armature to slip one or more poles. This method does not always give the required polarity for, if the armature slips two poles instead of one, the polarity will not be reversed. It is therefore a "try" method. The field switch must be open when opening and closing the high-tension switch. The correcting of polarity is done only when the machine is running on the starting tap. To reverse the field of the machine at a higher voltage would cause a dangerously heavy inrush of current to the armature.

The machine running at synchronous speed with correct polarity, the starting switch is quickly thrown from the starting to the running position. On commutating pole machines the brushes are now lowered on the commutator. The machine is ready for paralleling on the d-c. end as soon as the voltage on the d-c. end is raised to a value slightly higher than that of the station bus.

Brush Position

On non-commutating pole machines, the brush position is located by operating the machine at no-load normal voltage and shifting the brushes ahead in the direction of rotation until a slight spark is observed at the brush. Full-load and guaranteed overload commutation is then observed, and the brushes shifted slightly "ahead" or "back," to give the best commutation over the entire range of load. The above applies to the generator of the motor-generator set, the rotary converter, and the series-booster rotary converter.

The location of brush position on a regulating pole converter is as follows: The machine is operated at no-load maximum voltage, and the brushes are shifted ahead until a slight sparking is observed. The voltage is then lowered and commutation noted over the entire range of voltage at no-load. Since the no-load commutation will be best at maximum voltage, and poorest at minimum voltage, it may be necessary to decrease the amount of shift as the voltage is lowered. It is to be kept in mind, however, that the first position is most desirable, and should be used unless the low-voltage commutation is very poor. The no-load position located, full-load commutation is observed and slight changes in brush position made to give the best commutation for all conditions of loads and voltage. At full-load and above, the best commutation is obtained at minimum voltage and the poorest at maximum voltage. This is explained by the action of the regulating pole, that becomes a commutating pole as well as a regulating pole at voltages below neutral, and becomes part of its main pole giving the equivalent of a straight rotary converter at the voltages above neutral.

On commutating pole machines, the brushes are first set at no-load, normal voltage, on electrical neutral. Since parallel operation as well as commutation are to be considered, the points mentioned under "Parallel Operation" must be taken into account.

Parallel Operation

It is very important that the various machines connected to the bus divide their loads in proportion to their ratings. Non-commutating pole machines usually give little trouble in parallel operation provided there is sufficient copper in the equalizer; the compounding of the several machines is the same, and the voltage drop through the line cable and series field to the bus is the same for normal-load current on each machine. If the drop across the series field and connecting line cable is not the same on all machines at normal load, a series resistance of the proper value should be connected in the line cable to obtain the required drop. This resistance should be connected in the line cable and not in the equalizer. The equalizer should always be of low resistance. (See Fig. 1.)

Consider a 1000 and 2000 kw. machine operating in parallel.

The 1000 kw. machine

Normal current = 1667 amperes.

Resistance between C and D = 0.00075 ohms.

Volts drop between C and D = 0.00075 × 1667 = 1.25 v.

The 2000 kw. machine

Normal current = 3334 amperes.

Resistance between C′ and D′ should equal $\frac{1.25}{3334} = 0.000375$ ohms.

Or the resistance should be inversely proportional to the kilowatt ratings of the machines.*

Commutating pole machines require great care in their adjustment to insure good parallel operation. On the converter, as well as the generator of the motor-generator set, the amount of series ampere-turns required for a given compounding varies greatly with the position occupied by the brushes with respect to the neutral point of the machine. If the brushes of the converter are off neutral, the commutating pole acts also as a regulating pole. The action is similar to that of the regulating pole of the "split pole" converter, hence, with the brushes ahead f neutral in the direction of rotation, the commutating pole is bucking the voltage, and with the brushes back of neutral, the commutating pole is boosting the voltage; the amount of buck or boost varies with the strength of commutating field, and hence with the load.

The forward position is therefore most favorable to good parallel operation. Fig. 2 shows that the action of the commutating pole reverses as the machine inverts or goes from generator to motor operation, and hence the effect is in the direction of stability and good equalization. The forward position of the brushes with the converter operating direct gives a drooping voltage characteristic with load, and with the converter operating inverted strengthens the main field and limits the motor load taken by the converter.

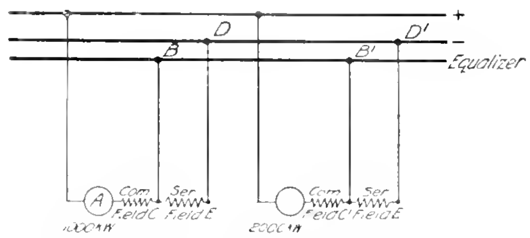

Fig. 1 Wiring diagram showing the standard connections of two commutating-pole generators operating in parallel

The result is the same, so far as d-c. voltage is concerned, on the generator of the motor-generator set as on the converter. On the generator, the commutating pole acts to lengthen or shorten the active polar arc of the machine, depending on whether the brushes are back or ahead of the neutral point. (See Fig. 2.) With the brushes at position "C," the armature conductors between the brushes are cutting a part of the flux of the commutating pole leading the main pole, as well as the flux from the main pole, and since the leading commutating pole and its main pole are of the same polarity, the commutating and main pole are accumulative. With the brushes at position "A," the armature conductors are cutting the flux from the main pole and the trailing commutating pole. In this case the main and commutating poles are of opposite polarity, and hence are differential. With the brushes at position "B," the commutating pole is not effective on the flux, except to overcome a part of the demagnetizing effect of the armature on the main field.

* In the Question and Answer Section of the March, 1913, Review, Question 3, this matter of adjustment of the series field circuit resistance is explained in somewhat greater detail.—Editor.

Parallel operation is particularly difficult when the load varies from no-load to normal load or overloads, and when the converters or motor-generators are driven from two separate sources of power: In the first case, because there is no load on the machines at times, and therefore no equalizing current; and in the second case, because the speed and voltage of the two separate sources of power will vary with respect to each other. Parallel

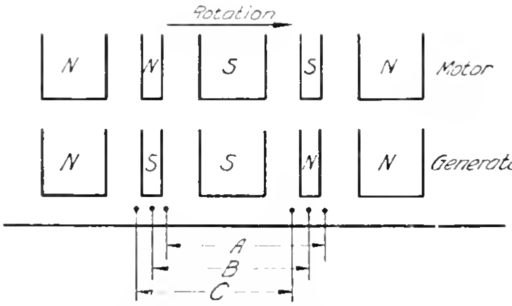

Fig. 2. A diagrammatic representation of the relative positions of the field poles and brushes on commutating generators and motors

operation is very difficult with the brushes back of neutral on a commutating pole machine: It means first, that less than normal ampere-turns are required on the series field for a given compounding, and consequently the equalizer circuit is less effective; and second, that a part of the ampere-turns of the commutating field are used for compounding, and since the commutating field is not equalized, any shift of load caused by the compounding of the field is not equalized. An equalizer circuit is not to be recommended on the commutating field as it unbalances the strength of the field with respect to the armature reaction, which causes poor commutation.

In operating commutating pole and non-commutating pole machines in parallel, the commutating pole machines are always more sensitive to load changes, due to their better inherent voltage regulation, and consequently take the major part of the swings. Care should be taken to equalize the no-load voltage of such machines, so that the commutating pole machines take the greater load on the swings. If this is not done, the commutating pole machine may, at light loads, reverse to such an extent as to trip its breaker on account of the reverse current.

Testing and Inspection

Weekly, or at frequent intervals, tests should be made on the speed-limit device, the setting of the d-c. circuit breaker, the a-c. oil switches, and the reverse-current relays. In fact it is good practice to test the reverse-current relay each time the machine is shut down. This is easily done by "motoring" the machine enough to trip its breaker, noting the amount of current taken. About once a month the armatures and fields of machines should receive an insulation test, and a log of these tests kept so that a machine will show weakness long before the danger point arrives.

The oil switch should be opened for inspection at frequent intervals, as poor contact at any part of the a-c. circuit results in poor operation of the machine. Commutator "spotting" and poor commutation are the usual results. The starting switches should be examined after each operation, to make sure that no pitting is evident on the switch blade or contact clips. If the blade and clip are not kept in good condition, it may be impossible to close the switch, with the result of severe burning at the contact points. This switch should work freely at all times, because its improper action may cause machines to flash over. The condition of the lightning arrester equipment is to be observed at the times of charging. Each day as the arresters are charged, the operator should note the size and color of the arc, or the reading on the charging ammeter if there is one, and in this way be able to keep a record of the condition of the arresters.

Care of Brushes, Commutator, and Collector Rings

Too much stress cannot be laid upon the proper care of the brushes, commutator, and collector rings. The reliance that may be placed in the operation of a machine, from day to day, and the continuity of service that may be expected, depends to a great extent upon their condition.

On starting up a new machine, if operating conditions permit, it is a great help to run the machine for some time at no-load to allow the brushes to properly fit themselves to the surface of the commutator, and thus allow the surface of the commutator to become polished. When a machine is first started up, the friction loss at the commutator is often high. This high friction loss, with its consequent heating, often starts the brushes chattering and binding in the holders. If the machine is carrying load at the time, a few hours may serve to destroy the surface of the commutator. On rotary converters, it often causes the commutator to develop burned spots, the spots coming at points corresponding to the taps from the collector rings.

Brush pressure is a very important item, and for it, it is very hard to lay down an iron-clad rule. 1½ lb. per square inch for carbon, and 2 lb. for graphite brushes are good practice. These pressures will usually be found satisfactory, and the instances where they are not, a little experimenting will be necessary.

The staggering of brushes should be such that an equal number of positive and negative brushes trail on the same part of the commutator. Staggering the brushes in this manner insures uniform wear, for the difference in wear incident to current flowing from brushes to commutator and from commutator to brushes is evenly distributed over the surface of the commutator, as well as is the mechanical wear. The brushes should be carefully fitted to the commutator, and should the face of any become coated with copper, it should be removed by use of very fine sandpaper. Particles of copper should never be removed from the face of the brush by any method that leaves the contact surface irregular, as the irregularities will fill with dirt, causing "under brush" sparking and pitting.

The chipping of brushes is often prevented by rounding off the sharp edge at the toe when the brushes are set at an angle with the direction of rotation of the commutator; and at the heel when set at an angle against the rotation. The brush is not rounded sufficiently to change the contact area, but just enough to remove the sharp edge. Brushes run much quieter when they are so sandpapered.

Commutators are usually well "seasoned" before leaving the factory, but there are cases when looseness develops. Great care should be exercised in the tightening of a commutator to see that all of the bolts in the clamping ring are tightened uniformly, and not too much at any one time. A commutator should never be ground or turned immediately after the last tightening of the clamping ring. It should be first run at full speed, and at a running temperature, to allow its many parts to take a final set.

Grinding a commutator is preferable to turning. While it requires more time, a minimum amount of copper is removed in truing; the grinding is done at full speed so that the machine is rotating as when in operation and therefore all the forces of rotation are present; and the mica between segments is always ground down to the surface of the segment. The mica between segments is left a little high when a turning tool is used, and this slightly high mica may give trouble where graphite brushes are used.

Carbon brushes are usually used on railway machines, on account of their relatively high contact resistance. Commutators with this grade of brush require some lubrication. This lubrication may be secured by using a number of lubricating brushes, staggered over the surface of the commutator, or by the application of a lubricant.

The operator must be depended upon to use discretion in applying lubrication. Too much lubrication is perhaps worse, and certainly no better, than too little. Once a commutator is polished, and the brushes fitted, the amount of lubrication required is a very definite quantity, with applications at definite periods. On large commutators with many brush studs, much is to be gained by applying the lubricant first at one side, and then at the other of the machine. This gives a very much better distribution of the lubricant to the various brush studs. Light engine oil or transil oil makes a good lubricant.

Collector rings with the late type, self-lubricating composition brushes require very little attention. A little lubrication at times however, may prove of some benefit. The brushes should be kept free in the holders, and be properly staggered over the surface of the ring. The rings should be slightly rounded at the edges to prevent the forming and breaking off of slivers. When a mop is used in cleaning and lubricating rings, care must be taken not to move the mop along from ring to ring in such a manner as to come in contact with more than one ring at a time, as metallic dust may collect on the mop and cause a short-circuit between rings.

Duties of Operator

The routine of the substation operator from day to day is much the same; the indicating and recording meters are to be read and recorded each half-hour or hour, and report made to the system operator. Machines are started up and connected to the load or disconnected from the load and shut down, as the peak load comes on and goes off. If the substation is large, one or more machines are out of service each day for cleaning and inspection.

Short-circuits on feeders are frequent, and the usual practice in closing the circuit breaker on a feeder under such conditions is three times in quick succession. Should it open after each closing, wait two minutes and close. Should it again open, wait five minutes, close and repeat if necessary until the trouble is cleared. Report is made of the trouble at the first five-minute interval.

During the peak-load period, the operator is on the alert as to the demands on the apparatus. Should a short-circuit occur of sufficient magnitude and duration to not only open the feeder breaker but one of the machine breakers, and should the remaining machines connected to the load not be capable of carrying the load, the operator must be quick of mind and hand to save the station from a shut down.

In large substations, the operator so schedules the machines as to obtain the best efficiency, and still not overload the machines above their overload capacity during the high swings of load.

The continued satisfactory operation of substation apparatus, once it is properly adjusted for the class of service that it is to perform, is largely determined by the care and attention that it receives at the hand of the operator. The life of brushes, commutator, collector rings, switch parts, and even the insulation on the machine windings is dependent upon the care that these parts receive.

AIR BRAKE EQUIPMENTS FOR ELECTRIC CARS

By G. Macloskie

Railway Equipment Engineering Department, General Electric Company

Until the advent of the electric car in street railway service the matter of retardation, or braking, was given little attention; the old style hand brake amply fulfilling all the requirements of horse and cable cars. With the coming of the electrically propelled car, a large increase in speed and in weight of equipment naturally followed, and a quicker acting and more powerful brake was needed. The air brake was soon found to possess decided advantages over other types that had been evolved, and now it is a part of the equipment of most cars. The many different methods of operating electric cars necessitate a number of different air brake arrangements to properly take care of all conditions. The author divides the several air brake systems under four headings and describes the main features of each.—Editor.

In the early development of the railway systems in our large cities, when the horse and cable cars were superseded by the electrically propelled motor car, the problem of deceleration or retardation was given little consideration, and the hand brake, which was in general use on the single truck cars, was considered sufficiently effective for all practical purposes.

The extension of the city lines to the outlying towns and the construction of the interurban roads meant the changing of the car equipment. This change increased the weight and speed to such an extent that some form of power brake was necessary for safe and effective operation. Hence the development of the momentum brake, the electric disk brake, the magnetic track brake, and numerous other forms of power brakes. These types of brakes served their purpose for a time, but as the weights and speeds still further increased, some more convenient and reliable method of brake control was necessary.

The successful use of the air brake on the steam railroad systems throughout the country called attention to the special advantages to be derived from this form of power brake and, with changes in the apparatus to meet the conditions peculiar to electric railroad operation, the air brake at the present time is considered an essential part of a car equipment.

It has been demonstrated by a series of tests that the power consumption of an electric car equipped with hand brakes is usually about 10 per cent greater than one equipped with air brakes. This is easily explained by the fact that on a car equipped with hand brakes it is necessary for safe operation to run with the brake shoes close to the wheels, in order to save time in applying the brakes. A further economy is effected in the increased schedule speeds that are obtained by the use of the air brake, and consequently a decrease in the number of cars required for a given service.

The necessity of stopping a car or train under all conditions of service is of greater importance than the necessity of starting it, as any failure of the starting apparatus means only a delay to traffic, while the safety of the service is dependent to a great extent on the reliability of the braking apparatus.

Another consideration in the design of an air brake equipment is the ability to make stops smoothly and accurately in a minimum amount of time, as this has an important bearing on the schedule speeds between terminal points.

The design, therefore, of any type of air brake equipment must fulfill the following conditions:

It must be as near fool proof as it is possible to make it.

It must be reliable under all conditions met with in operation.

It must stop a car or train under regular or service conditions smoothly, and without shock to the passengers.

It must provide for an emergency condition when it is necessary to obtain the maximum braking power in the shortest possible time.

It must be designed to meet the requirements of the service under which it is to operate with the view of obtaining the maximum safety factor.

Application of Air Brake Systems

The great variety of conditions met with in the operation of electric railways necessitates different types of air brake equipment and a different arrangement of apparatus. The equipments in general use at the present time are:

The straight air brake equipment for a service where the cars are operated as single units, and where the weight and speed are not excessive.

The emergency straight air brake equipment for cars that are operated a part of the time as single units, and a part of the time in trains not exceeding three cars, and where the weight and speed are not excessive.

The automatic variable release equipment for cars that are operated in trains, and where the cars are heavy and the speed is high.

The combined straight and automatic variable release equipment for cars that are operated a part of the time as single units, and a part of the time in trains, and where the cars are heavy and the speed is high.

The Straight Air Brake

This equipment is confined strictly to single car operation, and is at the present time in use on the large majority of cars operated in city and interurban service. The advantages of this type of equipment are flexibility and the convenience of controlling quickly and positively the increase and decrease in braking power, making it suitable for cars where there is a great variation in speed and where the load is an appreciable proportion of the equipped weight. The essential parts of this equipment are:

An independent motor-driven air compressor for furnishing a supply of compressed air.

One or two main reservoirs for storing the supply of compressed air.

A brake cylinder for providing the necessary braking power.

A governor for maintaining the pressure in the main reservoir between predetermined limits.

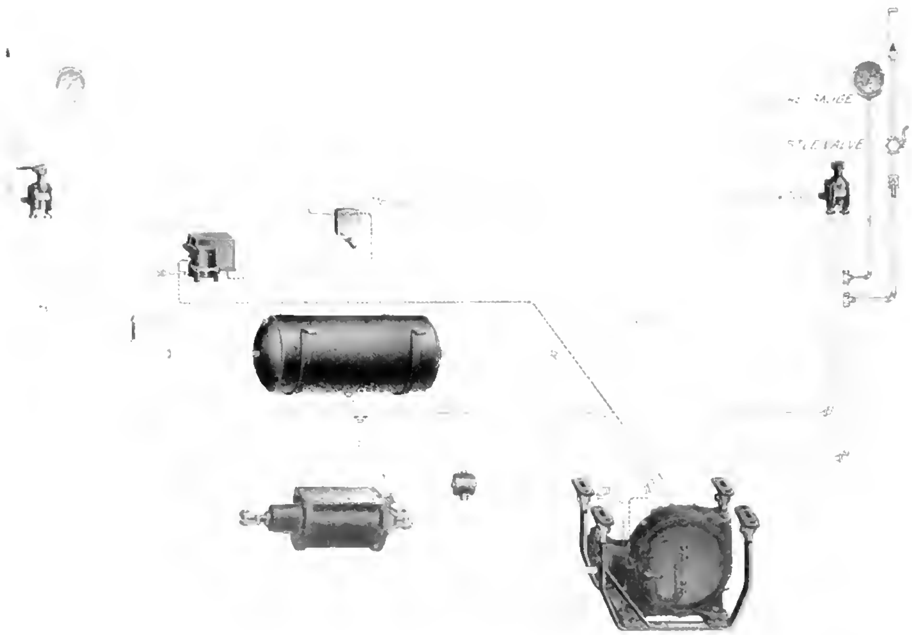

Fig. 1. Straight Air Brake Equipment for Motor Car

A motorman's valve in each operating end of the car under the direct control of the operator for applying and releasing the brake.

The parts mentioned above are common to all types of equipments.

In the straight air brake system the air is admitted directly from the main reservoir to the brake cylinder when the motorman's valve is placed in the service or emergency position, and is exhausted from the brake cylinder when the motorman's valve is placed in the release position. With this equipment the brakes can be applied and released quickly and the braking power can be accurately and easily controlled. The equipment is composed of a minimum number of parts, and is simple and flexible, making it possible to locate the apparatus to advantage on the small single truck cars as well as the larger double truck cars.

The absence, however, of any automatic feature in this type of equipment makes it unsuitable for train operation, because of the loss of braking power in case the train should part or the hose couplings between the cars become uncoupled.

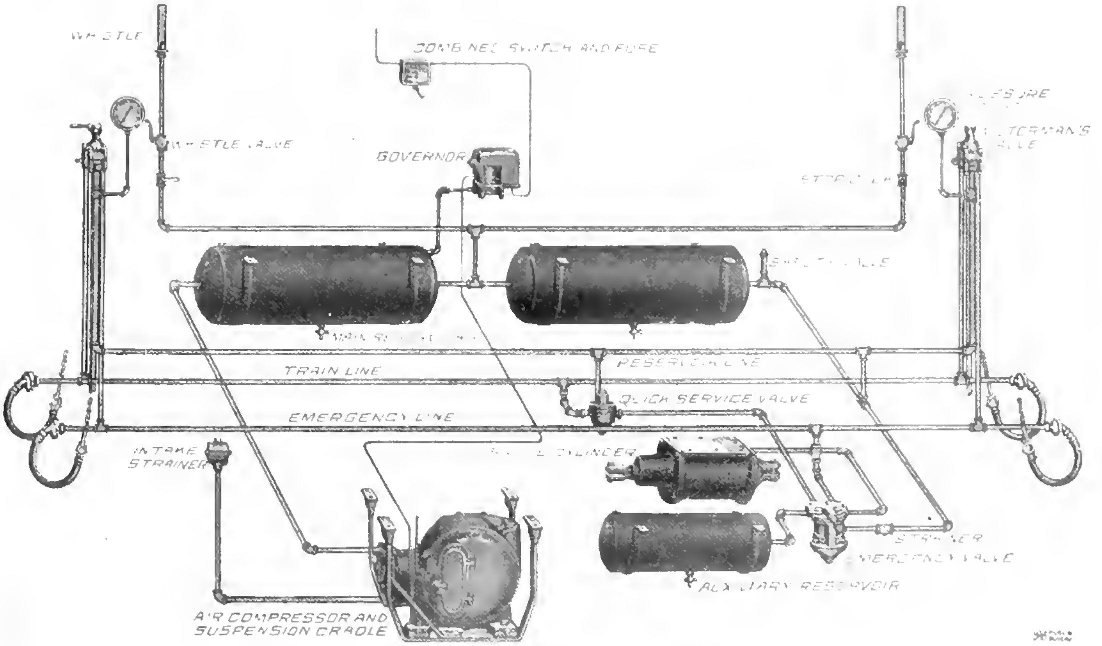

Fig. 2. Emergency Straight Air Brake Equipment for Motor Car

The Emergency Straight Air Brake

Cars which are normally operated as single units, but which under certain conditions, such as handling traffic during rush hours, and on Sundays or holidays, are required to operate in short trains consisting of a motor car and trailer or two or three motor cars, require special features in the air brake equipment to provide a reliable, positive and convenient brake control, and also to provide a proper factor of safety. Such conditions require a braking system which will not only give as positive and reliable control of the train as can be obtained with the straight air brake, but will also give the protection that is afforded by the automatic air brake for train operation.

The emergency straight air brake equipment is essentially a straight air brake with the addition of an emergency valve and auxiliary reservoir to provide for the automatic application of the brakes in case the train should part or any damage should occur to the coupling hose. The emergency valve is connected between the emergency line and the train line, both of which are installed on the cars and are connected together by means of hose and couplings between the cars, making these pipes continuous throughout the train. Additional connections are made from the emergency valve to the brake cylinder, to the auxiliary reservoir, and to the main reservoir.

A service application of the brake is made by admitting air to the train line direct from the main reservoir. Under these conditions the emergency valve remains in the normal position and communication is established between the train line and the brake cylinder. The brakes are therefore applied or released by an increase or decrease of pressure in the train line. If the pressure of air is suddenly reduced in the emergency line, the emergency valve is moved to the emergency position, connecting the auxiliary reservoir directly to the brake cylinder. In this position no air can flow from the auxiliary reservoir to the emergency line or to the train line. An application of the brake is therefore made by opening the conductor's valve or by the opening of the emergency line hose connections between the cars, or by turning the motorman's valve handle to the emergency position, as will be explained later.

In train operation it is necessary to make service stops without jars or shocks. To obtain these results the brake equipment must be provided with such apparatus as will make uniform the admission or the release of brake cylinder air on all cars of a train. To accomplish this a quick service valve has been introduced in the branch pipe leading from the train line to the emergency valve. The duty of this quick service valve is to accelerate the application and the release of the brakes, and to reduce to a minimum the time element between the movement of the valve handle and the increase or decrease of pressure in the brake cylinders. This quick service valve is connected in the branch pipe leading from the train line to the emergency valve, and has an additional connection to the main reservoir. Two pistons are located in the body of this quick service valve. When air is admitted to the train line one of these pistons is moved so as to open a lift valve and admit air direct from the main reservoir to the brake cylinder. When air is exhausted from the train line, the other piston in the valve is moved, opening a connection in the train line direct to atmosphere at the quick service valve. The introduction of this type of valve, which relays the application and release of brake cylinder air, is a marked improvement in this type of equipment and makes the application and release of the brakes on all cars of the train uniform.

A service or automatic application of the brake may be made at the will of the operator by placing the handle of the motorman's valve in the service position or in the emergency position.

In the service position air is admitted direct from the main reservoir to the train line, and through the quick service valve to the emergency valve and to the brake cylinder. In the emergency position the emergency line is connected to atmosphere and an automatic application of the brakes is made on all cars of the train.

The straight and automatic features of the equipment, combined in one motorman's valve under the direct control of the operator, have the advantage of giving a maximum degree of protection for train operation, as any damage to the train line does not prevent automatic application of the brakes being made, and any damage to the emergency line is indicated at once by the automatic application of the brakes independent of the operator.

To release the brakes after an automatic application has been made, provision is made in the emergency valve for connecting together the emergency line and the train line; and when the motorman's valve is placed in the service application position air flows from the main reservoir through the train line and through the emergency valve to the emergency line, charging the latter to main reservoir pressure and allowing the piston and slide valve in the emergency valve to be returned to the normal position by a spring located in the valve cap. This method of releasing the brake after an automatic application has been made prevents the train being moved until the motorman is in the proper position on the platform.

The equipments just described are limited to cars of moderate weight and where the speed is not greater than forty-five miles per hour. These limitations are necessary because there is no excess braking power in reserve for emergency application, and also because of the variations in the braking power due to changes in the main reservoir pressure between the cutting in and cutting out points of the governor. On heavy cars that are equipped with 12 in. or 14 in. diameter brake cylinders the difference of 10 lb. in the main reservoir pressure, which is the usual difference between the cutting in and cutting out points of the governor, means a large variation in the available braking power. The percentage of variation is the same for a large or for a small cylinder, but in case of a car equipped with a large cylinder, the actual pounds of unbraked weight due to this variation is a maximum for a condition where it should be a minimum.

The Automatic Variable Release Air Brake

The quick action automatic air brake has been adopted universally for train operation, and has been in general use on the steam railroads throughout the country for the past twenty-five years. An application of the brakes is obtained indirectly, by means of a triple valve, from air stored in an auxiliary reservoir on each car of the train. The triple valve performs the three functions of charging the auxiliary reservoir with compressed air from the brake pipe and applying or releasing the brake in accordance with variations in the brake pipe pressure these variations being governed by the motorman's valve under the direct control of the operator. By this means a partial or full brake application on all cars of the train may be made, subject to the variations of the brake pipe pressure.

The chief disadvantages of this type of equipment for electric service are that a succession of brake applications cannot be made at short intervals of time without seriously depleting the quantity of air stored in the auxiliary reservoir, and consequently the brake cylinder pressure at each succeeding stop. Accurate control of the brake cannot practically constant, and the brakes may be quickly applied or released as often as desired, and can be partially released after an application has been made.

The new type of triple valve is well adapted for use on cars that are operated in multiple unit service, as each car is equipped with an independent motor-driven compressor and main reservoir.

In the automatic variable release equipment a brake pipe connects together all the

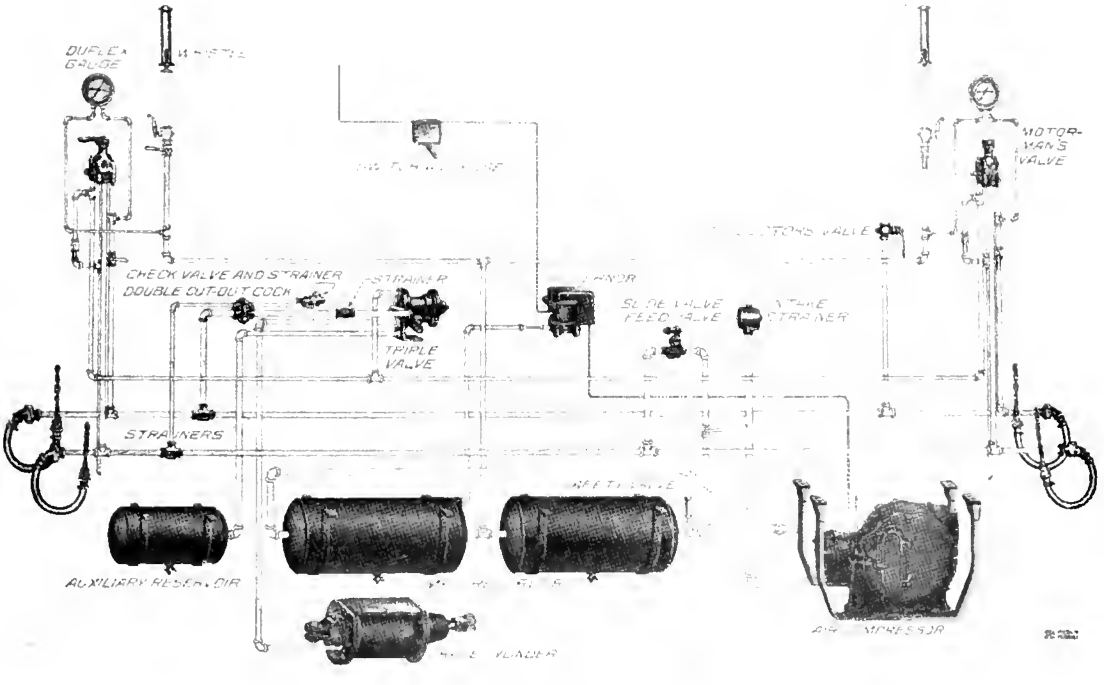

Fig. 3. Variable Release Air Brake Equipment for Motor Car

be secured except by the skillful manipulation of the motorman's valve. These objectionable features are due to the fact that after once being applied the brakes cannot be partially released, but must be fully released and reapplied when a reduction of braking effect is required. Also the auxiliary reservoir is charged from only one source, viz., the brake pipe, and the rate of charging is therefore limited. To overcome these objectionable features, which are more prominent in electric railway service where the stops are frequent, a radical change has been made in the triple valve and consequently in the means of charging the auxiliary reservoir; the result being that the braking effect during retardation of a train can be maintained triple valves on the train. A control pipe is also installed on each car and is connected together between the cars by means of hose and couplings in the same manner as the brake pipe. This control pipe connects together the main reservoirs on the motor cars, and air from the main reservoir is admitted to this control pipe through a feed valve or reducing valve adjusted to reduce the pressure in the main reservoir, which varies from 85 to 95 lb. according to the range and adjustment of the governor to a constant pressure of 70 lb. The variable excess pressure is thereby confined to the main reservoir, and a uniform pressure is insured in the brake pipe and auxiliary reservoirs for braking purposes independent of the governor adjustment.

This uniform braking pressure is very desirable for heavy equipments as it means the elimination of variable braking effects due to changes in main reservoir pressure.

The arrangement of the control pipe and the feed valve has a further advantage of providing automatically for the even distribution of the work done by the several compressors on the train without the use of the balancing wire or special governing apparatus.

The characteristics of this type of equipment are entirely dependent on the functions performed by the triple valve, and may be briefly stated as follows:

Quick Recharge

The quick recharge of the auxiliary reservoir from two sources.

The brake pipe and the control pipe whereby the maximum braking pressure is always available, and the prompt application of the brake is insured regardless of the frequency of the stops.

Quick Service

By the venting of a small amount of air from the brake pipe to the brake cylinder, when a service application of the brake is made, a serial operation of the braking effect is obtained; that is to say, the time element between the brake applications on each car is reduced, the result being a more prompt, uniform and positive brake application.

Variable Release

Charging the auxiliary reservoir from the control pipe as well as from the brake pipe, when in the full release position, provides a means for making a partial release of the brake, and thus reduces the braking effect step by step as the speed of the train is decreased. This feature makes possible the smooth handling of the train at stations where individual cars are required to stop at certain definite points. A saving of air is also effected, as it is not necessary to release and reapply when approaching the station.

High Brake Cylinder Pressure in Emergency

In the emergency position of the triple valve, part of the air contained in the brake pipe is vented to the brake cylinder through a large port which increases the brake cylinder pressure. The available braking power is thereby increased above the maximum that can be obtained with a full service application. This feature insures shorter stops when an emergency condition arises, and contributes an increased safety factor in train operation.

The Combined Straight and Automatic Air Brake

The addition of a straight air feature to the automatic air brake equipment described above increases materially the flexibility and promptness of operation without in any way sacrificing the safety features of the automatic part of the equipment.

The straight and automatic features of this equipment are combined in one motorman's valve and a change from the straight air application of the brake to the automatic, or vice versa, is made by simply placing the valve handle in the different operating positions on the valve quadrant. An automatic application of the brake is made by placing the valve handle in the automatic service position. This reduces the pressure in the brake pipe in the usual manner, and a brake application is made on all cars of the train through the medium of the triple valve. A straight air application of the brake is obtained on the operating car only by means of a quick service valve, which is the only additional piece of apparatus added to the automatic equipment. The purpose of this valve is to provide a means for admitting air directly from the straight air application pipe to the brake cylinder without destroying any of the safety features of the automatic equipment.

The quick service valve is connected in the branch pipe leading from the straight air application pipe to the brake cylinder and has additional connections made to the auxiliary reservoir and to the exhaust port of the triple valve.

When the valve handle is placed in the straight air application position air is admitted to the straight air application pipe and the piston in the quick service valve is moved downward, opening a lift valve which admits air from the auxiliary reservoir to a chamber below the piston. The movement of this piston also uncovers leakage grooves which allow air from the straight air application pipe to enter the chamber below the piston. This chamber is in direct communication with the brake cylinder. When the valve handle is placed in the release position, the straight air application pipe is connected to atmosphere, and brake cylinder air flows from the triple valve exhaust to the quick service valve and through a check valve located in the body of the quick service valve to the straight air application pipe. A release of the brake is therefore made after a straight or an automatic application, by simply placing the valve handle in the release position.

In this type of equipment the automatic portion is used for train operation, supplemented by the straight air in order to increase the accuracy of the stop and to hold the train after a stop has been made. The straight air part of the equipment is also used for single car operation.

With this equipment the most satisfactory results are obtained in the operation of heavy cars at high speed whether in trains or operated as single units. This equipment is therefore coming into general use for heavy interurban service and also for the control of light locomotives which are used for switching service or on gas electric motor cars that are required to interchange with steam railroad equipments.

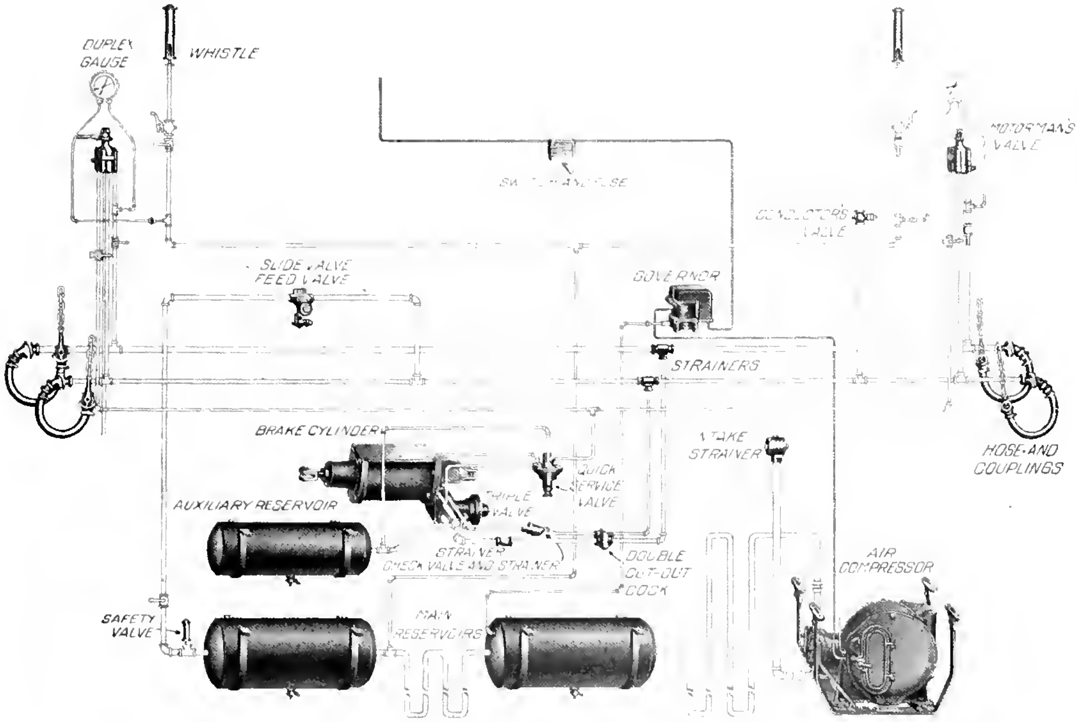

Fig. 4. Combined Straight and Automatic Air Brake Equipment for Motor Car

DISPLACEMENT *versus* DELIVERY OF AIR COMPRESSORS

By C. M. Spalding

Railway Motor Department, General Electric Company

In order to ascertain the actual service value of air brake compressors, it is necessary to take into account the various factors which directly influence their volumetric efficiency. In this article the author has outlined the conditions upon which the rating of a compressor should be calculated, in order that the reader may understand the basis of the deductions and comparisons given in the context. The article treats this subject in a very practical manner, and only the most elementary mathematics have been used in the analyses.—Editor.

The phrase "air compressor capacity" which is frequently used in correspondence and conversation is ambiguous and often misleading.

Air compressor capacity may mean piston displacement in cubic feet of free air per minute when working against any given gauge pressure; or it may mean the quantity of air delivered, expressed in cubic feet at atmospheric pressure; or it may even be used by some to mean the quantity to be delivered, expressed in cubic feet of air at the pressure at which it is intended to be stored or used. The word capacity should be avoided in this connection as it results in confused ideas, and some precise expression of the quantity of air desired should be used instead.

Air compressors are commonly rated by their piston displacement, or, when fully stated, by the piston displacement in cubic feet of free air per minute when operating against some stated gauge pressure. This is a value easily determined as it only involves the diameter of cylinders, the stroke, and the revolutions per minute of the crank shaft, when operating against the stated gauge pressure. It is used by all builders of reciprocating air compressors and is very convenient in determining, approximately, whether a [illegible] compressor is suitable for a given [illegible] it is necessary to understand its [illegible] delivery of the compressor in order [illegible] such use of it.

The [illegible] which follows is limited to [illegible] compressors because electrically [illegible] compressors for railway service are ordi[illegible] this type. Let us consider the [illegible]

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It should be understood that this result, while stated in terms of cubic feet of free air, is not a measure of a quantity of air at all, but only the expression of a volume, which may be filled with air at any pressure. As an example, if a compressor was used as a vacuum pump it would have its displacement volume filled with air at approximately the pressure of the chamber which is being exhausted instead of with air at atmospheric pressure and temperature (free air). And, further, this piston displacement volume does not imply the delivery of the entire quantity of air corresponding to the piston displacement, but holds some relation to it which is explained in the course of this article. Finally, it does not include the gauge pressure at which the air is delivered; this pressure only being referred to because compressors when working against different pressures run at different speeds. In the case of a two-stage compressor, such as is used for the higher pressures required on the heavier locomotives, the low pressure cylinders only are used in the calculation.

The delivery, in cubic feet per minute, is a percentage of the piston displacement; this percentage is known as the volumetric efficiency of the compressor. It varies quite widely, the fundamental causes of this variation being the size of the compressor and its terminal gauge pressure at which the air is delivered. These causes will produce a considerable variation in the delivery of a series of compressors of different sizes, even though all are designed along the same lines with equal care; or in the same compressor when delivering air at various gauge pressures. Besides these there are other causes of variation in the volumetric efficiency which affect the results obtained, but which may be controlled and reduced to a minimum; among these are the volume of the clearance spaces, the type of valves, piston rings, etc.; much may be gained in efficiency by giving intelligent thought to these points in designing a compressor. Also the seating of valves, the fit of the piston rings, etc., are points where the workmanship becomes a very important item in producing the desired result.

This percentage of volumetric efficiency may be as high as 88 per cent in a large two-stage compressor operating at 135 lb. gauge pressure or as low as 57 per cent with the smallest single stage air compressors used for air brake service on street railway cars.

The gain in volumetric efficiency by two-stage operation over single-stage operation is due to the much lower terminal pressures in the low pressure cylinders of the two-stage machine, as compared with the terminal pressures in the single-stage machine. These pressures affect both the quantity of air left in the compressor clearance spaces and the amount of leakage past the piston rings and valves. The same relation between volumetric efficiency and terminal pressure may be observed when considering single-stage machines only. For example, if we take the case quoted above of the very smallest type of compressors for air brake service and operate it at 60 lb. instead of 90 lb. its volumetric efficiency becomes 66 per cent instead of 57 per cent. It should also be understood that in the smaller compressors the clearance volume becomes necessarily a larger percentage of the total volume.

It is not proposed in this article to enter into a detailed statement of volumetric efficiency of various compressors, but to make some general statements showing why the delivery is less than the displacement. We will assume a compressor of 70 per cent volumetric efficiency and state the approximate amount of the various losses which combine to account for the missing 30 per cent.

The intake air is never quite up to the atmospheric pressure from which it is drawn; that is, if we consider the atmospheric pressure as 14.7 lb. absolute pressure, then the air in the cylinder at the end of the intake stroke may be assumed to be 0.7 lb. less, or 14 lb. absolute, and this incoming air will be heated by contact with the walls of the cylinder head and cylinder to perhaps 12 deg. C. above the atmospheric temperature. Thus our quantity of air which might be contained in the cylinder and its clearance spaces is reduced to 91.5 per cent of its value in free air before we begin to compress it.

The compressor must have a certain amount of mechanical clearance to prevent the piston striking the cylinder head, and to this volume must be added the volume of the ports which are provided for the passage of air from and to the valves. The combined volume of these items is the clearance referred to in the preceding paragraph when considered with reference to the air delivery. It is kept as small as possible by careful designing but must be consistent with a suitable area of air passages, and may be taken as from 2.5 to 3.5 per cent of the total volume of the piston displacement plus clearance. In the comparison here made it is assumed to be 3 per cent. The speed of the compressor is assumed to be 200 r.p.m.; that is, the compression stroke of each piston in a two-cylinder compressor occurs in approximately 0.15 sec. This time being so short, there is very little interchange of heat between the compressed air and the walls of the cylinder, which means that the air becomes very hot and the compression is nearly adiabatic. In addition to this it is necessary to carry our compression considerably above reservoir pressure for the purpose of lifting the valve, and it remains slightly above reservoir pressure after the valve is opened to induce the flow of the necessary quantity of air through the valve ports and the pipe to the reservoir, during this brief interval of approximately 0.04 sec. in which the valve is open. Our clearance volume is now filled with air at a pressure slightly above that in the reservoir. This air is left behind in the cylinder, when the piston begins its return stroke and the valve closes. Under the conditions stated, our clearance volume has become 14 per cent of our total volume so that if there were no other losses we should have a delivery of 77.5 per cent, but we have still to account for the air which leaked past the piston rings and that which has leaked back past the inlet valve, these leakages should be, and are, kept as low as possible; but they exist in all compressors and must be taken into account. These piston and valve losses taken together represent the $7\frac{1}{2}$ per cent not already accounted for.

When the intake air separator, which is provided to remove dirt from the incoming air, is improperly installed so that dirt gets under the valves, the valve losses become very much greater and the delivery correspondingly less. For example, in one instance the writer when overhauling a compressor which had been in service several years increased its delivery 50 per cent by simply taking it apart, washing out the valves and valve chambers and re-assembling.

Two or three other points may be profitably noted, which, although they are not a part of the statement of volumetric efficiency, should be kept in mind when considering the suitability of a given air compressor for a given service.

When compressed air is used in moving a piston in a cylinder it must be considered in terms of absolute pressure; for example, when an air brake piston is moved through an assumed stroke, dependent upon the mounting of the brake rigging, wear of shoes, etc., with a gauge pressure of say 50 lb.; the quantity of free air used would be expressed by the absolute pressure in atmospheres multiplied by the volume of the cylinder including its clearance in cubic feet: $\frac{50+14.7}{14.7}\times$vol. in cu. ft. = quantity in cu. ft. free air. There is a very small temperature correction which may be disregarded.

When compressed air is to be measured as delivered to a tank or reservoir of known volume the procedure is as follows:

The tank ordinarily contains air at atmospheric pressure and temperature at the beginning of the test. Let us assume that we are going to fill it to 90 lb. gauge pressure; then we have at the end of our test a tank full of air at $\frac{90+14.7}{14.7}=7.122$ atmospheres; that is, we have that many times its volume in terms of free air, except as affected by temperature, but it is usually at somewhat higher temperature than the surrounding air, and in this case the temperature correction should be included if close results are desired. For example, if the surrounding atmospheric temperature is 25 deg. C. or 298 deg. C. absolute and the temperature of the air in the tank is 40 deg. C. or 313 deg. C. absolute, then the air actually in the tank when it had cooled to the surrounding temperature would be reduced in absolute pressure to $\frac{298}{313}=0.951$ of its absolute pressure at 40 deg. C. Its value for the cubic feet of free air, at atmospheric pressure and temperature, actually delivered after deducting the air in the tank at the beginning of the test would be $[(7.122\times0.954)-1]\times$tank volume in cu. ft. = cu. ft. free air delivered.

It may be of interest to compare the relative values affecting the volumetric efficiency found for larger compressors of the double acting type, such as are used in stationary service, as given by Mr. E. A. Rix when discussing the same general subject in the Mining and Scientific Press. It will be noted that his figures include leakage through the piston rod stuffing box, which feature does not exist in single acting compressors; and valve slippage or the shifting of the valve on its seat, which is so small an element in railway air compressor valves that it has been considered negligible. He takes as typical for the purpose of his illustration 70 per cent volumetric efficiency when operating a single-stage compressor at 100 lb. receiver pressure. If the compressor were operating at 90 lb. pressure its volumetric efficiency would be 73 or 74 per cent. On the other hand he is considering a line of compressors of larger displacement, so that on the whole the conditions are sufficiently near to furnish us with an interesting comparison. His item of temperature losses includes losses due to the intake fall in pressure.

Railway air brake compressor single acting against 90 lb. gauge pressure.	Stationary air compressor double acting against 100 lb. gauge pressure.
Intake loss due to fall in pressure 4.8 per cent. Intake loss due to increase in temperature, 3.7 per cent.	Temperature loss, 7 per cent.
Clearance loss, 14 per cent.	Clearance loss, 16 per cent.
Piston loss, 7.5 per cent.	Piston and rod loss, 3 per cent.
Valve loss, 7.5 per cent.	Valve leak and slippage, 4 per cent.
Total, 30 per cent.	Total, 30 per cent.

Insert this note in your file copy of the November, 1913, REVIEW.

Article on "Displacement *versus* Delivery of Air Compressors", by C. M. Spaulding, page 910.

In the left-hand summary of losses at the end of article, the combined ***Piston and Valve Loss*** *amounts to 7.5 per cent and not the separate losses as indicated.*

CURRENT COLLECTING DEVICES FOR ELECTRIC RAILWAYS

By S. B. Stewart, Jr.

Railway Equipment Engineering Department, General Electric Company

There are three principal systems in use for distributing current to the moving equipments on electric railways; namely, the overhead trolley, the third rail, and the underground conduit. Each system requires its own special current-collecting devices, such as the trolley wheel and pantograph for the overhead conductor, the shoe for the third rail system, and the conduit plow for the underground conductor. In this article the several types of collectors are discussed in detail with respect to the best design, most suitable material, current-collecting capacity, and life of parts.—Editor.

In the electrification of railways there are various methods of collecting current direct from the highway power feeders for the equipments, and it is the intention in this article to treat somewhat intimately with the design and construction of the different devices in general use.

The three standard methods of distribution are the overhead trolley, the third-rail and the underground conduit. Other schemes, such as surface contact systems, have been exploited, but by reason of their many complications have never come into prominence.

The trolley is by far the most universally used and, although this is the case, it has always been viewed with more or less disfavor, owing to the unsightliness of its overhead wires. In fact in the pioneer days, the early installations were looked upon with skepticism, it being doubted that they would ever be a serious factor in the operation of our railways.

The trolley is, however, peculiarly adapted to small and medium sized cities and for this class of work nothing thus far has been developed to really supersede it. The underground conduit, which would seem to be a possible substitute, is unfortunately enormously expensive and therefore prohibitive.

Overhead Collectors

In the case of the overhead trolley, three distinct types of collectors have been developed; the ordinary trolley wheel with its attendant harp, pole and base; the pantograph equipped with either pan or roller, and the bow generally fitted with a rod or bar contact. Each form has its particular functions and advantages, although the type selected is to a certain extent at the whim of the constructing engineer; for instance, the choice between the roller pantograph and the pole and wheel may be deduced from the fact that the former, when once raised, is practically automatic in operation, while the pole and wheel require constant attention at frogs and cross-overs and further must be reversed when changing the direction of the car or locomotive. Other characteristics may be the determining features governing the selection, such as the methods of raising and lowering. The pantograph, being better adapted for pneumatic operation, can be remotely controlled, and is therefore most suitable for multiple unit operation. Furthermore, for high tension installations pneumatically controlled trolleys can be manipulated by grounded valves, introducing an element of safety not as readily obtained with the pole and wheel.

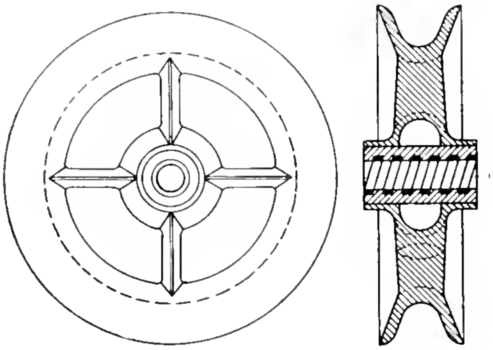

Fig. 1. Composition Trolley Wheel

Trolley Wheels

The greatest difficulties experienced with collectors using wheels or rollers are to secure satisfactory lubrication and to conduct the current from the revolving part to its support. For the lubrication of wheels for both low and high speed service, the ordinary method is to employ graphite paste pressed into spiral grooves scored in plain brass bushings. (See Figs. 1 and 2.) Grease or oil, however, applied in a variety of ways, is not uncommonly used.

In reference to lubrication and the most efficient size of bearing, it is interesting to note that a 5 in. roller at a car speed of 56 m.p.h., eliminating slip, makes approximately

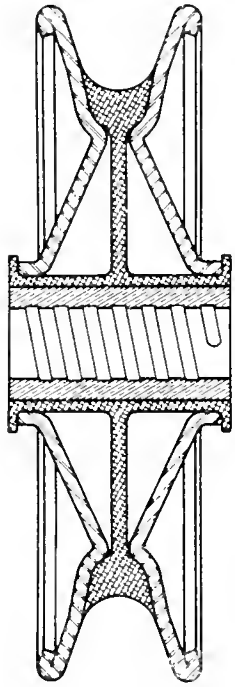

Fig. 2. Cross Section of Steel Flanged Trolley Wheel

3360 r.p.m., giving a peripheral speed at the surface of a $\frac{5}{8}$ in. pin bearing of about 550 feet per minute. This is exceedingly low when compared with turbine and generator shafts where the surface speeds are sometimes carried as high as 8000 feet per minute. But the conditions are really in no way comparable on account of the hammering and end thrust that a wheel or roller is constantly subjected to, and the matter is cited simply [illegible] the difficulty in establishing an absolute [illegible] for calculating efficient dimensions and determining what will be the most suitable [illegible] lubrication for this class of work.

Many railways in [illegible] the small $\frac{1}{2}$ in. or $\frac{5}{8}$ in. pin bearings [illegible] preferable to the larger sizes, such as [illegible] $\frac{3}{4}$ to 1 in. in diameter. The growing tendency is, however, towards the larger pin.

Probably the reason why there is no fixed opinion as to the most efficient diameter of these bearings is that a sort of equality in results exists, inasmuch as for a given diameter and speed of wheel, as the pin's diameter increases its surface speed and friction decrease, while on the other hand the leverage for the revolving force increases as the pin's diameter decreases.

Ball or roller bearings for this class of work are not altogether satisfactory, as they become quickly pitted and scored by the current unless insulated. Unfortunately, it is necessary to depend upon the bearings to carry part of the current, as the side collecting springs often become worn out or do not give full pressure. This means that as the current cannot readily get through the bearings rapid destruction of the wheel follows.

Trolley wheels vary in diameter from 4 in. to 7 in. with corresponding diameters at the tread approximating $2\frac{1}{2}$ in. to 5 in. The larger sizes are employed for high speed operation and, while the smaller wheels are still quite universally used for city and low speed service, they are gradually being superseded by the larger types.

The chief advantage of the larger diameter wheel lies in the fact that at a given car speed it makes less revolutions than one of smaller proportions, and, having a greater leverage for being revolved about its bearing, overcomes more readily the bearing friction, which is one of the causes of slipping between the wheel and wire.

The standard wheels of today are mostly cast from an alloy or are built up with steel flanges and a copper center. (See Figs. 1 and 2.) Hardness and conductivity, the essential characteristics, are obtained in the case of the alloy wheels by a mixture over 90 per cent copper with a small amount of tin and zinc; the tin in combination with the copper introducing hardness, while the zinc improves the flow point for casting.

Cast iron wheels are used to some extent, the claim being that they last much longer than those made from other material. While this is undoubtedly the case, they cause excessive wear on the trolley wire due to their contact surfaces becoming pitted and covered by fine points from the arc, which are then chilled by the air to a cutting hardness. These conditions are much exaggerated during rain and sleet storms.

With reference to the life and amount of current that can be collected by trolley wheels, the speed and capacity of the equipment upon which they are used, together with the character of the line, whether straight or full of curves, all have an important bearing. It may be said, however, that for the average interurban road, assuming the life of a wheel to be from one to three thousand miles, current approximating 800 amp. during acceleration can be safely handled.

As previously stated, the limitations for collecting current are primarily due to the difficulty in getting it from the rolling parts to their support, and it must be confessed that the ideal arrangement has not as yet been found. The usual method of doing this is by side springs and washers, a scheme not entirely satisfactory, as aside from the difficulty in obtaining sufficient contact surface, friction is a serious obstacle and the pressure of the springs must be exceedingly

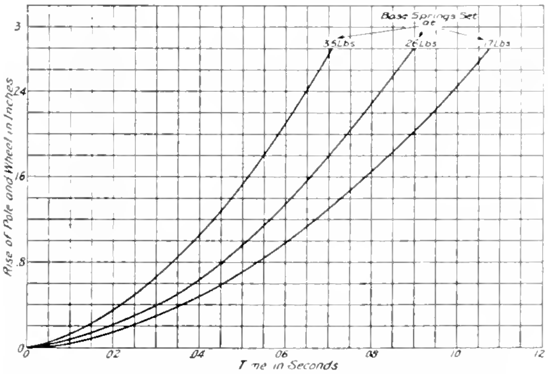

Fig. 3. Representative Time-Rise Curve Resulting From Inertia of a Standard Pole and Wheel Raised by Trolley Base Equipped with Compression Springs

light, otherwise it will prevent the wheel from revolving and will introduce slip between it and the wire.

Harps and Poles

In the design of trolley harps for carrying the wheel, it is obvious that they must be as light and simple as possible. Attention has to be given to smooth surfaces so that in case of leaving the wire the guy or spans of the overhead construction will ride over the parts without tearing them from the pole, or base. Loose pins in the harp together with unbalanced wheels are the chief causes which shorten the life of a wheel and must be avoided.

Trolley poles are made in a variety of ways; some are rolled up from steel and butt-welded together, while others are cold drawn and seamless in construction. All types are tapered and reinforced to permit the greatest uniform strength throughout the length consistent with lightness.

Trolley Bases

In the design of trolley bases sensitiveness in responding to the irregularities of the over-

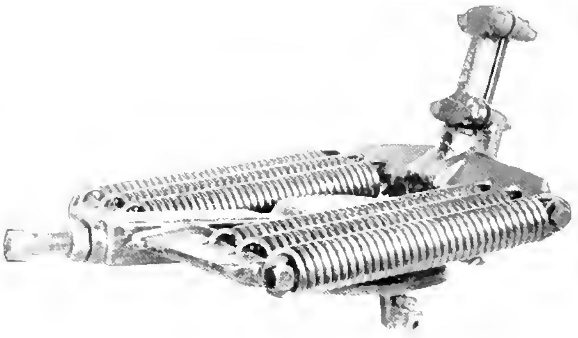

Fig. 4. Ball Bearing Trolley Base

head line, both laterally and vertically, is most essential, and for this reason ball or roller bearings with a battery of tension springs to raise the pole are now very generally employed (see Figs. 4 and 5). The great length of wire which can be obtained by the use of tension springs introduces sensitiveness to the vertical movement of the wheel not readily derived from compression springs (see Fig. 3), and the ball and roller bearings give the necessary freedom to the

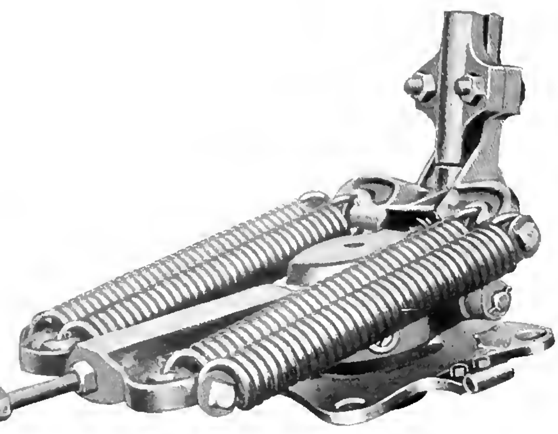

Fig. 5. Roller Bearing Trolley Base

lateral movement. For the bearings there is little choice between the two types when fitted with properly hardened parts. The rollers give greater wearing surfaces and may perhaps be considered preferable. On the other hand, the use of balls permits a lower base, which is often necessary to meet restricted bridge or tunnel clearances.

The upward operating pressures delivered at the wire by the base springs are adjusted to meet the speed and capacity of an equipment. For instance, for city or low speed service not exceeding 30 m.p.h., and where accelerating currents are not greater than from two to three hundred amperes, pressures ranging between 20 and 30 pounds are used. For greater speeds and heavier equipments, the pressures are increased, 30 to 35 pounds and often as high as 40 pounds being employed.

Retrievers

Before leaving the subject of pole trolleys a word should be said in regard to retrievers or trolley catchers. Hundreds of schemes have passed through the patent department at Washington, disclosing almost every conceivable idea to prevent the wheel from leaving the wire or catching it in case it does. The accepted arrangement, however, is the rope catcher and retriever. This device is manufactured in numerous ways, although in principle they are all essentially alike; mechanical dogs are thrown out by centrifugal force as the disk to which they are attached is spun by the rapidly rising rope when the pole leaves the wire. These dogs in their outward movement not only release catches which grip and hold the rope but disengage a powerful spring which has been previously wound up and which reacts upon the rope to bring the wheel below its normal operating height.

Pantograph Collectors

The design of the pantograph trolley has been brought about by the demand for an overhead collecting device which, unlike the ordinary pole and wheel, requires little attention on the part of the operating employee. They are usually fitted with long rollers or pans with horns extended at either side to guide and lead the contact through switches or cross-overs of the overhead construction. The frame is built up of light steel tubes or angle iron, as inertia of the parts plays an important part towards the successful operation of collectors of this type.

Friction is also eliminated as nearly as possible. In the case of heavy roller contacts, if ball or roller bearings are not used at the ends a very marked difference in the upward and downward pressure at the wire is caused. For instance, if the springs are set to deliver 30 pounds pressure when the contact is rising, it may require as high as 50 pounds to start to move it down. This excessive pressure in falling is serious, especially for catenary suspensions, as it may hold the wire lifted and throw it badly out of alignment. This puts severe strains upon the trolley and causes many other troubles with the overhead line.

Selection of Pantograph

In the selection of a pantograph, the type of contact, whether pan or roller (see Figs. 6 and 8) is largely determined by the amount of current to be collected. With rollers, 1200 amperes during acceleration or short grades can be safely taken care of with a single unit. With the pan contact 150 amperes during acceleration is about the limit. These figures are, of course, very general, and will vary in accordance with the life expected to be obtained from the contacts. From the foregoing it will be apparent that the pan is particularly adapted to high voltage equipments.

In part explanation of the difference in collecting capacities of the two types of contacts: with pans, very light pressure at the wire must be maintained, otherwise serious wear is caused not only on the wire but on the pan itself, the latter grooving and soon being cut through. Furthermore, the lightness of the pan and construction results in low inertia for the parts, which prevents the contact from jumping and eliminates serious arcing which would otherwise occur with a heavy frame and contact and light pressure.

Where rollers are used the upward pressure can be raised sufficiently to maintain a reasonably good contact without arcing, and the fact that they revolve prevents, to a large extent, the surface becoming grooved and permits a good life for the tubes. For the roller contacts, thin pipes or tubes of either brass or steel are customarily used; the complete roller and parts being as perfectly balanced as possible, as their life and successful performance are largely dependent upon this feature.

Steel, while wearing the trolley wire somewhat more than brass, has a much greater life. The wear is not, however, as serious as in the case of steel wheels, as the constant play of the wire from side to side over the roller tends to smooth off the surface when roughened by the arc. For pan contacts 1/8 in. steel pressed into channel shape is generally employed. Its life is short, but this is practically offset by the extreme simplicity and cheapness of the piece. Bar or rod contacts

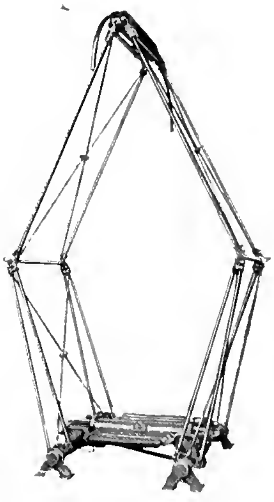

Fig. 6. Roller Pantograph Extended

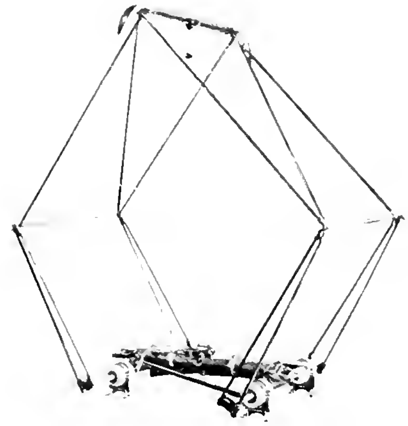

Fig. 8. Pan Pantograph Extended

Fig. 7. Roller Pantograph Collapsed

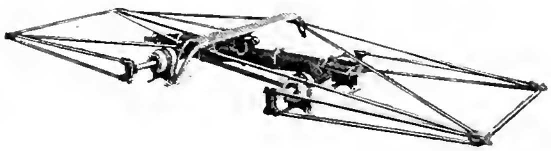

Fig. 9. Pan Pantograph Collapsed

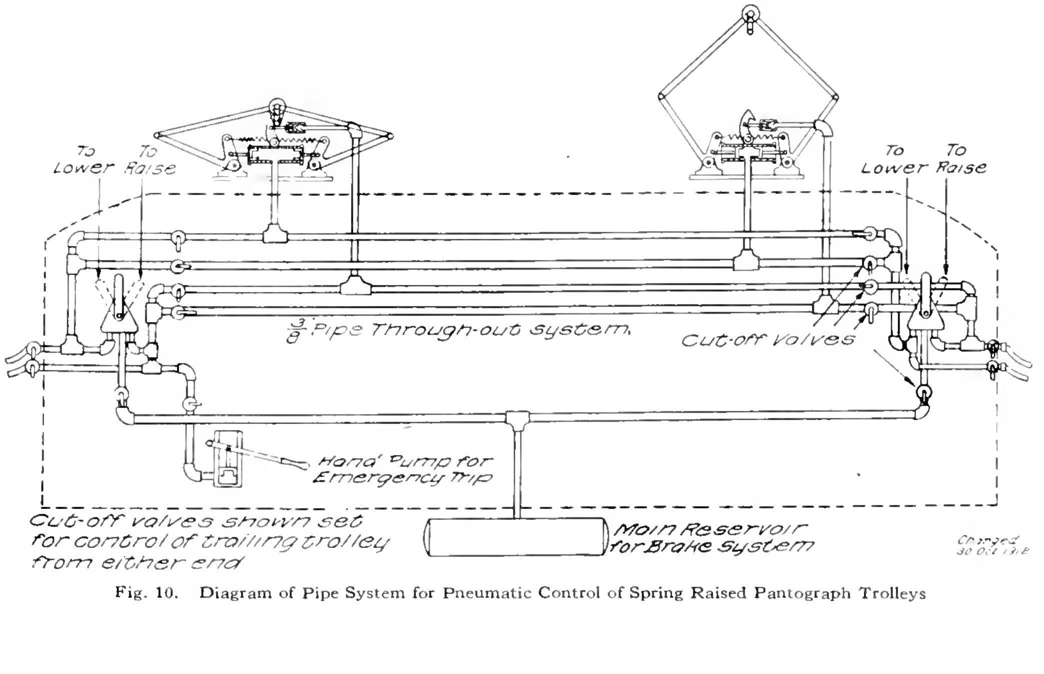

Fig. 10. Diagram of Pipe System for Pneumatic Control of Spring Raised Pantograph Trolleys

are not uncommon in Europe, but in this country are applied to bow trolleys only.

Pantograph Control

The pantograph, as in the case of pole trolleys in its simplest design, is raised by tension or compression springs and lowered by means of a rope. Pneumatic control is, however, most generally used, the desired results being secured in a number of ways. For instance, the trolley may be raised by the compression or extension of springs through means of air admitted and held in the controlling cylinder, the release of the air permitting it to collapse. Again the springs may be brought into action pneumatically and locked by catches so that the air may be entirely released and when necessary to lower the trolley the catches may be tripped by admitting air to an auxiliary cylinder. Other designs are normally held raised by springs and depressed pneumatically against the spring pressure into catches controlled by an auxiliary cylinder (see Fig. 10).

The various schemes for raising and lowering have their advantages as well as disadvantages. With the trolley held up by springs there is always the possibility of it slipping its catches when collapsed and rising at some inopportune time; on the other hand, when dependence is placed upon the air for holding the trolley up, the loss of air means the pumping up of an auxiliary reservoir or the main trolley cylinder itself by a hand pump to establish the compressor motor circuit. Sometimes it is done by direct fish pole connections, but at high voltage this is dangerous practice.

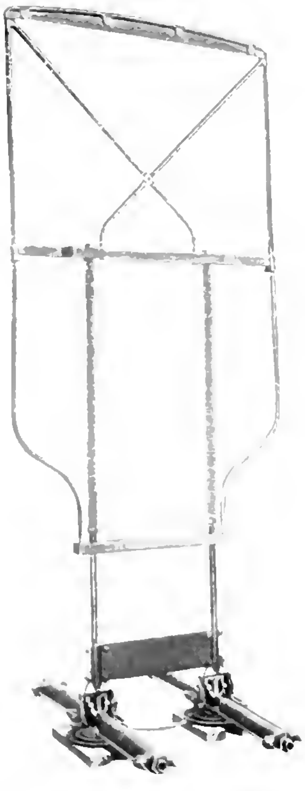

Fig. 11. Bow Trolley for Freight Yard Shifting Service

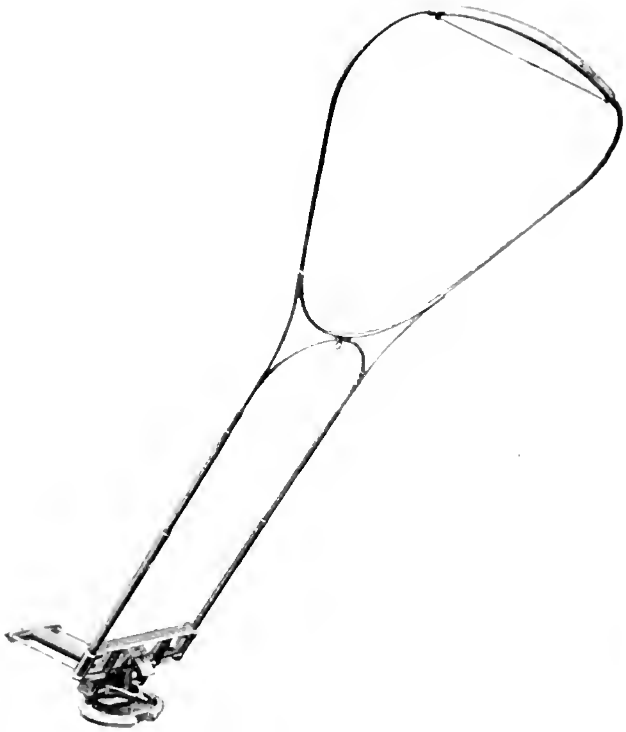

Fig. 12. Foreign Light Service Bow Trolley

The pros and cons with reference to different pantograph designs and their operation are too numerous for further consideration in the limited space of this article. A few words should, however, be said in regard to their control. For single car or locomotive installations, this is done by means of a valve somewhat similar to the ordinary motorman's brake valve. For multiple unit operation electro-pneumatic valves fitted with coils for remote control are employed; handles for raising or lowering the pantograph individually and not electrically, also being provided.

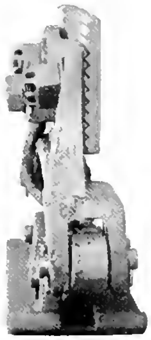

Fig. 13. Gravity 3rd Rail Collector, Side View

Bow Trolleys

Passing to the subject of bow trolleys, this type is not used extensively in this country, the few installations being upon yard or freight shifting locomotives. Their construction is not complicated, the bow or frame usually being carried by standard trolley bases and made virtually in two halves (see Fig. 11), the upper section being balanced upon springs so that it will depress when the direction of the locomotive is changed. This relieves the strains on overhead construction.

Fig. 15. Folding Gravity 3rd Rail Collector

Catenary suspension is best suited for bows, as it will lift when reversing and this together with the flexibility of the frame eliminates serious wear and tear on the line as well as upon the trolley itself. The bow is, furthermore, so constructed that, in case it slips off the wire at Y's or cross overs, it will ride out freely, consequently largely eliminating personal attention.

In Europe bow trolleys are used for various classes of railway service, but are made exceedingly light and often fitted with contact bars of aluminum grooved for the reception of grease or graphite lubrication (see Fig. 12).

3rd Rail Collectors

There are two distinct types of collecting devices for third rail equipments; one where the shoe or slipper rests upon the rail by gravity alone (see Figs. 13 and 14) and the other where a light slipper is pressed against

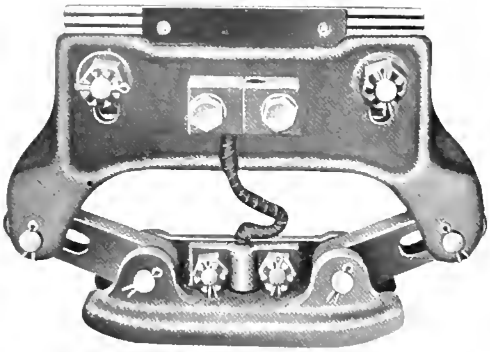

Fig. 14. Gravity 3rd Rail Collector, Front View

the rail by springs (see Figs. 19 and 21). In a general comparison of the two designs, the spring-depressed collector is usually fitted with a thin flat shoe pivoted at one side and projecting out at right angles to the equipment, while the other type carries a loose shoe supported from a frame by links.

The former design, on account of the shape of the slipper, permits better protection for the third rail and is, therefore, quite generally used for surface roads.

Fig. 16. Folding Gravity 3rd Rail Collector (Raised)

For private right of ways, such as elevated railways where full protection is not needed, the gravity shoe meets the requirements.

In the selection of the type of collector to be used the speed of the equipment is a factor not to be overlooked, as above 30 or 40 m.p.h. serious arcing from jumping will occur unless the slippers are backed up by springs. The shoes are usually supported on the car or locomotive by heavy oak beams thrown across the axle boxes. This arrangement affords ample insulation and at the same time avoids the vertical play incident to its attachment to the main body of the car.

For elevated railway service, where gravity shoes are generally used, the links are made as strong as possible to prevent trouble from the shoe breaking away and falling to the street. For surface roads, the opposite stand is taken and the links are made the weakest part of the equipment; the idea being that in case of meeting an obstruction, the links will break and prevent the complete beam and shoe from being torn off, which might result in more serious trouble. The same idea is followed out in the spring-depressed slippers, the cross section of the casting being reduced at a point several inches back from where it rests upon the rail.

Collectors for under-running third rails must necessarily be held in contact by springs. They are, however, identical with the over-running types, except that the slipper wearing surfaces are reversed and the springs made to give pressure in the opposite direction. If required, by a peculiar arrangement of its springs, the same shoe can be made serviceable for both systems.

Where railways operate their equipment by both the trolley and third rail, it is often desirable at such times as the shoes are not in service to have them folded back out of the way. This is done in the case of the gravity type (see Figs. 15 and 16) by turning up the complete beam with the shoe, the beam being hinged upon the car axle boxes. For collectors depressed by springs, it is customary to fold up the slipper only (see Figs. 17 and 18).

The pressure for the slippers at the rail depends largely upon the currents to be collected and the speed of the equipment. For gravity shoes used only with slow speed light equipments, the slipper and links will not weigh more than 15 or 20 pounds; while for high speed, heavy current service the weight of the slipper, plus the spring pressure, is often carried as high as 45 pounds. Under the latter conditions currents from 1200 to 1500 [illegible] can be successfully handled [illegible] during acceleration or upon [illegible]

Underground Contact Collectors

The method [illegible] for collecting current for the [illegible] conduit is perhaps not as generally [illegible] those for the trolley or third rail [illegible] be due to the fact that the collectors are [illegible] under the car and practically hidden [illegible] view. The conducting rails in the conduit are usually twin steel T sections, spaced about 6 inches apart and carried parallel with the street. They are, furthermore, suspended from insulators 10 to 15 inches below the track surface and are supported by cast steel yokes imbedded in the ground, which are also designed to carry the track and slot rails. To take the current from the rails, the collectors or conduit plows, as they are commonly called (see Fig. 23), are fitted with contact shoes which slide on the face of the T section.

These contact shoes are generally made of chilled cast iron and are mounted upon leaf steel springs to give the required flexibility to take care of irregularities in the slot or conductor rail alignment, wheel play, etc. Fuse leads join the shoe to the main leads passing through the plow to the truck to protect the body of the plows from destruction in case of short circuit from shoe to shoe.

On account of the narrowness of the street slot, which, due to traffic conditions, is limited to from $\frac{5}{8}$ in. to $\frac{3}{4}$ in., the leads passing through the plow are necessarily made thin; usually of solid strip copper, insulated by a high grade rubber vulcanized in place. They are protected from injury by thin steel sheets which act as tie pieces between the plow head and the insulation apron which carries the shoe. Nosing plates of very hard steel are also added to resist the severe wear caused by the slot rail edges. The apron or insulated space block which supports and separates the shoes is made of several pieces of impregnated wood and is large enough to act as an effectual barrier to flash-overs or short circuits. Filling pieces of gasket rubber with high dielectric strength prevent possible current leakage.

The head of the plow is made in the form of a receptacle for the compound which is poured in hot to give the necessary insulation for the connecting joints of the out and inside leads.

For supporting the plow to the truck various methods are employed. All the different schemes, however, provide for freedom to lateral movement, to take care of any irregularities which may occur between the alignment of the slot and track rail, as well as to provide for the play of the truck wheels between the track gauge limits.

For conduit equipments which also operate over third rail or trolley systems, many automatic schemes have been devised for removing or replacing the plow at transfer points. The accepted method is, however, for an employee stationed in a street pit to do the work by hand.

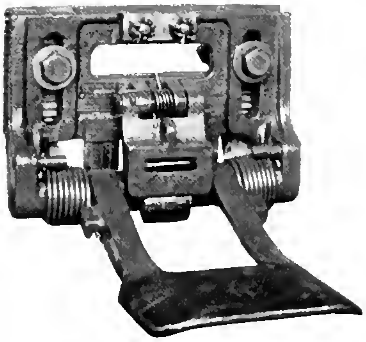

Fig. 17. Folding Under-Running Slipper Collector

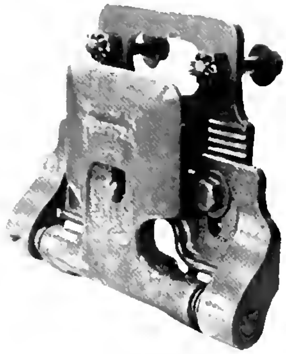

Fig. 18. Folding Over-Running Slipper Collector

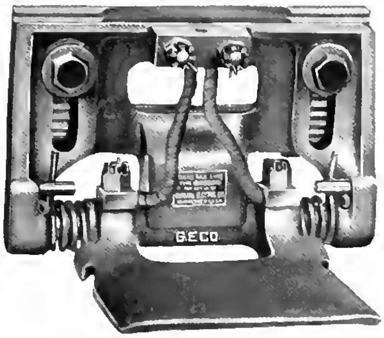

Fig. 19. Front View Under-Running 3rd Rail Collector

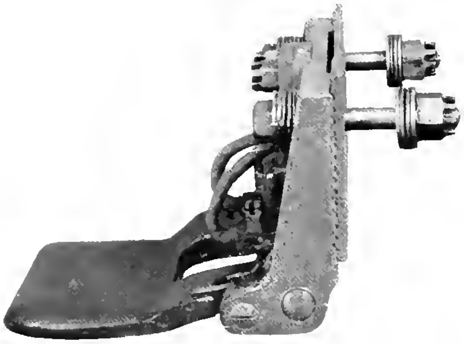

Fig. 20. Side View Under-Running 3rd Rail Collector

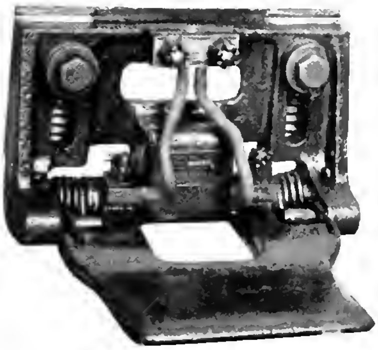

Fig. 21. Front View Over-Running 3rd Rail Collector

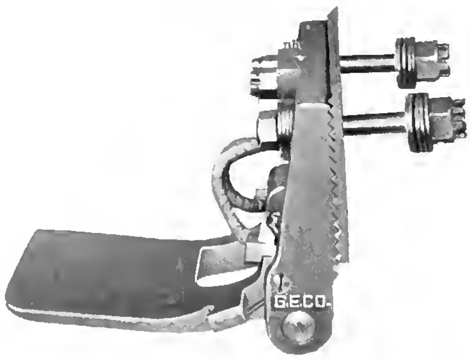

Fig. 22. Side View Over-Running 3rd Rail Collector

Conduit plows are subjected to the most severe kind of service and, although the conduit proper is carefully drained and

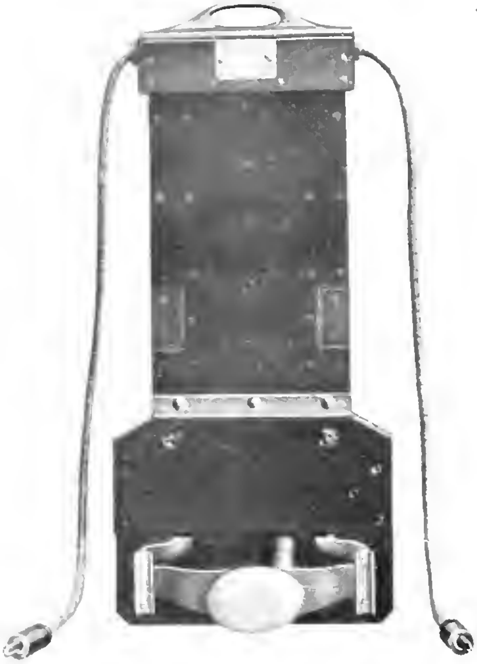

Fig. 23. Underground Conduit Plow Collector

kept as clean and dry as possible, street filth and moisture are bound to accumulate on their surfaces. Furthermore, as the conductors in the conduit are practically concealed, they cannot be closely watched and their condition and alignment may therefore be such as to throw serious strains and wear upon the plows. For these reasons conduit plows require more care and attention than any of the various devices designed for railway current collection, and unless frequently inspected and kept clean develop defects which are a source of a great deal of traffic delay, with consequent annoyance both to the public and the railway.

In conclusion, a word should be said in regard to the bearing which the line voltage has upon the design of the different types of collectors. For conduit plows, on account of the difficulty in getting proper insulation incident to underground installations, it is doubtful if they can be made to advantage for potentials very much in excess of 600 volts. For trolley and third rail systems the line potential plays an unimportant part in the design of the collectors proper, as it is customary to mount the apparatus upon suitable insulated supports.

Railway collecting devices, as in the case of other electrical apparatus, are ever in a state of evolution and development; increased speeds, higher voltages and greater equipment capacities as well as experience arising from the constant change in operating conditions demanding greater efficiency and perfection in their design.

CATENARY LINE MATERIAL

By C. J. Hixson

Railway Equipment Engineering Department, General Electric Company

The first part of this article is devoted to a series of definitions of the various terms and devices used in connection with trolley wire installation. Curves are included showing the relation between pole spacing, sag, line tension, and temperature which enable the stringing of messenger and trolley wires according to the latest approved practice. The importance of vertical flexibility in the trolley wire and elasticity in the line as a whole is made apparent, and the means whereby these features are secured by the supporting devices is described.—Editor.

The introduction of higher operating voltages than 600, as well as increased speed of operation, has resulted in the development of catenary line material. This construction, in addition to allowing of suitable insulators for high voltages, provides the necessary flexibility of the contact wire for high-speed pantograph operation, as well as minimizing the interruption of service due to breakage of the trolley wire.

In order to conveniently and accurately express certain functions which have to be performed and to have definite names for the parts employed for these purposes, it is necessary that the names adopted have particular meanings of their own.

"Hanger" refers to the device used to support the trolley wire from the messenger wire.

"Pulloff" refers to the device used to hold the trolley and messenger wires in place laterally, especially upon curves.

"Anchorage" refers to that part of the overhead system designed to hold the trolley and messenger wires from longitudinal movement.

"Deflection" means the distance between the trolley and messenger wires at the point where the messenger wire is supported.

"Sag" refers to the distance between a straight line drawn through the adjacent points of support of any wire and its lowest position.

The "reference line" is an imaginary line located at the proper trolley-wire height above the center line of the track, equi-distant from the two rails. One railway system is making use of a large **T**-square to locate this line, similar to that shown in Fig. 1. A vertical adjustment can easily be arranged for measuring different heights if desired.

The "displacement factor" or displacement at any point is the lateral displacement of the trolley wire from a line drawn through the center line of the track and the reference line. This may also be defined as the distance of the trolley wire from a plane passing through the reference line and the middle of the track line. See Fig. 1.

"Displacement" is introduced in order to improve the operation of the collecting device; and it varies in its values for different localities along the line, as well as for different types of cars and collecting devices. Between adjacent pulloffs on a curve the trolley wire (being a straight line between the two pulloff points) crosses and re-crosses the reference line which follows the curvature of the track. Starting at a pulloff point on the trolley wire, the displacement will be a maximum on the pulloff side of the reference line. Its values then decrease to zero, at which point the trolley wire crosses the reference line, then increase to a maximum on the other side of the reference line, then gradually decrease to zero where reference line and trolley wire cross for the second time, then increase to a maximum again, the same as at the first pulloff point. The number of pulloffs used on a curve should be such that the displacement at a pulloff point does not exceed the limits of successful operation for all of the collecting devices used upon that road.

It is desirable to have a convenient means for measuring displacement in order that the pre-determined limits may not be exceeded. It is more economical to keep the trolley wire in proper alignment than to correct it after trouble has occurred. By an attachment to the **T**-square previously referred to which takes the form of a stationary

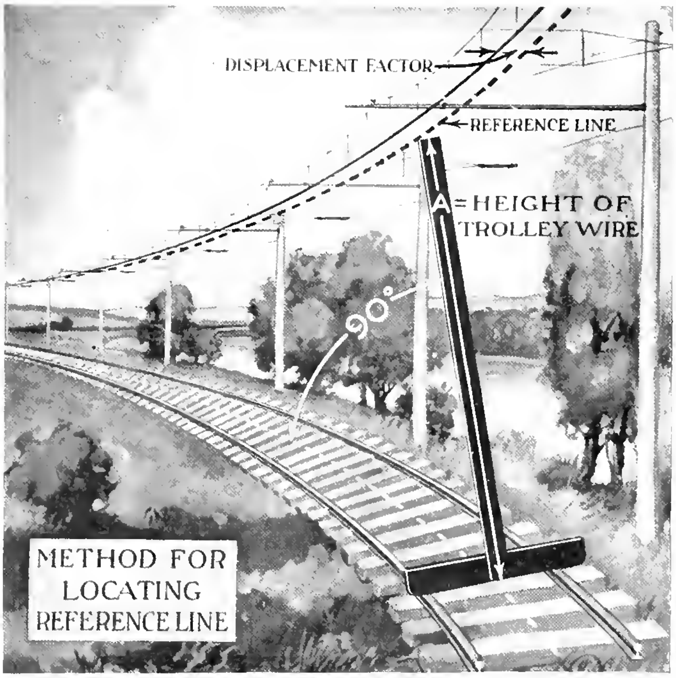

Fig. 1
Fig. 1 Illustration Showing the Dimensions Used in Locating the Parts of an Overhead System with Reference to the Track and the Device Used in Making the Measurements

base resting upon the surface of the track rails, it is possible to slide the head of the **T**-square back and forth and measure the displacement on the top of the stationary base.

The "normal trolley wire position" refers to a trolley wire occupying that position which differs only from the reference line by the displacement at that point.

The "vertical variant" is the distance which the trolley wire rises above or falls below the normal trolley wire position, and is due primarily to changes in temperature. The movement is in the direction of gravity and it should not be confused with movements due to the collecting devices.

The terms which have been indicated are not difficult to measure and definitely fix the position of the trolley wire with reference to the track. In order, however, to describe the stress conditions within the overhead system, it is necessary to have terms connecting the stresses in the various wires with the terms relating to positions.

A "stress-position standard" is a relation between the stresses within an overhead system such that at some assumed average

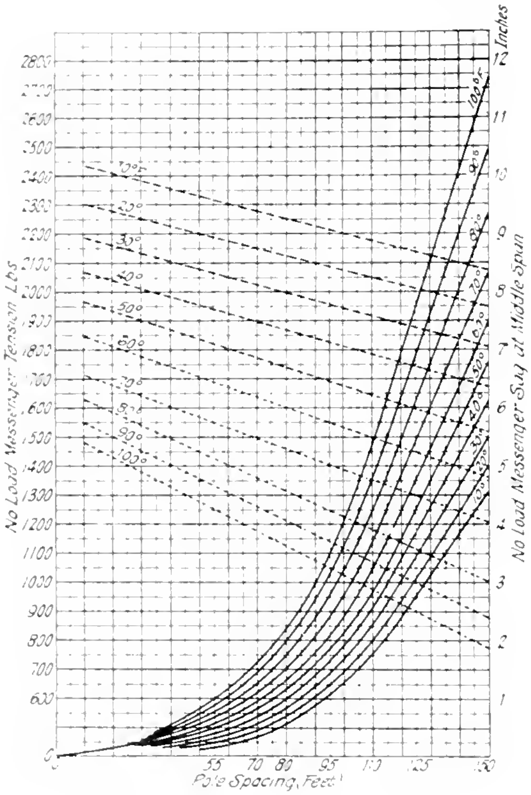

Fig. 2. Relationship Curves for a Particular Messenger Wire

temperature the trolley wire will coincide with the normal trolley wire position. Such standards are of particular importance since they serve as a basis for installing overhead systems at different temperatures. When the temperature in each of several systems installed according to the same stress-position standard reaches the basic value of that standard, the trolley wires will have the same definite stress and occupy the same definite position. It is possible to have a number of such standards depending upon, among other factors, the temperature variations in that latitude, the sizes of the trolley and messenger wires, and the type of the collecting device.

The stress-position standard "A" is most commonly used, and may be defined as that relation between the stress within an overhead system which will produce at 70 deg. F. in a 4/0 trolley wire, a tension of 1500 lb., with the trolley wire coinciding with the normal trolley wire position. The temperature of 70 deg. F. was chosen since this represents approximately a mean temperature; and the stress of 1500 lb. was selected, since at that value the stress does not appear to increase to the danger mark during cold weather nor does the wire appear to become too slack in hot weather.

When installing an overhead system so as to have a standard trolley wire, it is necessary to make certain allowances both in the messenger and trolley wires at different installation temperatures.

Fig. 2 shows the allowances to be made for the messenger wire, and Fig. 3 the corresponding allowances for the trolley wire. These curves hold good, however, for only a definite set of conditions, viz., the system must be of a stress-position standard "A," the messenger wire be of stranded steel $\frac{7}{16}$ in. in diameter, the suspension be 11 points at 150 ft. pole spacing with an 8 inch center

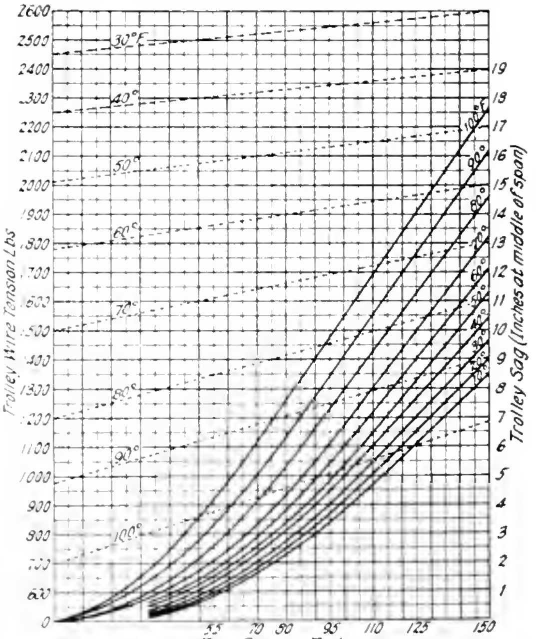

Fig. 3. Relationship Curves for a Particular Trolley Wire

hanger, the deflection be 28 inch, and the line elasticity be neglected.

Should a different set of conditions be encountered, as for example a 5/8 in. steel messenger wire with 300 ft. pole spacing, an entirely different set of curves would be necessary even though the overhead system were of a stress-position standard "A."

Messenger Wire

The messenger wire is first installed with the proper tensions (or sags) so that when the trolley wire is afterwards hung from it the result will be a standard "A" trolley wire. Two curves are shown in Fig. 2 in which one has pole spacing in feet as one co-ordinate and sag in inches as the other; the second curve has pole spacing in feet as one co-ordinate and pounds tension as the other. Both of these curves are given since the use of the dynamometer when measuring tensions is not as convenient for an experienced workman as it is for him to sight over the points of support and measure the sag.

In order to illustrate the method of using the curves, assume that the definite conditions exist as previously stated and the temperature at the time of installing the wire is 40 deg. F. It is desired to find the correct sag where the pole spacing is 80 feet. Locate the vertical line corresponding to the 80 ft. pole spacing, and the point of intersection between this line and the 40 deg. full-line curve gives a no-load sag of 1 inch, reading the vertical co-ordinates at the right of Fig. 2. If, instead of the sag, it had been desired to know what would be the pound-tension, the intersection of the vertical line corresponding to the 80 ft. pole spacing with the diagonal dotted line corresponding to 40 deg. would give 1870 lb. tension, reading the vertical co-ordinates at the left of Fig. 2.

Fig. 4 Loop Hanger

Trolley Wire

Fig. 3 refers to the trolley wire which should also be installed with certain sags and tensions in order to insure that it will be in accordance with stress-position standard "A."

In case it is desired to measure sags, instead of using dynamometer readings, this can be done by temporarily supporting the trolley wire at the brackets and cross spans.

Assume that the conditions are identical with those stated for the messenger wire, except that we should like to find the proper sag where the poles are 125 ft. apart. Referring to Fig. 3, the intersection of the vertical line corresponding to the 125 ft. pole spacing with the full-line curve corresponding to a temperature of 40 deg. F. gives a sag of 7.65 in., reading the vertical co-ordinate at the right. If, instead of sag, tension had been required, the intersection of the vertical line corresponding to 125 ft. pole spacing with the dotted line corresponding to a temperature of 40 deg. F. would give a tension of 2375 lb., reading the vertical co-ordinates at the left of Fig. 3.

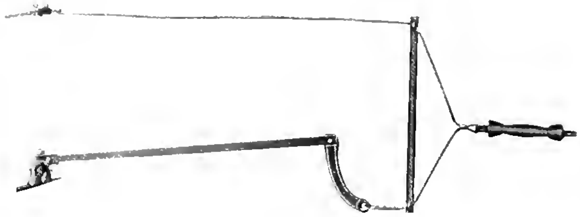

Fig. 5. Flexible Hanger used at Pull-Off Point on Curves

VERTICAL FLEXIBILITY OF THE TROLLEY WIRE

It is of the greatest importance that the trolley wire should have an approximately uniform vertical flexibility throughout its entire length as both the life of the wire and the successful operation of the collecting devices depend upon this feature. To accomplish this it has been necessary to design suitable hangers, pulloffs, anchorages, etc., in order to eliminate all rigid points in supporting and holding the contact wire. For tangent track a hanger is used having a long loop passing over the messenger wire, and fastened at the ends of the clamps which grip the trolley wire, see Fig. 4. These hangers are free to rise with the trolley wire, independent of the messenger wire, as the collector passes beneath them.

Upon curves, flexibility is provided at pulloff points by means of the arrangement shown in Fig. 5. The messenger and trolley wires are held in position by separate clamps and a strut of proper length is located some three or four feet away from the trolley wire which allows the latter to rise without lifting the weight of the messenger wire.

Vertical flexibility curves can be made for different points along the trolley wire, and these curves can be combined into one curve showing the height to which the trolley wire will rise when subjected to a definite collector pressure. Such a curve is known as a "trolley wave crest curve" and is shown in Fig. 6. It is to be noted that the height of movement is greatest at the center of the span, growing gradually less toward the points where the messenger is supported. This difference in upward movement or vertical flexibility is due to the lifting action exerted by the messenger wire, as well as the fact that the hangers in the center of the span are of less

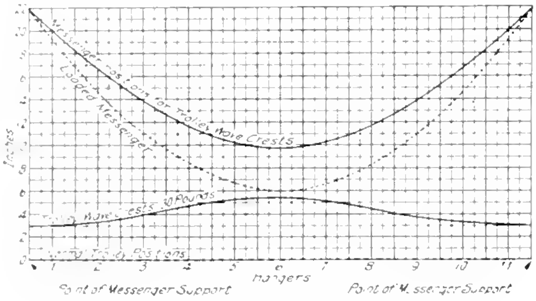

Fig. 6. Trolley Wave Crest Curve for One Span and Corresponding Position of Messenger

weight than those near the points of messenger support. These curves represent the height to which the wire will rise when the collecting device reaches that point and it is not to be confused with the trolley wire wave at any particular instant. The trolley wire wave extends for several spans in either direction gradually decreasing in its height, whereas for the same location if the adjacent span happened to be the same, the wave crest curve would simply repeat itself at each span. Fig. 7 shows wave crest curves for the same span but with different collector pressures.

Line Elasticity

It is desirable that a line when subjected to the extremes of temperature during several years of service should have sufficient inherent elasticity to retain the same stresses as existed at the time of the installation. This can scarcely be expected to hold true until after the first year as the supporting structure and back guys do not reach their permanent positions for some time. Actual measurements made upon one line show that after a period of five years the stresses have remained the same without automatic or mechanical [illegible].

It is a [illegible] practice in Germany to assist line elasticity by a system of weights. The trolley wire [illegible] in sections having one end rigidly anchored and at the other end a weight is arranged which rises and falls with the temperature changes. The difficulties arising from not making such provisions have not been so great thus far as to cause railways in this country to adopt such measures. It is desirable, however, that provisions be made for insuring sufficient line elasticity to take care of temperature changes, but tests lead us to believe that it is possible to accomplish this without resorting to pulleys and weights.

The elasticity of the line is made up, among other factors, of the elasticity of the metals entering into the overhead structure. The elasticities of steel and copper are known quantities but the remaining factors are variables with but little definite data available at present. In general, line elasticity is influenced by the type of poles, the nature of the soil in which these poles are placed, the supports for the overhead system, the number of curves and grades, and the type of anchorages for holding the line. The frequency of the hanger points are also a factor, as for example, if a three-point suspension is used and afterwards an 11-point suspension under identically the same conditions, the three point will have considerably greater elasticity than the eleven point owing to the action of the greater sag between the hangers. Wooden poles are more flexible than rigid steel poles or towers. Hangers and pull-offs which allow a free and independent movement of the trolley and messenger wires tend to increase and equalize line elasticity by giving it a longer range and more gradual operation. Short, tight, and frequent anchorages tend to reduce line elasticity. The selection of other stress-position standards than standard "A" may result in increased line elasticity for a definite set of conditions.

One of the most recent applications of the methods outlined in this article was in connection with the Butte, Anaconda &

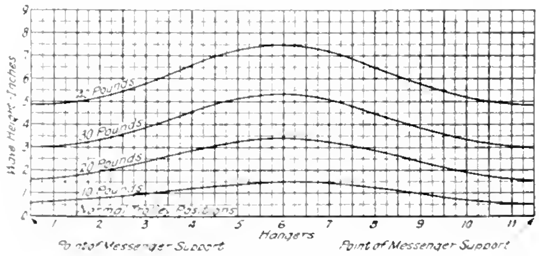

Fig. 7. Trolley Wave Crest Curves at Different Collector Pressures for the Same Span

Pacific Railway, Butte, Mont., which, although being formerly a steam road, employs the same type of overhead construction as is used for interurban and suburban roads.

THE PROTECTION OF ELECTRIC RAILWAY CIRCUITS FROM LIGHTNING

By E. E. F. Creighton

Consulting Engineer, General Electric Company

The continuity of service which railways are able to maintain in districts where lightning is prevalent is largely due to the use of arresters on the cars and along the pole line. The author shows that the use of arresters should not be confined to such vicinities only, for on all lines they render service by dampening the line surges caused by short-circuits, etc. The construction and operation of the aluminum and the magnetic blowout arresters, which are the two most effective types, are described, and statements are made which should be borne in mind when making a selection.—Editor.

Introduction

The main object of this article is to present, in the briefest manner, the general conditions of protection against lightning on electric railway circuits. Brevity requires bald statements of engineering conditions, which in actual detail may call for compromises. With this apology for an apparently arbitrary attitude, reference is made to more detailed discussions elsewhere giving some of the reasons for these brief statements and showing the limitations of the individual factors which enter the problems of protection. Many details will be found in an A.I.E.E. paper, Schenectady meeting, May 17, 1912, "Studies of Protection and Protective Apparatus for Electric Railways." The information on protection, freed from matters of interest to the designing engineer and student, that is contained in the thirty-five pages of that paper is condensed herein.

The design of a lightning arrester, its current rate, energy, kilowatt capacity, etc., is just as definite as the design of a railway motor. The service to which the arrester is subjected is also about as definitely known as that of the motor. A motor can be made to meet the most severe duty that may occasionally be imposed on it; so can a lightning arrester. But neither is so made, for the same reason: the interest on the whole investment would be greater than the occasional losses, and therefore the object in view is to make the occurrence of these losses exceedingly rare.

* The following explanation is given of the term "dielectric spark-lag." If across any gap in the circuit the voltage is raised until a spark passes, this particular value of voltage is called the *spark voltage* or *spark potential*. If now the voltage is removed and applied again at full value, a spark does not take place instantly; there is a brief delay of a fraction of a second which has been called the dielectric spark-lag. Although this time is usually extremely short, it is important because the lightning charge flows along a straight conductor at the rate of 180,000 miles per second. Since lightning travels a mile in 5½ millionths of a second it does not need much of a delay in forming the spark to permit the charge to penetrate into the windings of the motors and generators.

The D-C. Aluminum Arrester

The nearest to perfection in lightning arresters is the d-c. aluminum arrester. It has no gap in series and therefore has no dielectric spark-lag*; its discharge rate of current is many times greater than the best arrester of any other existing type; it has no appreciable inductance in its circuit; and its electrostatic capacity, combined with its internal losses, absorbs high frequency oscillations and thus shunts them away from the windings of the motor; and its electric valve effect prevents a rise of voltage resulting from opening an accidental short circuit, and thus prevents all flash-overs due to this cause. This statement applies also to rotary converters and generators.

The relatively higher cost of this arrester for use on cars is more than offset by the fact that its high efficiency permits of the use of a lesser number of arresters along the trolley line. The application of d-c. aluminum arresters to the apparatus of the Denver City Tramway has made it practicable to operate this system continuously through all lightning storms. All the other types of arresters were tried previously, but failed to give sufficient protection to permit the operation of cars during thunder storms.

An illustration of the d-c. aluminum arrester and surge protector, embodied in one device, is shown in Fig. 1. The device consists of two aluminum cells in glass jars, with a high resistance in shunt to the cells to give equal distribution of voltage between the cells. There is no series gap and therefore the arrester begins to discharge when the voltage rises in the least above the normal running voltage. The discharge rate at double potential is of the order of one thousand amperes as compared with a discharge rate for other types of arresters of the order of one hundred amperes and besides this low discharge rate with the other arresters a spark potential of 1800 to 3000 volts must first be overcome.

Lightning Induction in Car Wiring

If the wiring of a car is faulty from the standpoint of protection, even a perfect arrester may fail to protect. The cable of

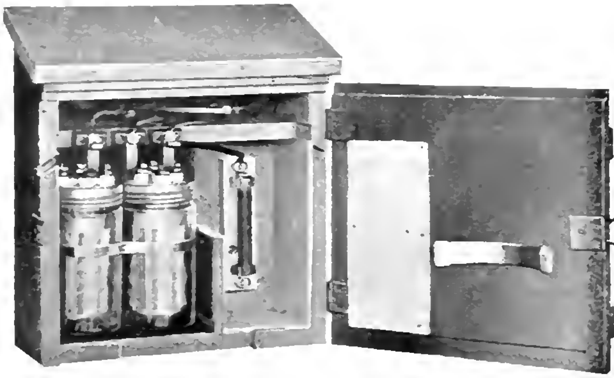

Fig. 1. Direct-Current Aluminum Arrester and Surge Protector

control wires for the motors must not contain either the ground wire or the trolley bus wire. Lightning current in the trolley bus wire or the ground wire will induce lightning directly in the motors, electromagnetically and electrostatically, if the lightning current runs near and parallel to the control wires of the motors. Most cars are wired to avoid this condition, especially if they have been built in recent years.

Arresters Along D-C. Trolley Lines

Arresters are installed along trolley lines for the purpose of relieving lightning strokes locally, and thus reducing the charge that reaches the cars. The better the car arrester, the less the number of arresters required along the line. Line arresters are not used for protecting the line unless the line is within [illegible] striking distance of grounded [illegible]. A line so placed [illegible] a *proximity conductor*, e.g., a trolley [illegible] from a grounded iron pole by means of [illegible] insulators. A long wooden strain insulator [illegible] the proximity and improves the protection against lightning, while a wooden pole for support separates the conductor from ground sufficiently to obviate the need of arresters for protecting the trolley wire insulation.

Gap-resistance Type of Lightning Arrester

The protective value of the gap-resistance type of arrester depends mainly on two factors; namely, the spark potential of the gap, and the resistance in series. In choosing the gap length, it would be desirable to have a spark potential not more than 25 per cent above the trolley potential, while the value of resistance should allow a free flow of several hundred amperes in order to discharge heavy lightning strokes. Nature has decreed that these two conditions shall not exist simultaneously in a gap arrester. A heavy current in a small gap will splash molten metal from the crater of the arc across the gap, and in consequence the generator current from the trolley will blow up the arrester. It is bad practice to draw the arc out mechanically and thus extinguish it, because lightning comes in multiple strokes and a subsequent stroke would puncture the insulation before the electrode could be returned mechanically to its original position. As a result of these natural conditions, a discharge rate is chosen as large as is consistent with a reasonably small spark potential, a powerful magnetic field being employed to lift the arc out of the gap before it can form a molten crater. Somewhat of an improvement has been made in recent years on this arrester for high potential d-c. circuits, consisting in the substitution of a permanent magnet for the electro-magnet to blow out the generator arc which follows the lightning stroke in the gap. The magnetic field of the permanent magnet is "on the job"

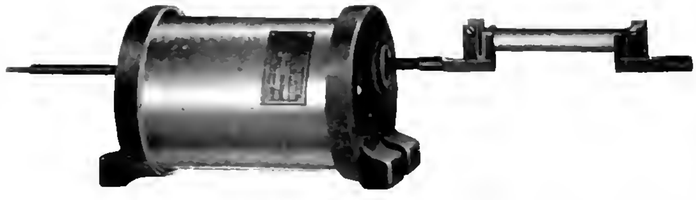

Fig. 2. The Magnetic Blowout Arrester for High Voltage D-C. Circuits. The gap setting is the minimum consistent with a reasonably large rate of current discharge. A permanent magnet is used, blowing the arc through a quenching arc-chute. The resistance is placed externally to facilitate inspection

constantly, whereas the electro-magnetic field must be built up with the current, and therefore may involve a small yet objectionable delay in moving the arc in the gap.

The gap and the resistance are intrinsic parts of the arrester. The gap has a dielectric spark-lag, and therefore when such an arrester is used on a car it is not complete without a choke coil to hold back the lightning charge from the motor until the spark is established in the gap. Thus the gap, resistance, and choke coil form the essential protective features. The magnetic blowout arrester is well adapted for use along trolley lines, for which service the dielectric spark-lag of the gap is not objectionable.

Choice of Protective Apparatus

The selection depends on conditions. How frequently do lightning storms occur? Are the cars limited to city streets, or do they run in the open country? How important is it to give reliable continuous service?

use of the best arrester to protect the motors. Although the aluminum plates wear out after a time (in from one to four years) the renewal cost is a low charge to pay for the insurance this arrester gives to continuous service.

If a gap type of arrester is used on the cars, then several arresters per mile should be used along the line. The more frequent the car service, the more arresters per mile should be used.

Protection of A-C. Railway Apparatus

The protection of a-c. railway apparatus does not differ materially from the protection

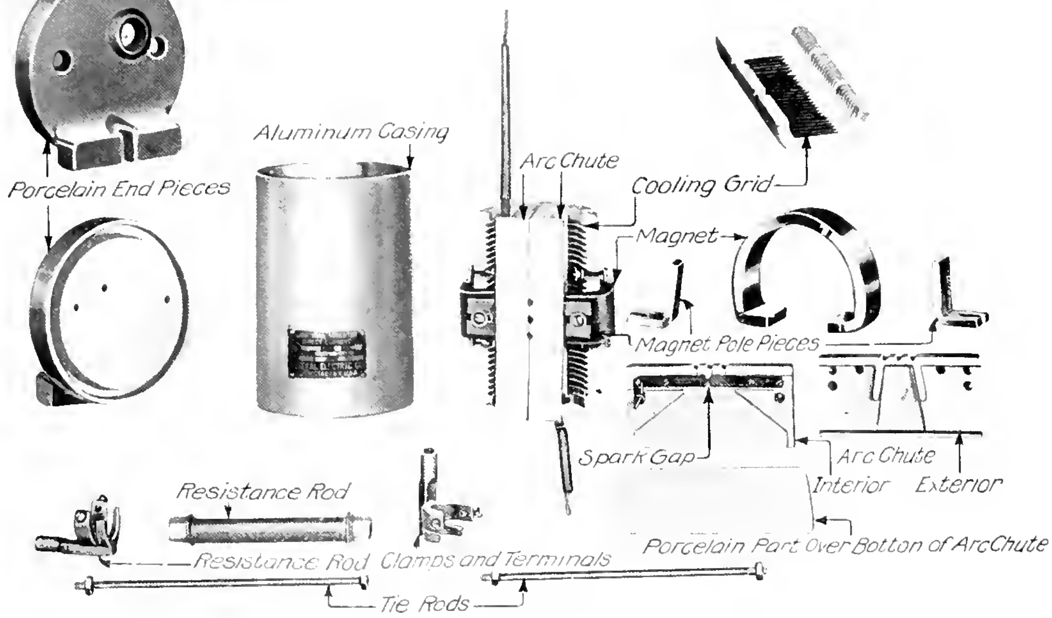

Fig. 3. Exploded View of the Magnetic Blowout Arrester shown in Fig. 2

It is evident, from what has preceded, that the d-c. aluminum arresters are of service even in districts where there is no lightning; for accidental short circuits and the resulting electromagnetic "kicks" of potential occur everywhere. In warm, humid climates where storms are frequent, an aluminum arrester is needed on every car, a gap type of arrester along the line at points where there are *proximity conductors*, and a few other line arresters widely spaced, according t the head-way of the cars.

On electric locomotives and interurban cars, the conditions invariably warrant the

of any other a-c. apparatus. This subject, in general, has been treated in previous articles. The one problem of great moment is how to protect the high-voltage line insulators from damage by lightning. Line arresters can not be used because it takes too many arresters and costs too much to install them and keep them in working condition. There is not yet developed an arrester which could be applied economically and practically to the line. The difficulties to be met are serious barriers to progress. This problem will probably require much scientific investigation before a workable solution is reached.

THE NECESSITY OF TESTING ELECTRIC RAILWAY APPARATUS

By P. P. Spalding

Supervisor of the Test Track, General Electric Company

The fact that a large part of the equipment of electric cars and locomotives is so located that it can only be periodically inspected, renders a preliminary testing of all parts of vital importance. The measure of success attained in actual service is, to a large extent, dependent not only on the design, character of materials, and care used in construction, but also on the thoroughness of the tests to which the component parts and completed units are subjected prior to their installation. That these facts are fully appreciated by both railway operators and the manufacturers of electrical apparatus is clearly indicated by the elaborate and exhaustive tests to which all electric railway equipment is now subjected by the manufacturer. The tests are made, as far as possible, to approximate the conditions under which the apparatus will be used in actual service.—Editor.

The testing of electric railway apparatus can be divided into two classes, namely: special tests which are made to determine the fitness of the apparatus for some definite service, or to bring out some special characteristic to aid in designing new apparatus; and commercial tests, that are made to detect any defective material and to make sure that the workmanship is up to standard. The testing of all kinds of electrical apparatus, and especially the various parts and the complete assembled equipments used on electric locomotives and cars, has been considered so important by the manufacturing concerns that they have provided very complete testing facilities, where every separate part and the complete equipment can be given test after test from the time that it is started to be built until it is put in regular commercial service.

Anyone unfamiliar with, and not directly interested in, the testing of this apparatus would not appreciate the value of these tests to the designing engineer, and the benefit derived from them in keeping the general workmanship and quality of the apparatus up to a fixed standard.

When the first railway equipments were being designed there were very few facilities for testing and no precedents to follow, so that all of the investigations were in the nature of research work, and it was necessary during the first few years to get most of the data for the changes and improvements by the slow method of watching the operation in actual service. On this account apparatus was put in commercial service in what we would now consider a very crude state of development.

In operating the first equipment the line pressure was kept down to approximately 500 volts, the feeder systems were installed in such a way that the voltage would drop off very materially in case of a short circuit on the line due to equipment failures or other causes, the power station had a capacity of only a few hundred kilowatts as a maximum, and the schedule requirements were such that equipment failures, that we would now consider prohibitive, were not considered excessive.

Conditions have been gradually changing until at the present time car equipments are being operated on line voltages up to 2400 volts direct current and 11,000 volts alternating current. Heavy interurban cars are being operated in multiple unit trains of 12 or more cars, at speeds as high as 75 miles per hour on schedules which require rapid acceleration, and under traffic conditions that make it absolutely imperative that delays due to equipment failures are reduced to a minimum. Locomotives are being used to haul the heaviest trains through tunnels and on heavy grades, as well as to handle the passenger equipment at the terminals of some of the largest steam railroads in the world, where the traffic is so congested that a delay of only a few minutes might disarrange the entire schedule for hours. The size of power houses has been increased until their capacities are rated in thousands of kilowatts instead of hundreds; the line voltage has been raised, and with the aid of adequate feeder systems is maintained at approximately a constant value under any ordinary loads obtained under service conditions.

New types of car equipments are being furnished to be installed on cars thousands of miles from the factories where they are built. The various parts of these equipments having been designed by several different engineers, and installed by construction men in accordance with blue prints furnished with the equipment. The first time that power is applied to the car, or in the case of a multiple unit equipment to the several cars of the train, they are run out on the main line for an exhibition for the railroad officials.

All railroad companies are now carefully considering the reliability, efficiency, cost of maintenance and the accessibility of the various parts for repair. On this account the manufacturing concerns have been obliged to make life tests on the various parts of the equipments and even on completely assembled car equipments and locomotives to ascertain their reliability and endurance. These tests sometimes extend over a period of several years time.

The development of all kinds of electrical machines has been so rapid that it is not always possible to use the data obtained on apparatus in regular commercial service, because this apparatus is being superseded so rapidly by equipment that is better suited for the work to be done.

In order to keep up with the change in requirements, and to meet the demands of the new operating conditions, it has been necessary to design new types of motors, control apparatus and, in fact, all parts of the equipment. The engineer has been greatly assisted in this work by the information that can be obtained by observing the equipments that were already in operation, but it has also become necessary to make exhaustive tests to hasten the development of the proposed changes, and to insure that each part was satisfactory for the service it was intended to do; for, although an immense amount of valuable data has been collected and formulas made up, no designing engineer is willing to make guarantees regarding the performance of any electrical machine until tests have been made under as near operating conditions as possible. At the present time no piece of electrical machinery is ever shipped out to a customer by any of the reputable concerns, to be put in regular commercial service, until it has been thoroughly tested.

The results obtained by observing the operation of equipment which is being operated in commercial service tend to show the needs of improvements. These improvements are made and new types of apparatus developed by means of tests carried on at the factories.

The following is a brief review of some of the advancements made and the results obtained in the few years that electrical railways have been operated.

The first railway motors for car equipments, although of small capacity, gave very good service on the light cars and the comparatively easy schedules at that time, but operating conditions soon began to demand heavier equipments, faster accelerations and higher speeds. In order to meet the requirements a new line of motors was designed with better electrical efficiency and a construction that was better adapted to withstand the weather conditions to which they were subjected under the car.

As the electrical railway field began to be extended to suburban and interurban districts, a separate line of motors was developed for each of these types of service. The high speed work brought out the necessity for a more rugged frame construction, and a better lubricated bearing, so that the box type frame and the waste packed bearings were developed.

The high acceleration and numerous stops with motors geared for the higher speeds, required for suburban and interurban work, soon demonstrated the necessity for a motor that would stand excessive overloads without injurious flashing, and this made it necessary to develop the commutating pole motors.

By this process of watching the operation of motors in service, making tests to develop the kind of motor that the conditions demand, and then having them built from selected material by careful and experienced workmen, it has been possible to produce a motor that is probably the most rugged and reliable piece of electrical apparatus that has ever been built.

The first type of controller, consisting of a circular rheostat with the operating handle brought up through the platform of the car, was superseded by the controllers with the magnetic blowouts, which have in turn been improved from time to time until they are very reliable in handling the smaller equipments.

When the larger cars began to be used, and it was found advisable to have several motor cars in a train, multiple unit control systems were developed and have been perfected to such a state that ten or twelve car trains can be operated from any of the master controllers in any of the cars. Automatic control equipments have also been developed so that when the motorman throws the controller to the full on position the control will notch up automatically, without exceeding the amount of current per motor that the current limit has been adjusted for. The perfection to which this part of the equipment has been developed by tests and improvements will be appreciated when we consider that a complicated system of this kind is being used on railroads where trains of several cars are being operated satisfactorily, on something like a one-minute headway, and that failure of a train under these conditions would disarrange the entire schedule of the system.

Due to the excellent facilities which the manufacturing concerns have provided for this purpose, they have been able to develop, through a system of tests, a line of protective apparatus consisting of fuses, circuit breakers, etc., for use on the various types of car and locomotive equipments on voltages as high as 2400 direct current, or 11,000 alternating current. Something of what this means can be appreciated when it is considered that the power equipment and feeder system on some of the railways is such as to give as high as 50,000 amperes, or more, at 550 or 600 volts, when a short circuit occurs on the line; and this amount of current has been satisfactorily ruptured with the types of fuses and circuit breakers which are at present in regular service. Line breakers have been perfected until they will open the circuit, in from 0.03 to 0.05 seconds, if the voltage drops below that for which they are built to trip. Fuse boxes with a flat copper strip as a fuse have been developed to interrupt practically any amount of current that can be obtained, when they are used on voltages for which they are intended.

The small trolley wheels and poles work satisfactorily for collecting current on the light slow speed equipments, but were not able to handle the current for larger high speed equipments, so that it was necessary to design some other type of current collecting device, and in this connection the third rail and third rail shoes were developed, starting with a comparatively crude arrangement and gradually being improved until the system of under-running third rail, as used on the New York Central and several other steam railroads, was obtained. Pantographs with sliding pans and rollers for collecting currents have been developed for use on high voltage circuits, and are still being improved and adapted for the heavier current high voltage work.

N.B.—We hope, at a very early date, to start a series of articles in the Review by Mr. P. P. Spalding on the Testing of Electric Railway Apparatus, in which he will deal with the many different phases of this important subject in a comprehensive way.—Editor.

SEE ANNOUNCEMENT OF

OTHER FORTHCOMING RAILWAY ARTICLES

ON SECOND PAGE FOLLOWING

GENERAL ELECTRIC REVIEW

A MONTHLY MAGAZINE FOR ENGINEERS

Manager, M. P. RICE | Editor, JOHN R. HEWETT | Associate Editor, B. M. EOFF | Assistant Editor, E. C. SANDERS

Subscription Rates: United States and Mexico, $2.00 per year; Canada, $2.25 per year; Foreign, $2.50 a year, payable in advance. Remit by post-office or express money orders, bank checks or drafts, made payable to the *General Electric Review*, Schenectady, N. Y.

Entered as second-class matter, March 26, 1912, at the post office at Schenectady, N. Y., under the Act of March 3, 1879.

VOL. XVI., No. 12

DECEMBER, 1913

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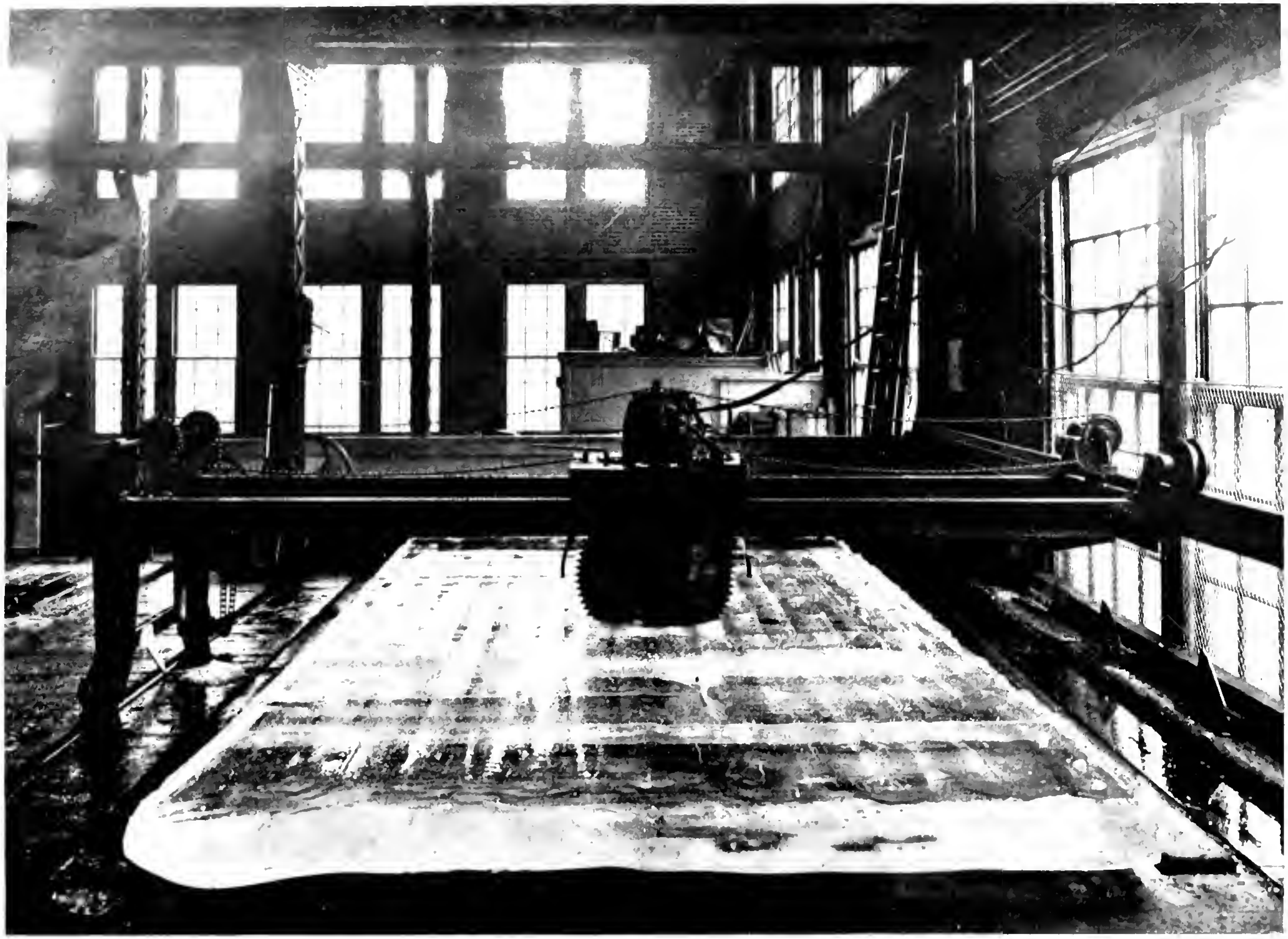


CUTTING A FOUR-TON CAKE OF ARTIFICIAL ICE BY MOTOR-DRIVEN SAW

GENERAL ELECTRIC REVIEW

THE PATHS OF PROGRESS

It has been pointed out more than once in these columns that modern modes of living are dependent upon the development and discoveries that have been made in science, engineering and industry; and Dr. Steinmetz in his address recently delivered before the A.I.E.E. in Schenectady showed very clearly how closely these developments have been dependent upon the use of energy and upon the form in which it is used. The savage and the barbarian who depended on their own muscles alone for all the necessities of life had to fashion their modes of living according to what they could procure in their immediate environment by such a limited amount of energy. Consequently, their lives were primitive and their activities confined to such simple operations as procuring the barest necessities for existence. With the progress of time it is evident that by organization wonderful things were accomplished even with this small supply of energy, and there are many monuments of the past which testify to what could be accomplished by human muscles alone when directed by some ancient master mind.

The use of animal energy and the discovery and application of the chemical energy in coal, and finally the use of electricity for the useful service of man have been mile stones in human progress, and life itself has now become dependent upon the proper distribution and use of energy, so that it must now be added to the necessities of life and rank in importance with food and clothing. Indeed, it would be impossible to supply the requisite food for any city of any size on this continent for a day if our system of energy supply were to fail.

Electricity is becoming of more and more importance every day and the great generating centers and distributing systems are fast becoming the most vital factors in the lives of large communities. Dr. Steinmetz pointed out the curious fact that while electrical energy is the most useful, it is at the same time the least used form of energy; that is to say, its use is almost entirely confined to transmission, as it only forms a medium for transmitting energy generated by chemical or mechanical means. The mechanical energy has to be converted to electrical energy for transmission, and the electrical energy must be converted to some other form of energy before it is used, such as mechanical, heat, light, or chemical energy. The one factor which has led to the great extension of the use of electricity is the fact that it is the most easily convertible form of energy, and its extensive use is entirely based upon economic considerations. It is easier to transport electricity over a transmission line and then to convert it into any other desired form of energy than it is to transmit the chemical energy stored up in coal over a railroad, and then convert it to the desired use.

The vital importance of electrical energy in modern life places the large manufacturers of electrical apparatus and the large generating and distribution companies in a unique position among the industries of any community. In fact, most other industries in one way or another are more or less dependent upon the electrical concerns and therefore anything which affects the progress and development of the electrical industry as a whole must be reflected in the progress of the country.

Each new use to which we can put energy, providing that it is accomplishing useful work in an economical manner, is a step forward along the paths of progress, and such uses as that described in Mr. Massa's article in this issue on "Mechanical Refrigeration" extends the field of central station activities and makes the central stations more and more an essential part of every day existence.

MECHANICAL REFRIGERATION

WITH SPECIAL REFERENCE TO SMALL PLANTS

PART I

By R. F. Massa

Manager of the General Refrigerating Machine Department, H. W. Johns-Manville Company

In our August, 1913, number we published an article on "Mechanical Refrigeration" which dealt with the subject from the central station point of view. The present article, which is in two parts, the first in this issue, the second to appear in the January issue, covers in a most thorough manner those phases of the subject which are of primary importance to the persons interested in the generation and utilization of the "cold" itself. Part I first states the advantages of mechanical refrigeration over ice refrigeration, explains the two types of mechanical refrigerating systems (compression and absorption), and discusses the refrigerants available and also the systems of distribution and of storing the cold. Next is a series of detailed directions, accompanied by the necessary data in the form of tables and maps, which when followed will indicate the size of machine necessary to supply a given refrigerator. An assumed numerical example supplementing the description step by step serves to render the instructions very clear. A short description of the advantages and disadvantages of open-type and enclosed-type compressors is next given. This instalment concludes with a glossary and explanation of the various terms used in the article.—Editor.

ADVANTAGES OF MECHANICAL REFRIGERATION

First: Lower temperatures can be obtained by the use of refrigerating machines than are possible by the use of ice.

Second: The slop and dirt involved in handling ice are avoided.

Third: There is no accumulation of slime in the refrigerator, as happens with the melting of even the best ice.

Fourth: Refrigerators cooled mechanically are drier than those ice-cooled, because the moisture is frozen out of the air and deposited on the cooling surfaces.

Fifth: The design of the refrigerators used in mechanical refrigeration is generally better than that of ice-cooled boxes. The result is a better air circulation, a more uniform temperature throughout the compartment, and also a drier and sweeter atmosphere.

Sixth: With proper design of refrigerator and refrigerating machine, any desired temperature can be obtained.

Seventh: Refrigeration produced mechanically is often cheaper than refrigeration produced by melting ice.

PRODUCING THE COLD

In almost all methods of obtaining cold advantage is taken of the fact that when a liquid evaporates (i.e., turns from a liquid into a gas or vapor) it absorbs heat from its surroundings. There are a number of liquids which are easily made to evaporate and produce this cooling effect, and, but for their cost, refrigeration could be very simply produced by supplying a steady stream of the liquid and allowing the vapor or gas evaporated to escape into the atmosphere.

A refrigerating machine is practically an apparatus for saving this gas, which has evaporated, and returning it to its liquid form to be used over again.

In this process of recovery and condensation, the gas gives out the heat which it has previously absorbed in evaporating. This heat is then carried away by flowing water, which, in consequence of absorbing the heat, rises in temperature.

The operation of a refrigerating machine causes a continuous cycle of evaporation, recovery, and condensation. A brief outline of the process follows: The refrigerant (liquid) evaporates or gasifies and absorbs heat. It is then drawn away from the point where it evaporated, i.e., from the evaporator or cooler, and is forced into a recovery chamber or condenser. The walls of this chamber are cooled by running water. This water absorbs the heat of the gas, thereby condensing it to a liquid. It is then passed back to the evaporator where it again goes through the same process.

TYPES OF REFRIGERATING MACHINES

Compression Type

In the compression type of refrigerating machine the recovery of the gas is effected by drawing it away from the point where it has been evaporated and pumping it under increased pressure into a chamber where it gives out its heat to the water-cooled walls of the chamber, thereby returning it to the liquid state ready to be used again. Fig. 1 illustrates such a system.

Absorption Type

In this type of machine the recovery of the gas is effected by bringing it into contact with water, with which it unites chemically. The solution thus formed is pumped into another chamber where the gas is driven off by heating the mixture. This gas is then condensed under the high pressure due to the heating, and as a liquid is then ready to pass back to the low-pressure chamber to be re-evaporated. A diagram showing the scheme of this system is shown in Fig. 2. In many cases where sufficient exhaust steam is available absorption refrigerating machines are very economical, as very little additional steam is required for their operation.

LIQUIDS USED IN REFRIGERATING MACHINES

Any one of a number of liquids can be used in compression-type refrigerating machines. The most common of these are ammonia, carbon dioxide, and sulphur dioxide. Various practical considerations determine which is to be used in a particular design of machine. The refrigerant used in the absorption machine is usually ammonia.

Carbon Dioxide

The chief advantage of this liquid is in its inoffensive odor. Its disadvantages are the extremely high pressure at which it is necessary to work (300 to 1200 lb. per sq. in.), the difficulty of holding these pressures, the difficulty of finding small leaks because of its slight odor, and its chemical inactivity which renders delicate tests impracticable.

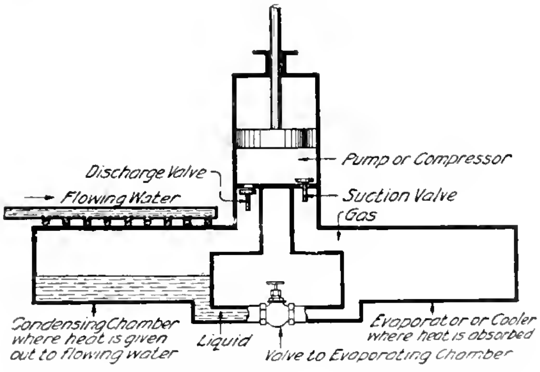


Fig. 1. Diagram of a Compression-Type Refrigerating System

Ammonia

The advantage of this liquid is in the lower working pressures (15 to 300 lb. per sq. in.), which are of course easier to handle and also, as compared with carbon dioxide, leaks are very easily located. However, ammonia fumes are so extremely offensive, and so dangerous to life in case of a break that its use is practically prohibited in a confined space, such for instance, as the engine room of a ship.

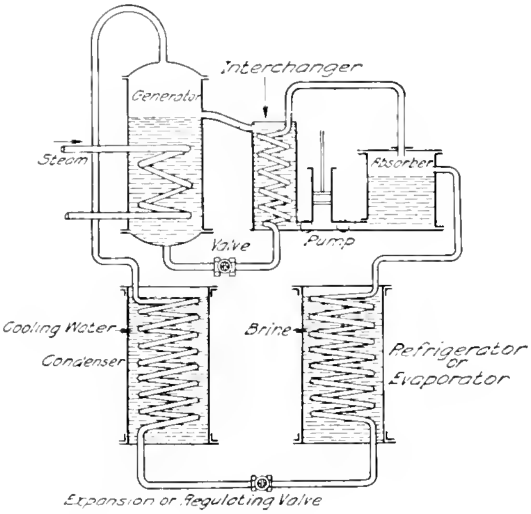


Fig. 2. Diagram of an Absorption-Type Refrigerating System

Sulphur Dioxide

The advantage of this liquid is its comparatively low working pressure (not above 75 lb. per sq. in.). It possesses a great disadvantage, however, in that when it comes in contact with moisture it forms an acid which rapidly corrodes the apparatus. This action is ever present in the old type of machine as air and moisture are constantly being mixed with the sulphur dioxide. This difficulty has been overcome in the Audiffren-Singrun type of machine, in which the refrigerant is hermetically sealed into the machine and chemical action therefore can not occur.

APPLYING THE COLD

There are three common systems of applying the cold.

First: The Direct-Expansion System in which the refrigerant is evaporated in coils of pipe placed directly in the rooms to be cooled.

Second: The Brine System in which the refrigerant is used to cool brine, the latter being then circulated through coils of pipe in the room to be cooled.

Third: The Cold-Air System in which a current of air is chilled by passing over coils of pipe cooled directly by the evaporating refrigerant, or by brine, or by passing it through a spray of cold brine. This chilled air is passed into the room to be refrigerated and then back to the cooling coils, thus maintaining a continuous circulation.

Direct-Expansion System

With direct expansion the temperature will begin to rise the minute the machine stops. Another and more serious objection to this system is the possibility of danger to life and of damage to goods, especially where ammonia is the refrigerant.

Brine System

The brine system is generally accepted as the safest and best. While it is a little more expensive to operate in large plants, temperatures are more easily and more accurately controlled than with the direct-expansion system, and in small plant practice it is found equally economical in operation in spite of its theoretical disadvantage. Furthermore, in case of any breakdown in the refrigerating machine the temperature can be held for a time by the circulating brine. Eventually, of course, this cooling medium will become too warm to be of any use.

Cold-Air System

This system is not applicable where any drying of the goods by air currents would be harmful. A serious objection to its adoption is the fire risk, i.e., the spreading of fire through the air passages. It is nevertheless used for such service as chocolate dipping rooms, ice cream hardening, fur storage, etc.

STORING THE COLD

When temperatures are to be maintained while the refrigerating machine is shut down, it becomes necessary to store sufficient cold for that purpose.

Brine System of Storage

In the brine system this is accomplished by cooling a comparatively large body of brine which absorbs heat from the surrounding air, and this slowly rises in temperature as it is circulated. Where it is necessary to stop the brine circulating pump as well as the machine, so called "pressure tanks" should be placed in the piping system in the room being cooled. The mass of brine in these tanks absorbs the surrounding heat and helps to maintain an approximately even temperature.

In calculating the proper size of tanks for storing brine it is to be remembered that, as a rule, the period when the machine is shut down coincides with the period when the demand for refrigeration in the box is the least. At such times the amount of heat to be absorbed is usually only that entering through the insulation, as the doors are shut and no food is being put into or removed from the box.

Where the direct-expansion system is used, a part of the cooling coils may be immersed in a tank of brine placed in the room and the remainder of the coils arranged for directly cooling the room.

Congealing Tank System of Storage

In many boxes the space available for brine storage tanks is so small that it becomes necessary to install congealing tanks, in spite of the difficulties involved in their use. In the congealing tank ice is formed by circulating brine or ammonia through a coil immersed in water which starts freezing around the outside of the pipe.

The space economy made possible by the congealing tank system is explained as follows. One pound of ice in melting will absorb 144 B.t.u., whereas one pound of brine (occupying practically the same amount of space) will absorb, with a rise of temperature of say 20 degrees, only from 14 to 16 B.t.u., or about one-tenth as much heat as the pound of ice.

Therefore, wherever a 20 degree rise of temperature is permissible, melting ice as a heat absorber will be practically ten times as efficient as brine per cubic foot of space occupied.

There are two difficulties involved in the use of these tanks. The first is the danger of straining or bursting the tank by the ice expanding as it freezes. This danger is reduced to a minimum by causing the ice to form from the bottom of the tank upward and the melting to take place from the top down. To accomplish this the piping system is so arranged that the supply of ammonia or brine shall first reach the bottom turn of the coil in the tank and the air to be cooled is caused to pass downward about the tank. The second difficulty with congealing tanks is that they cannot produce as low a temperature in the refrigerator as is secured by ice since it is the water that acts to cool the refrigerator rather than the ice direct, and this water, which surrounds the ice in the tank, must be warmer than the ice in order to cause it to melt.

RATING OF REFRIGERATING MACHINES

Refrigerating machines are usually rated by the amount of heat that they will absorb if operated for twenty-four hours. Thus a "one-ton" refrigerating machine is one which, if operated for twenty-four hours, will absorb the same amount of heat as will one ton of ice in melting.

If the machine is operated for a shorter time per day a lesser amount of heat will, of course, be absorbed, and in order to maintain the temperature during the period when the machine is not running some one of the previously described means of storing the cold must be adopted.

Refrigerating machines are sometimes rated in terms of ice-making capacity, i.e., in terms of the amount of ice the machine will make in twenty-four hours. This is always less than the refrigerating capacity because a certain amount of refrigerating effect is required to cool the water down to 32 degrees before the freezing can begin, and the ice is usually cooled somewhat below 32 degrees which requires still further capacity. There is also some flow of heat into the apparatus. These elements vary so considerably that the ice making capacity is an unsatisfactory way of rating machines.

CALCULATING CAPACITY OF MACHINE REQUIRED FOR VARIOUS WORK

How Heat Enters Refrigerators

Heat enters refrigerated compartments first, through the walls; second, in warm goods; third, by the interchange of air through the opening of doors and by air leaks (cold air is heavy and immediately flows out when a door is opened); fourth, from lights or from the heat of the bodies of workers; and fifth, from any change of state occurring in the goods, such as freezing, fermenting, etc.

In large rooms these various sources of heat should be analyzed separately. In small refrigerators such as those for hotels, kitchens, private homes, etc., a rough rule (stated in the next paragraph) that gives quite as accurate results as a more elaborate analysis, allows for a certain number of B.t.u. per cu. ft. of refrigerated space per twenty-four hours. This amount varies with the character and location of the box, the nature of its insulation, the temperature desired, etc. The insulation of this class of boxes, while of very great importance, is not by any means the only important factor.

TABLE I

For Rooms Containing Less Than 1000 Cu. Ft.

If held							
at zero	F. multiply	exposed	surface	by			1775.
5 deg.	"	"	"	"	"		710.
10	"	"	"	"	"	"	535.
20	"	"	"	"	"	"	355.
32	"	"	"	"	"	"	265.
36	"	"	"	"	"	"	180.

For Rooms Containing From 1000 to 10,000 Cu. Ft.

If held							
at zero	F. multiply	exposed	surface	by			1250.
5 deg.	"	"	"	"	"		600.
10	"	"	"	"	"	"	300.
20	"	"	"	"	"	"	190.
32	"	"	"	"	"	"	160.
36	"	"	"	"	"	"	125.

For Rooms Containing Over 10,000 Cubic Feet.

If held							
at zero	F. multiply	exposed	surface	by			1100.
5 deg.	"	"	"	"	"		550.
10	"	"	"	"	"	"	275.
20	"	"	"	"	"	"	180.
32	"	"	"	"	"	"	150.
36	"	"	"	"	"	"	110.

Rule of Machine Sizes for Small Boxes

For domestic refrigerators held between 35 and 45 degrees F. in climates having an average summer temperature of about 70 degrees and a maximum temperature about 100 degrees allow 300 to 350 B.t.u. per cu. ft. of refrigerator per twenty-four hours. For boxes in hotel or restaurant kitchens allow 600 B.t.u., or even 900 B.t.u. in extreme cases and where low temperatures are required. For butcher's coolers or large storage boxes in hotels, etc., allow 200 to 250 B.t.u. per cu. ft. per twenty-four hours. In climates varying appreciably from these average temperatures corresponding allowances must be made.

Having calculated the total heat in B.t.u. to be absorbed per twenty-four hours, divide this sum by 144 and it will give the number of pounds of ice that would have to melt to absorb this same amount of heat. Dividing this result by 2000 gives the tons of refrigeration required per day.

Rule of Machine Sizes for Medium and Large Boxes

A check on the preceding figures for the larger type of box held at 36 degrees or lower may be gained from the following which is taken from Levey's "Refrigeration Memoranda," page 41.

"When the exact conditions are known under which cold storage rooms are to be

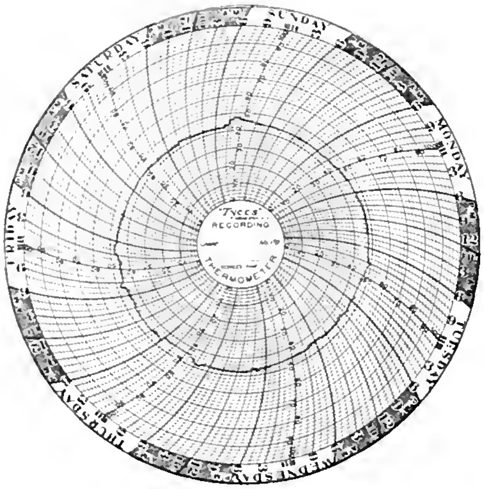


Fig. 3

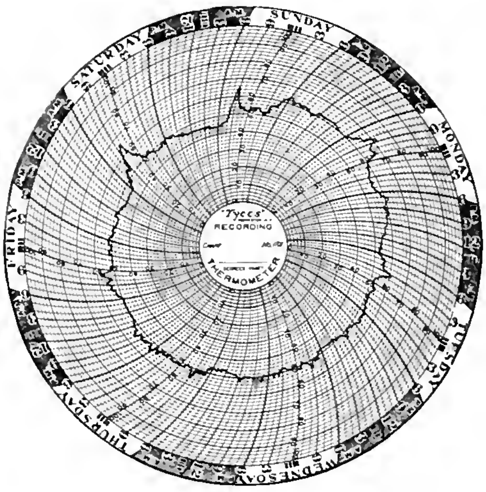


Fig. 5

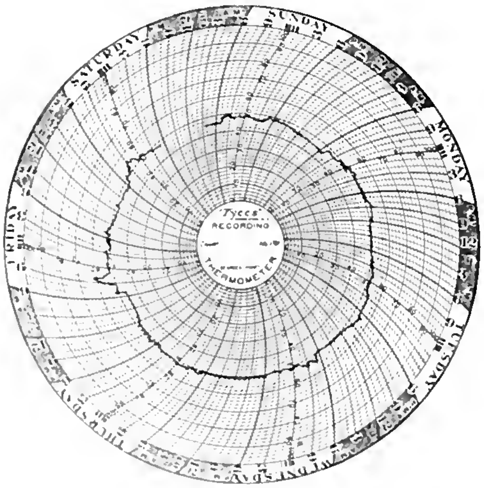


Fig. 4

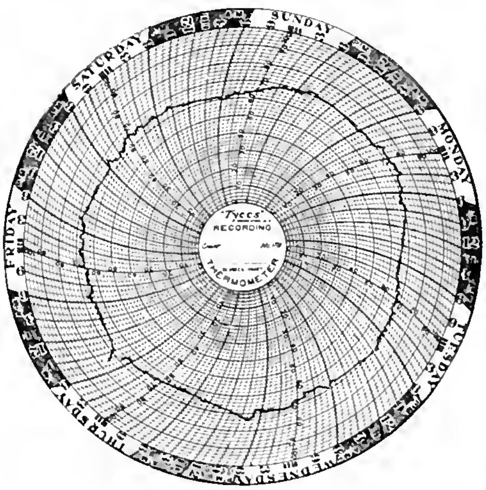


Fig. 6

Recording Thermometer Records From New Ice-Cooled Refrigerators of Well Known Makes

operated, namely, size and shape of the room, the quality of the insulation, the kind and quantity of goods to be handled per day, and the temperatures at which they are received and at which they are to be held, the amount of refrigeration required can be estimated very closely by the following rule:

First: Calculate the exact area of exposed surface in the walls, floor, and ceiling of the room in sq. ft., and multiply the total number of sq. ft. by the number given in Table I for the required temperature and divide by 288,000.

Second: Then multiply the amount of goods (weight in pounds) to be stored per day by the range of temperature (in degrees) through which they must be cooled and this in turn by the specific heat of the goods.

Finally divide the result by 288,000 and the quotient will be the tons of refrigeration required per day to cool incoming goods. (For specific heat of various goods see Table II.)

TABLE II

APPROVED COLD-STORAGE TEMPERATURES

	Degrees Fahr.	Specific Heat
Beef	36–40	0.68
Hogs	29–32	0.51
Lamb and mutton	32–36	0.67
Veal	34–36	0.70
Meats (in pickle or brine)	35–40	0.58
Butter (must be kept separate from other goods)	0–38	0.64
Eggs	29–32	0.76
Cheese	32–34	0.64
Lard	38–40	0.64
Poultry (to freeze)	5–10	0.78
Poultry (when frozen)	25–28	0.80
Game (to freeze)	5–10	0.78
Game (when frozen)	25–28	0.80
Fish (retail fish counter should be cooled with ice rather than mechanically)		0.82
Oysters	33–40	0.84
Beer	33–40	0.90
Wines	40–45	0.90
Cider	30–40	0.90
Fruits	33–36	0.92
Vegetables	34–40	0.91
Canned goods	38–40	0.91
Flour and meal	40	
Furs	25–32	
Brine for ice cream freezing	5–10	about 0.75
Ice cream (air hardening)	5	
Ice cream (serving temperature)	14–16	about 0.80

Third: Add these amounts together and the total will be the amount of refrigeration (in tons per day) required to hold the temperature of the goods and of the room.

Fourth: If the goods are to be frozen, the latent heat of freezing should be added to that to be extracted."

Importance of Reserve Capacity in Small Machines

With small machines it is necessary to allow a greater machine capacity for a given size of box than with large machines. With the latter, one can always throw a large part of the machine capacity to any given box where special need may exist, whereas to do this with the small machine would almost certainly rob some other box, if indeed there happened to be another box. It is never possible to determine with mathematical certainty exactly how much refrigeration is required for a given case. It is best to allow for this and be sure the machine is amply large.

Checking Machine Size by Actual Ice Consumption

Where an existing ice-cooled refrigerator is to be cooled mechanically, one check upon the size of the machine required is given by the amount of ice which has been used. This check is, however, more likely than any other to lead to erroneous conclusions unless the figures are properly analyzed. In the following is presented a method which gives good results, but it should be remembered that an allowance may be made in the case of large boxes and where brine storage tanks are provided in the box for the steadying effect of these tanks.

First: Determine the average daily ice consumption for a summer month, say July or August, from the actual weighing or from the ice bills. (For example, assume the bills show 300 lb. per day for a box 8 by 8 by 9 ft. in a New York butcher shop.)

Second: Determine as accurately as possible the average temperature that was secured by ice in the refrigerator. This will usually be from 55 to 60 degrees, and although it is commonly stated as anywhere from 40 to 45 degrees these lower figures are so seldom obtained as to practically warrant the statement that they are never reached. It is only with a full ice chamber and with the box closed for long periods that such low temperatures can be secured at all, and even under those conditions the average temperature will still run well above these figures. Figs. 3, 4, 5 and 6 are examples of temperature records obtained in actual practice where ice is used as the refrigerant, and show that the temperatures thus maintained are not as low as commonly supposed. Therefore, unless positive assurance is to be had to the contrary, use 55 to 60 degrees F. as the average temperature.

(In our example assume 55 degrees.)

Third: Calculate the heat inflow through the insulation with the temperature in the box as actually observed (or assumed at 55 degrees) and with the average summer temperature prevailing outside. For the average and maximum summer temperatures in the various parts of the United States, see Figs. 7 and 8.

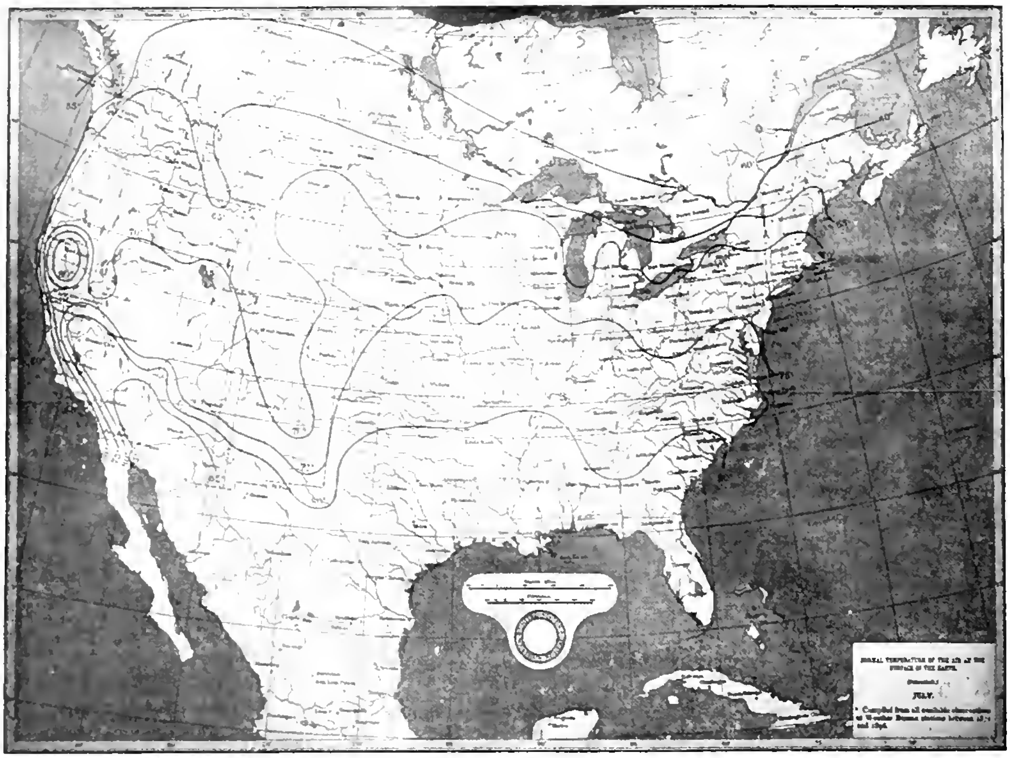


Fig. 7. Map Showing the Average Temperature over the United States

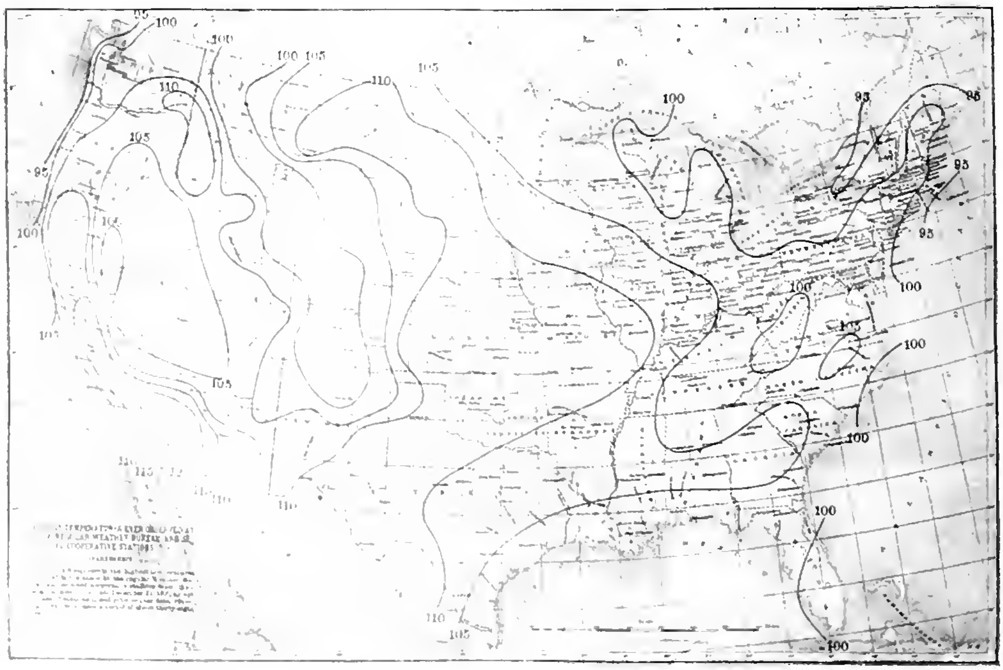


Fig. 8 Map Showing the Maximum Temperature over the United States

(In our example assume the insulation, regarding which we have presumably little information, to transmit 5 B.t.u. per sq. ft. per degree temperature difference per twenty-four hours. The average summer temperature in New York is 71 degrees.

We have 416 sq. ft. of box surface, including 4 walls, ceiling, and floor.

The temperature difference between 71 degrees and 55 degrees is 16 degrees.

This excess of heat ordinarily occurs during the day time only, i.e., when the box is being opened, since at night the box remains closed.

A machine to be of sufficient capacity to produce the temperature actually obtained with ice, therefore, must be large enough to absorb the heat inflow through the insulation and also the additional heat entering during the daytime from other sources.

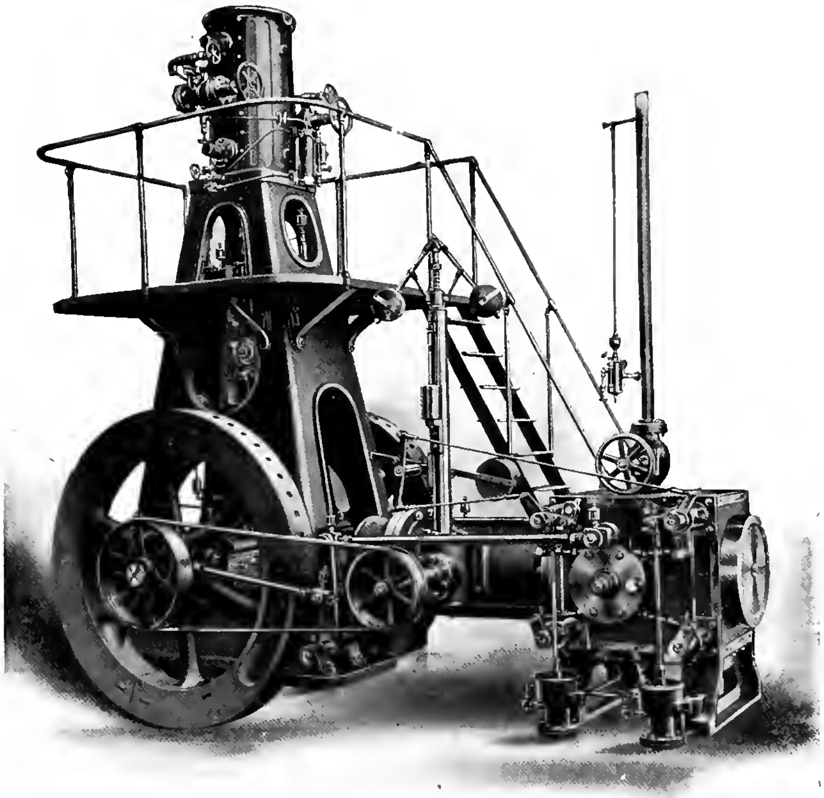


Fig. 9. A Vertical, Double-Acting, Open-Type Ammonia Compressor

We calculate the heat inflow through the insulation, therefore, as follows

$$\frac{416 \text{ (sq. ft.)} \times 16 \text{ (deg.)} \times 5 \text{ (B.t.u.)}}{144 \text{ (B.t.u. per lb. of ice)}} = 231$$

lb. of refrigeration.)

The difference between the heat inflow through the insulation and the total heat actually absorbed by the melting of the ice is the amount of heat entering the box from other sources than through the insulation.

(In our example, the heat inflow through the insulation we have calculated as 231 lb. The difference between this and the 300 lb. actually melted in the average day is 69 lb. Our machine must therefore be capable of handling $\frac{69+231}{2} = 184$ lb. of refrigeration in 12 hours, or 368 lb. in 24 hours.)

Fourth: A further fact to be taken into account in determining the proper size of machine is that the temperatures which are obtained with ice are not satisfactory. If they were satisfactory the greatest reason for putting in cooling machinery would be void. Where a temperature of 55 degrees can be obtained with ice, 35 to 45 degrees will naturally be demanded of mechanical cooling. Therefore, the machine size must be further increased in proportion to the number of degrees difference of temperature required. (In our example the 368 lb. per 24 hours, which we have calculated is required to produce 55 degrees, must be increased as follows, if 35 degrees is to be obtained.

$$368\times\frac{71^\circ-35^\circ}{71^\circ-55^\circ}=827 \text{ lb. per 24 hours.)}$$

Fifth: Furthermore, if the cooling machine were installed in accordance with these figures it would handle average weather conditions but would be insufficient for extreme hot weather, the most important condition to be satisfied by refrigeration. It is necessary, therefore, to further increase the size of the machine in the ratio of the difference between the maximum summer temperature and 35 degrees, and the average summer temperature and 35 degrees. (In the example the average summer temperature in New York is 71 degrees and the maximum summer temperature 104 degrees. Therefore we must increase the size of our machine beyond 827 lb. per 24 hours as follows.

$$827\times\frac{104-35}{71-35}=1580 \text{ lb. per 24 hours.)}$$

Sixth: One further allowance should be considered, viz., the fact that in many cases, for one reason or another, it is either impossible or undesirable to operate the machine except during certain parts of the day, and the machine size must therefore be increased by as much as may be required to produce the desired amount of refrigeration in the short time available. (In our example, if we assume that 15 hours running time is permissible, our machine must absorb 1580 lb. of refrigeration in 15 hours, or at the rate of

$$1580\times\frac{24}{15}=2530 \text{ lb. per 24 hours.)}$$

Seventh: And, finally, if the machine is not placed directly beside the box to be cooled, allowance must be made for the heat inflow into the insulated cold mains. The amount of heat entering from this source is often of considerable importance, particularly with small machines.

Table III gives the heat transmission of cork pipe covering. (In our example assume the machine is 20 feet from the refrigerator and the mains are $1\frac{1}{4}$ in. in diameter. Assume the room temperature as 104 degrees and the brine 20 degrees. The heat inflow into the 40 feet of main required will therefore, using cork pipe covering, be as follows.

3.87 (from table)×84 (deg. temp. diff.)×40 (length of main in ft.)÷144 (B.t.u. per lb. of ice melting effect)=90 lb. of refrigeration.*

This sum added to the 1580 lb. already provided for gives 1670 lb. of refrigeration to be absorbed in 15 hours or at the rate of

$$1670\times\frac{24}{15}=2670 \text{ per 24 hours.)}$$

In many refrigerating plants the failure during the half-dozen hottest days of summer to maintain a temperature of 35 to 40 degrees

TABLE III
PIPE COVERING

TRANSMISSION IN B.T.U. PER 24 HOURS, PER LINEAL FOOT FOR ONE DEGREE TEMPERATURE DIFFERENCE BETWEEN INSIDE AND OUTSIDE OF

Size of Pipe in In.	Bare Pipe		Cold Water Cork Cover		Ice Water Cork Cover		Brine Cork Cover	
	Outside Dia. in In.	B.t.u.	Outside Dia. in In.	B.t.u.	Outside Dia. in In.	B.t.u.	Outside Dia. in In.	B.t.u.
$\frac{1}{2}$	0.84	9.50	2.62	5.76	3.25	3.84	4.25	3.37
$\frac{3}{4}$	1.00	11.88	2.85	6.00	3.75	4.00	4.75	3.53
1	1.31	14.81	3.31	6.39	4.25	4.26	5.31	3.73
$1\frac{1}{4}$	1.66	18.77	3.75	7.17	4.62	4.78	6.31	3.87
$1\frac{1}{2}$	1.90	21.49	4.00	7.90	4.75	5.27	6.90	3.96
2	2.37	26.80	4.62	8.82	5.31	5.88	7.25	4.44
$2\frac{1}{2}$	2.87	32.46	5.12	10.47	5.62	6.98	7.87	4.84
3	3.50	39.58	5.62	10.95	6.62	7.30	8.87	5.20

* The calculation of losses through cold mains where the machine runs short hours will be observed to be not quite logical, but errs on the side of safety.

can be tolerated, as long as it does not rise over 50 degrees. In those cases where a temperature of 40 to 50 degrees is sometimes permissible obviously a considerable saving in first cost of plant can be made.

Machine for Water and Milk Cooling

Mechanical refrigeration as applied to cooling water and milk usually presents one feature different from other classes of refrigerating work, viz., a large quantity of cooling effect is required in a short time. For instance, in a drinking water system the heaviest requirements may come at the noon hour. In a bakery also the demand for chilled water will be intermittent, a large quantity of water being required for the dough mixing. In dairy work, the milk must be cooled very rapidly to check the development of bacteria, which propagate with incredible rapidity within the temperature range of 110 to 50 degrees.

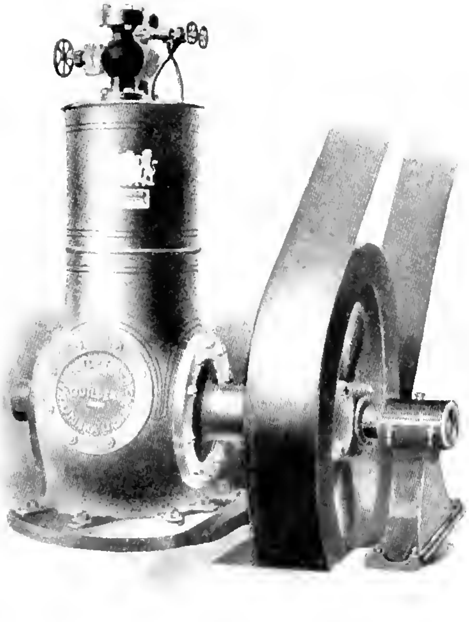


Fig. 10. A Vertical, Enclosed-Type Ammonia Compressor

To install a refrigerating machine large enough to produce the required cooling effect as it is needed would call for a very large machine in most cases. This is overcome by using a smaller machine and allowing it to operate for a longer time, say throughout the day, storing the refrigerating effect produced by cooling a large body of brine or by making ice which may be melted as rapidly as may be required. For instance, if 50 cans of milk (40 quarts each) are to be cooled from say 75 degrees to 35 degrees F. in one hour, the refrigeration required

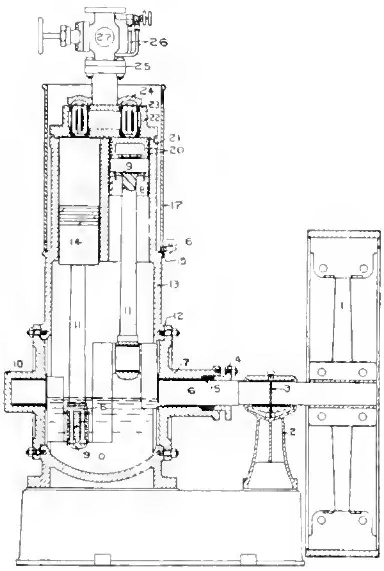


Fig. 11. A Sectional View of the Compressor Shown in Fig. 10

KEY TO FIG. 11

1—Flywheel.
2—Out Board Bearing.
3—Oiling Chain.
4—Packing Gland.
5—Shaft Packing.
6—Crank Shaft.
7—Main Bearing.
8—Crank Pin Box Bolts.
9—Crank Pin Box.
10—Blind Bearing.
11—Connecting Rods.
12—Bearing Gaskets.
13—Compressor Frame.
14—Pistons.
15—Water Jacket Gaskets.
16—Drain Cock.
17—Water Jacket.
18—Piston Pin Set Screws.
19—Piston Pin.
20—Piston Rings.
21—Cylinder Head Gaskets.
22—Cylinder Head.
23—Suction Valves.
24—Valve Caps.
25—Main Valve Gaskets.
26—By-Pass Connections.
27—Main Valve.
28—Water Jacket Bolts.
29—Discharge Valve.
30—Equalizing Line.
31—Gauge Glass Valves.
32—Gauge Glass.
33—Gauge Glass Guard.
34—Bed Plate.
35—Cover Plate.

will be 50 cans×40 quarts×2 lb. per quart ×(75 degrees—35 degrees) which is equal to 320,000 B.t.u. (Milk is treated in the calculation as having the same specific heat as water, since water forms so large a percentage of its total weight.) This amount of refrigeration produced by a machine running 12 hours per day would require the machine to absorb 320,000 B.t.u. divided by 12 which equals 26,000 B.t.u. per hour.

The quantity of brine necessary to store the cooling effect may be calculated closely enough for practical purposes by using the following approximate figures. Specific heat of brine equals 0.75. Weight of the brine 9 lb. per gal. The permissible temperature range of the brine depends on the conditions and may be 30 degrees to 15 degrees F., or lower. In other words, the temperature to which the brine may be permitted to rise is limited by the temperature it must produce in the room or in the substance being cooled; and the temperature to which the brine can be cooled in storing cold is limited by the decrease in economy of the refrigerating machine at the low temperature.

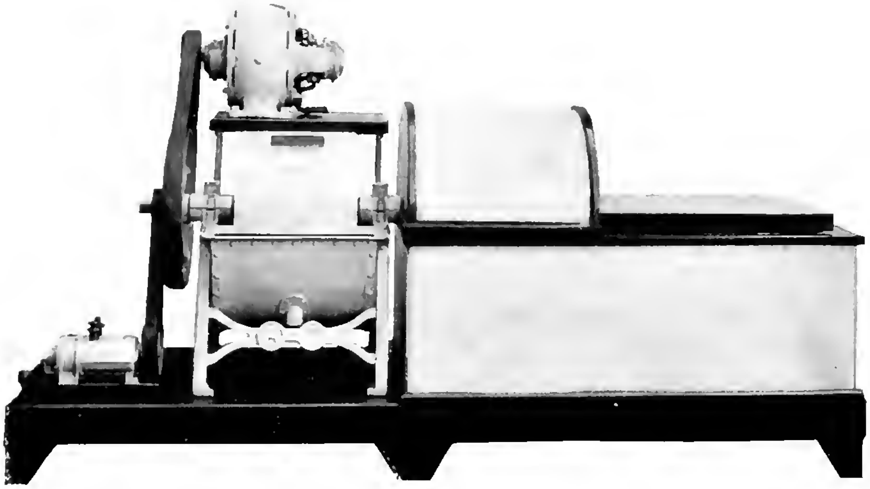


Fig. 12. Motor-Driven Compression Refrigerating Machine, Audiffren-Singrun Type

DESCRIPTION OF COMMERCIAL TYPES OF REFRIGERATING MACHINES

The means by which refrigerating machines produce their cooling effect has already been described. It remains to describe briefly the general type of design of those machines that are commercially successful.

Compression-Type Machines

Compression-type refrigerating machines may be divided into three classes.

First: The open type, which is made both vertical and horizontal, and both single and double acting (that is, compressing the gas at one end or at both ends of the cylinder). Fig. 9 is an example of a vertical, double-acting, machine of this type with direct-connected steam engine.

Second: The enclosed type, in which all the moving parts of the compressor proper, except the flywheel and the main shaft which enters the frame of the machine through a stuffing box, are enclosed within the frame of the compressor. Such valves as are required in the system are exposed. An external view of a machine of this type is shown in Fig. 10, and a section of it in Fig. 11.

Third: The Audiffren-Singrun type of machine, in which all the working parts of the machine are enclosed in a hermetically sealed container, there being no joints, no stuffing boxes, and no valves that can leak by any possible chance. The extreme simplicity and compactness of a machine of this third type is shown by Fig. 12 which illustrates the machine exterior, by Fig. 13 which pictures the complete rotating parts, and by Fig. 14 which shows a sectional view of the condenser end of the dumb-bell.

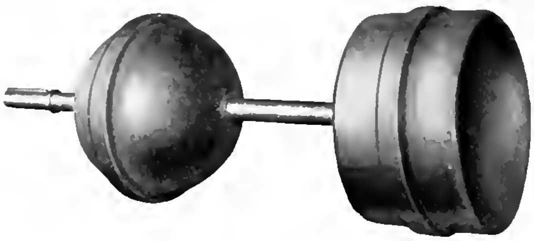


Fig. 13. Hermetically Sealed "Dumb-bell" Constituting the Complete Rotating Element of the Refrigerating Machine Shown in Fig. 12

Absorption Type Machine

There are two forms of this machine which differ principally in the proportion of their parts. In the one machine high-pressure steam is used, in the other the proportions are such that low-pressure or exhaust steam may be used. In some cases where large quantities of exhaust steam are available these latter machines proved very economical.

All absorption machines, however, are subject to rapid deterioration of the pipe coils in the generator, to losses of refrigerant from defective or leaky pipe joints as in compression machines, and from certain difficulties peculiar to this type, such as foaming in the generator, a condition resulting in what is called a "boil-over" which practically puts the machine out of commission for the time being.

The Enclosed Type Machine

This machine resulted from the effort to reduce the care required by the open machine, to lower the cost of construction and to reduce the possibility of trouble from inexpert tampering. When adjustment does have to be made, however, the working parts are very inaccessible. Further, builders of the open-type machine who do not build the enclosed type claim that the cylinder walls in this design wear more rapidly than where a cross head is used, with resultant decreasing capacity and efficiency. This judgment is not, of course, universal. The greatest sources of loss of ammonia and of objectionable odors, i.e., stuffing boxes and pipe joints, are still essential parts of the construction.

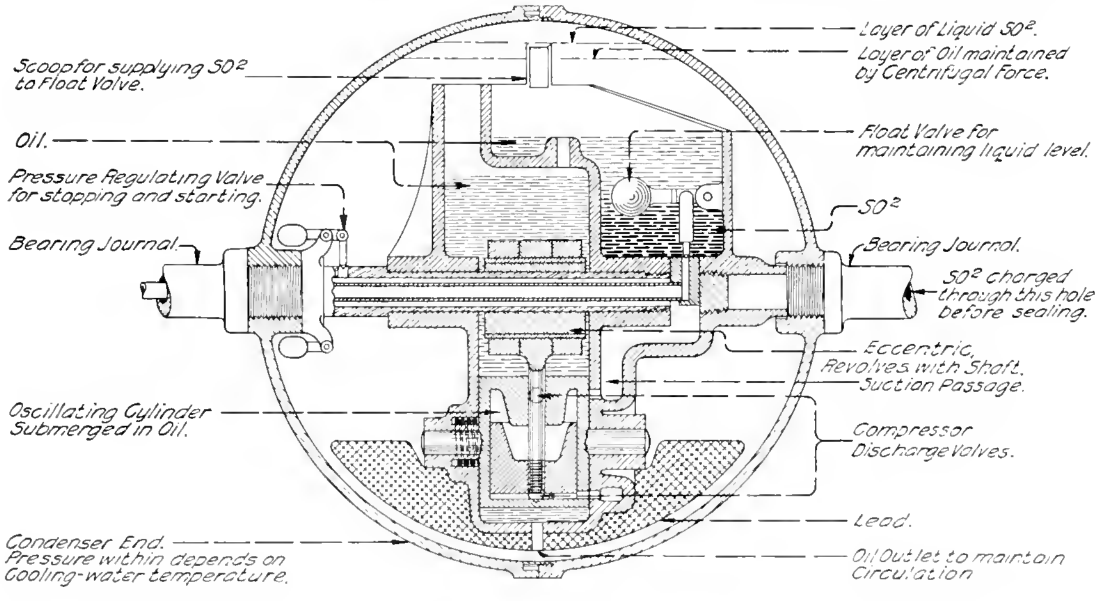


Fig. 14. Sectional View of the Compressor or Spherical End of the "Dumb-bell" Shown in Fig. 13

THE ADVANTAGES OF VARIOUS TYPES OF COMPRESSION MACHINES

The Open Type Machine

The advantage of this type is that any lack of adjustment due to wear can be readily corrected; and if the attendant has the skill and inclination to give the machine proper attention it will give excellent results for large installations, and is the preferable type of machine.

Audiffren-Singrun Type of Machine

The development of the open machine reaches its logical conclusion in this type. The loss of refrigerant is absolutely prevented by the hermetical sealing of the apparatus. Sulphur dioxide, the refrigerant used, has a much lower working pressure than ammonia, and consequently it is an easy matter to retain it in the machine. The working parts being completely enclosed are absolutely protected from deterioration, due to outside causes and also from unskilled tampering. The wear is reduced to a negligible quantity by a system of lubrication which constantly forces oil between all working surfaces. Metal to metal contact is minimized and the wear is proportionately reduced. The Audiffren-Singrun type compresses the gas under almost theoretically perfect conditions, which are independent of and beyond the control of the person in charge of the machine, regardless of whether he may be a skilled or unskilled operator. With the ammonia type machine these conditions are difficult to produce, and are in fact very rarely attained even by the most skilful engineer handling the most perfectly designed installation.

(To be Continued)

GLOSSARY AND EXPLANATION

British Thermal Unit (B.t.u.)

This is the quantity of heat required to raise the temperature of one pound of water one degree Fahrenheit. Heat used to raise the temperature of water or other substance is said to be present in that substance as "sensible heat," i.e., heat the presence of which we can feel or sense.

Heat of Liquifaction

This is also known as "Latent Heat of Liquifaction." It is the amount of heat absorbed by ice in melting. One pound of ice at 32 degrees Fahrenheit will absorb 144 B.t.u. in melting to water at 32 degrees Fahrenheit. In other words, the heat coming into a cake of ice is thus absorbed in melting the ice, and becomes what is known as "latent heat," i.e., heat absorbed by the ice without any rise in temperature, or heat that cannot be sensed.

If the ice is at a *lower* temperature than 32 degrees F., or if the water resulting from the melting rises *above* 32 degrees F., additional heat will be absorbed, as "sensible heat."

Specific Heat

This is the ratio of the quantity of heat required to raise the temperature of the substance one degree to that required to raise the same weight of water one degree.

For example, the specific heat of cast iron is 0.1298, i.e., it requires 0.1298 B.t.u. to raise the temperature of one pound of cast iron one degree, whereas it takes 1 B.t.u. to raise one pound of water one degree.

Heat of Vaporization

This is the amount of heat that water or any other liquid will absorb in vaporizing (evaporating from a liquid to a gas), or will give out in returning from the gaseous or vapor state to the liquid state.

Transfer of Heat

This occurs in three ways:

Convection: A warm substance carried bodily from one point to another "conveys" heat. For instance, a dish of warm food put into a refrigerator brings heat into the box by "convection." Similarly, when warm air enters a refrigerator through open doors it brings heat into the box by "convection."

Radiation: A refrigerator so placed that its walls are exposed to the direct rays of the sun will have the outer surface of these walls heated by "radiation."

Conduction: A small part of the heat which has reached the outer surface of the wall of a refrigerator, from the sun or from any other source, is "conducted" inward by the insulation.

Heat Transmission

When the temperatures on opposite sides of any surface, as for instance, a wall, are unequal, heat will flow by conduction through the material from the warmer to the cooler side. The rate of this flow is called the rate of heat transmission and is stated in terms of the quantity of heat (B.t.u.) which will pass through one sq. ft. of surface in 24 hours per degree temperature difference between the two sides of the wall.

Saturation of Air and Dew Point

Air always contains a certain amount of moisture, the amount depending upon a great many conditions. Its moisture-carrying capacity increases with rising temperature and decreases with falling temperature. The amount of moisture which the air contains is its absolute humidity. The percentage of moisture which the air contains at a given temperature in comparison with what it might contain at that temperature is known as its relative humidity. For instance, when air contains half the moisture which it might contain it is said to have a relative humidity of 50 per cent. The dew point is the temperature at which air begins to allow its water vapor to condense. Air which it saturated is at the dew point.

FREQUENCY CHANGERS

By Gordon Harris and L. B. Bonnett

Lighting Engineering Department, General Electric Company

The need of frequency changer sets is experienced where, for instance, a 25 cycle system has to supply lighting to the communities in its neighborhood, or where a 60 cycle system is to supply current of 25 cycles or less for railway operation, or where two systems of different frequencies are to be tied together. In this article the authors have confined themselves to a discussion of the types of frequency changer sets that have been commercially developed, in particular the synchronous-synchronous sets and the induction-synchronous sets. Reference is made to the matter of the most suitable speed for a given set of conditions and the limitations on capacity imposed thereby, and to the more important features embodied in present day construction. A full text of the proper procedure to be followed in starting synchronous sets is given; this being followed by an outline of the operations necessary to secure parallel operation of frequency changer sets, and a discussion of the inter-relations between the machines on the motor end and on the generator end.—Editor.

Field of Application

Frequency changers are necessary wherever power of a different frequency from that of the supply is desired. Sixty cycle current has become practically standard in America for lighting purposes and also for a large number of power applications, since, in the first place, it permits the successful operation of incandescent lamps of all sizes, and particularly of multiple arc lamps, and secondly, gives a much larger number of possible speeds for induction motors.

The most common use of frequency changers, therefore, is to furnish 60 cycle service from a 25 cycle hydro-electric transmission line or steam system. For instance, a large water power development brings cheap 25 cycle power over a long transmission line to many cities having a 60 cycle system. The steam plant is often shut down and power obtained from the hydro-electric system through frequency changers; the steam plant being maintained as a reserve in case of low water or transmission line trouble. Many plants which were originally laid out for 25 cycle railway operation have absorbed the lighting business in the villages and towns along their transmission lines, and it has become necessary for them to transform their power to 60 cycles in order to give the best service. In many of the large cities steam plants were laid out for 25 cycles and the a-c. power was converted to d-c. by synchronous converters and distributed by the Edison three-wire system. As these plants grew and service was required at greater distances from the power station, it became necessary to distribute at higher voltages to the remote districts, owing to the excessive loss in transmission over long feeders and mains at the direct current voltage. Frequency changers were therefore installed to furnish 60 cycle alternating current to customers too scattered to be supplied by the Edison three-wire system.

It is often necessary to obtain 25 cycle current from a 60 cycle system. An instance of this would be where a large central station giving 60 cycle service is located in the same community with a railway system which generates its own power at 25 cycles and converts to d-c. through synchronous converters. As is becoming common in these days, such plants often consolidate, or the railway company buys power from the central station. In this case frequency changers may be necessary to give 25 cycles for the railway system. There are some railway installations using single-phase alternating current, and for satisfactory operation of single-phase motors these systems must be 25 cycles or less. An advantage of motor-generator sets in this case would be that the power-factor of the railway load would in no way affect the regulation of the transmission line from which power is taken, and by using a polyphase motor driving a single-phase generator, no unbalancing would be caused.

Frequency changers are also often used as a tie between two plants or two systems. For instance, in many places in this country will be found a 60 cycle system which has expanded until it comes into close touch with a neighboring 25 cycle system, which may have its peak load at an entirely different time. In a case like this it would be to the mutual advantage of both systems to interchange power, and a reversible frequency changer set could be installed to tie in the two systems. When a 60 cycle hydro-electric transmission line comes into touch with a community where a 25 cycle steam plant is installed, it is common for the latter to buy power from the new company, supplying all new customers with 60 cycle power direct from the transmission line and using frequency changers to supply what 25 cycle load cannot be changed over. The 25 cycle steam station would be held in reserve for breakdown service, and with reversible frequency changers could furnish power to the 60 cycle system in times of necessity.

It has already been mentioned where some 25 cycle systems supplying Edison three-wire circuits had so grown that it became necessary to transmit 60 cycle power. As some of these systems grew still larger it became more economical to have separate generators to generate directly at 60 cycles, and we have the frequent case in large cities of generators side by side feeding two different systems, one at 25 and the other at 60 cycles. In cases like this, reversible frequency changers tied in between the two systems could transmit power from one system to the other, depending on the relative demand, and so operate both systems at their best efficiencies.

The tendency in new hydro-electric transmission lines is toward 60 cycles, a notable exception being the Mississippi River development. With this tendency, and the improvement that has taken place and is still taking place in 60 cycle synchronous converters, it is probable that 60 cycles will become more and more the standard for all purposes, using 60 cycle synchronous converters or motor-generator sets to obtain direct current. Therefore the field of application of frequency changers seems likely to gradually decrease in the future.

Selection of Speeds

Confining this discussion to types of frequency changers which have been commercially developed, the speeds for which a given set can be designed are limited to those which are common to the two frequencies concerned. For instance, the highest synchronous speed possible for a 25 to 60 cycle set is 300 r.p.m. Sets at this speed can be built in sizes up to the maximum for which there is any market at the present. The small sizes can be more economically built at a considerably higher speed, and when 60 cycles is not absolutely needed on the high frequency side, $62\frac{1}{2}$ cycles is chosen. Such a generator, with a 25 cycle motor, can be built for 750 r.p.m. in the smaller sizes, and 375 r.p.m. up to the maximum sizes. This frequency is just as satisfactory for lighting and power service as 60 cycles, and 60 cycle equipment can be used on it without change. Table I shows the different speeds available for a few of the more common combinations of frequencies, giving the number of poles for the respective units and the approximate limit of capacity for which it is economical to build at the given speeds. Large capacities at high speeds require long barrel type rotors, which approach the expensive turbine type of construction. It then becomes more economical to go to a larger diameter and slower speed.

TABLE I

Cycles: Motor	Cycles: Generator	Poles: Motor	Poles: Generator	Speed R.P.M.	Approx. Max. Kw. Capacity	* Chance of Gen. Phase being O.K. when Started by Syn. Motor	* Field Reversing Switch: Motor	* Field Reversing Switch: Generator
25	60	10	24	300	max.	1 in 5	yes	4
25	$62\frac{1}{2}$	4	10	750	600	1 in 2		yes
25	$62\frac{1}{2}$	8	20	375	max.	1 in 2		yes
40	60	4	6	1200	150	1 in 2		yes
40	60	8	12	600	3000	1 in 2		yes
40	60	12	18	400	max.	1 in 2		yes
25	50	4	8	750	600	Certain		
25	50	8	16	375	max.	Certain		
$33\frac{1}{3}$	60	10	18	400	max.	1 in 10	yes	yes
30	60	6	12	600	1000	Certain		
30	60	8	16	450	max.	Certain		

*From Mr. J. B. Taylor's paper on "Parallel Operation"—A.I.E.E. Transactions.

Physical Construction

Commercial frequency changers may consist of, first, one induction and one synchronous machine; second, two synchronous machines.

The first arrangement is occasionally used, especially where the set is not necessarily reversible. Such a set usually consists of a low frequency wound-rotor induction motor driving a synchronous generator. This arrangement is frequently used as a tie between two systems, and when so used is not subject to such wide variations of load as a set composed of two synchronous machines. When the frequency of either system varies a trifle, the slip of the induction motor increases with increase in load, and vice versa, so tending to limit the variations. Frequency changers of this type are usually made for 25 to 62½ cycles, which gives a generator frequency at full load (owing to the slip of the induction motor) of from 61 to 61½ cycles. When tied between two systems, it becomes an easy matter to vary the load on such a set by varying the resistance in the rotor of the induction motor. While usually considered non-reversible, this type of set can be reversible in an emergency, the frequency of the circuit to which the induction machine supplies energy being twice its slip below normal. For instance, if the slip of the induction motor were 2 per cent, the extreme variation between the frequency of the 25 cycle system supplying this set as a motor and taking energy from it as a generator would be 4 per cent, or 25½ to 24½ cycles, assuming a constant frequency at the other end of the set.

The second construction, consisting of two synchronous machines, is the one most commonly used, and is completely reversible without change of frequency on either system. When used as a link between two systems, it will transfer power in either direction, according to the demand and to the comparative speed regulation of the governors of the two generating systems. If desired, either unit may be designed for power-factor correction. When used as a tie between two systems this construction makes an inflexible link, subject to wide variations in load with the slightest tendency to change in speed of either system. It is advisable, therefore, to have synchronous sets of large capacity as compared with the systems which they tie together, or they may be subject to such overloads as would pull them out of step. With sets having induction motors it is not necessary to be so careful in this regard for reasons given before.

The foregoing statements show that commercial frequency changers consist of two entirely separate units, viz., a motor mechanically driving a generator in which the power transmitted by the shaft is reconverted to electrical.

It is, of course, possible to build a frequency changer consisting of two induction machines; but this could not be operated unless there were other synchronous generators operating on both the low frequency and the high frequency systems, as the induction motors or generators cannot excite themselves, but must be provided with excitation from synchronous generators running on the same system. Because of this disadvantage and the fact that the ratio of the frequency of the two systems would be affected by the combined slip of both induction machines, sets consisting of two induction machines have not been used commercially.

Another construction which has been used in a very few cases consists of a synchronous machine and a frequency converter, the latter machine being an induction motor running at fractional speed and having its stator supplied with current from the higher frequency system and its rotor delivering current to the lower frequency system. The synchronous machine coupled to the frequency converter is used as a motor or generator, according to the direction of flow of power. This combination has been designated by Dr. Steinmetz as the general alternating current transformer, because it may be used to transform voltage, frequency and phase.

Theoretically it is more economical in material than the ordinary frequency changer, because each machine forming part of this frequency converter construction need be rated only slightly more than one-half the total output, while with the other constructions each unit has to be equal practically to the total output. However, the disadvantages are such that this form of construction has been very seldom used. One disadvantage is the drop of voltage with load and the fact that the machine has no inherent means of regulating the voltage of its output. This indicates that some auxiliary means of regulating the voltage, such as an induction regulator, or a series booster mounted on the shaft must be furnished. Another disadvantage is the fact that the a-c. output, consisting partly of mechanical power on the shaft and partly of electrical power transformed from the stator, must all pass through the rotor and through the collector rings. The design of the rotor is therefore limited to comparatively low voltages, such as are safe to handle on revolving coils and collector rings, otherwise the outfit would be handicapped by a static transformer in addition. Although this construction has not met with any recognition, has only been used in a few cases, and would be objectionable on account of its special and unfamiliar features, it still appears that it would be cheaper than the ordinary construction of two synchronous machines when the two frequencies are close together; that is, when we wish to transform from 40 to 60 cycles, 50 to 60 cycles, or other similar cases.

Some illustrations of larger modern frequency changers are shown in this article.

From these it will be seen that one of the machines is usually swung in a cradle, which in turn is bolted to the base of the set. This allows the stator to be rotated through a small angle around the shaft, and to be easily adjusted to operate in parallel with other frequency changers.

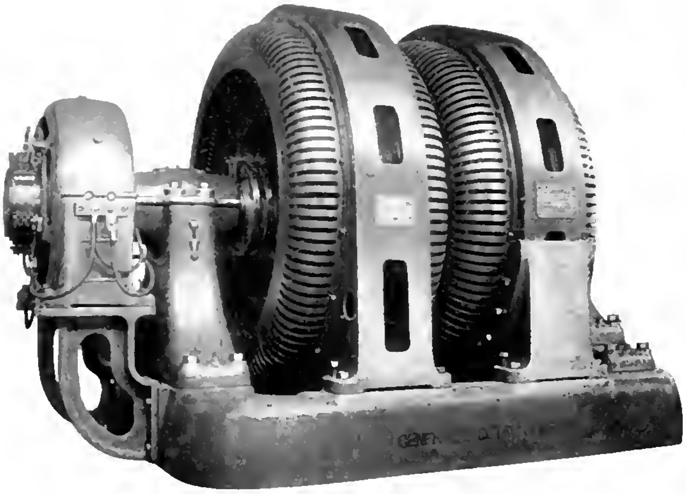


Fig. 1. 1000 Kw. Frequency Changer Set and Exciter

Fig. 1 shows the characteristic construction of sets of medium capacity. The present tendency, however, is toward a three-bearing design, except where space is a very important factor, as it gives greater accessibility.

Fig. 2 shows the sub-base under one of the middle bearings. In case of accident to either machine, this sub-base can be removed, leaving the pedestal proper hanging on the shaft. The shaft would be supported by the other middle bearing in case of large four-bearing construction; or, in case of three-bearing construction, with one middle bearing, the shaft could be suitably blocked up. The stator of the damaged machine could then be moved along the base; the pedestal, which is smaller than the inside diameter of the stator, passing inside. This would give easy access to both stator and rotor for any repairs.

Fig. 2 2500 Kw. Frequency Changer Set and Exciter with Sub-bases under Middle Bearings

Fig. 3 shows large end shields for controlling the ventilation and forcing the air out through ducts in the lamination. With very large sets having high peripheral speed, these shields tend to prevent the noise due to air currents, which would eddy around through open shields and the field poles. This illustration also shows a slip ring type induction starting motor.

Fig. 4 shows an oil system for forced lubrication at starting. This consists of only a small motor-driven pump with suitable piping, and is not at all a complicated equipment. It permits the set to start with less initial starting current by forcing oil into the bearings, in case they have become dry from an interval of rest. After the set begins to turn over the bearings are self-oiling. This figure also shows another type of end shield which completely protects the end windings from accident. Note also the steel straps which are bolted to the poles and to the rim of the spider, giving additional strength against centrifugal forces.

The amortisseur winding on the sets, while not shown in any of the photographs, consists of bars passing through holes in the pole tips and short circuited on both ends by sectional end rings. The bars fit accurately into holes in the end rings and are upset, making a securely riveted joint, good mechanically and electrically without soldering. The end rings are divided between poles and bolted together to make complete rings. Therefore, by removing a few bolts, each section may be disconnected from the rest, and a pole and its winding removed for any reason without disturbing the rest of the amortisseur winding.

Where economy of space dictates, vertical sets may be built, the rotating parts being supported by a thrust bearing at the top or a step bearing below.

Methods of Starting

It is hardly necessary to discuss the starting of frequency changers driven by induction motors, as such machines have the inherently good starting characteristics of that class of motor. Synchronous motor frequency changers are usually, except in the largest sizes, started at fractional voltage by a starting compensator, or from taps in the winding of the step-down transformers if such are used. When thrown on a suitable fraction of normal voltage in this way, the kilovolt-amperes drawn from the line by a low frequency motor will not exceed normal load kilovolt-amperes. When the set reaches nearly synchronism, the field may be applied and over-excited, so that the motor takes leading current while still running on the low voltage tap; then, when the motor is thrown on full voltage, the field will be strong enough to hold the line current down to a small value. Referring to Fig. 5, it will be seen that the field may be given such a value that the line current will be the same when thrown on full voltage as when running on the tap voltage, but of course lagging instead of leading. Curve *A* shows the armature curren taken by a 4250 kv-a. motor of a frequency changer set at compensator voltage with varying field excitation. In case a suitable compensator is used to reduce the voltage from 2300 to 800 volts, the armature current shown by *A* becomes the line current shown by curve *B*. Curve *C* shows the line current taken with full voltage on the motor. The excitation corresponding to the intersection of curves *B* and *C* would seem to be the best value to hold when throwing over from tap to line voltage in order to cause the minimum disturbance to the system. The great advantage of this method of starting is its simplicity, and the fact that the motor is self-synchronizing.

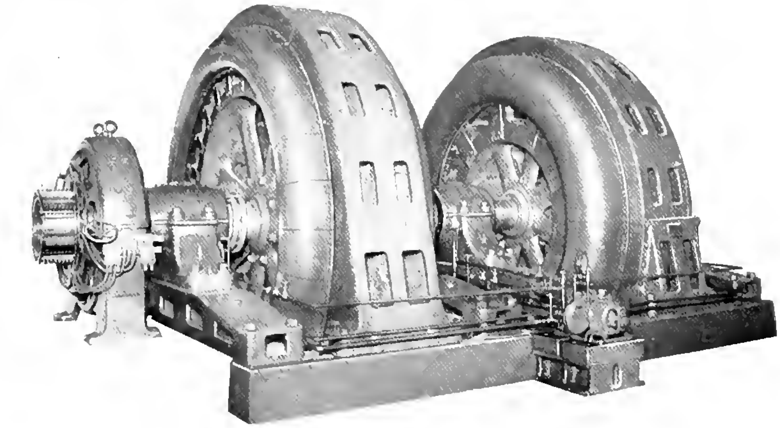


Fig. 4. 5400 Kv-a. Frequency Changer Set and Exciter with Motor-Driven Pump for Forced Lubrication at Starting

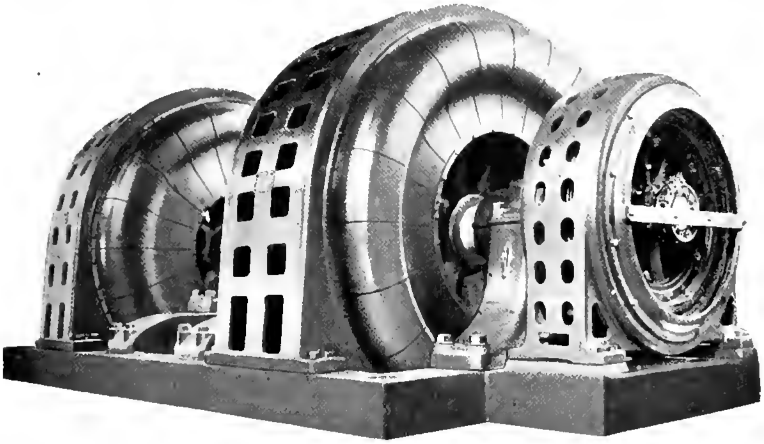


Fig. 3. 7050 Kv-a. Frequency Changer Set Showing Starting Motor

In some cases, when certain conditions render it objectionable to draw considerable current from the line at low power-factor, a starting motor may be supplied. This is frequently done in the case of a horizontal set whose capacity is large compared with the circuit to which it is connected.

If direct current is available, a direct connected exciter is often used, designed with enough capacity to start the set and bring it up to speed. This starting motor would have a rating from 10 to 20 per cent that of the set, depending on the design of bearings, etc., and how the motor is rated in reference to its maximum torque. After the set is running, this motor could be switched over to its ordinary duty as an exciter.

A more common method is to use a wound rotor type induction motor designed with two less poles than that of the synchronous motor, since it must be capable of bringing the set above the synchronous speed of the main motor. This motor also would be rated from 10 to 20 per cent the capacity of the set. The current required would be considerably less than that required by the synchronous motor, but it is difficult to make a general statement of the amount since that varies so greatly, depending upon the frequency of the motor and the design of the rest of the set.

With a comparatively small set, a high resistance squirrel cage induction motor is occasionally used for starting it and bringing it up above synchronism. Then a resistance is inserted in the line, reducing the voltage on the starting motor and increasing its slip,

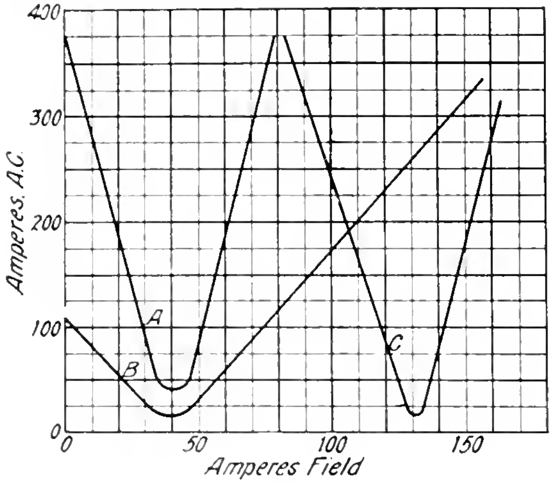


Fig. 5

and the set slowly drifts down until it may be synchronized. Separate motor starting, of course, has the disadvantage of additional cost for the extra starting equipment, and also is not self-synchronizing as is the first method.

When it is necessary to have the starting kilovolt-amperes as small as possible, oil pressure under the bearings at the instant of starting is frequently used. This forces a film of oil between the bearings and the shaft, which decreases the power required to break the set from rest. This allows the use of a lower tap on the compensator if the set is self-starting or requires less torque from the starting motor, thus reducing the initial rush of current, in some cases 25 per cent or more. As soon as the set turns over, the pressure is no longer needed.

Excitation

The question of the advisability of direct connected exciters depends upon the number of units in the station. When a station contains three or more sets, it is usual to have separate excitation in duplicate to take care of the entire capacity. A few large exciters, of course, can be operated more economically than several small ones, and offer less complication under operation with voltage regulators. Where there are fewer units or where the unit system is employed, direct-connected exciters are used. Sets have been built with two direct-connected exciters, one for the motor and one for the generator; as have also sets with one exciter only large enough to excite the motor, the field of the motor being under hand control, while the field of the generator is excited from a separate source under automatic regulator control. A direct connected exciter, however, is usually made large enough to excite both the motor and generator of the set under their worst rated condition of power-factor and overload. To have the motor and generator excited from the same source would often be an advantage, because as load comes on the set and the excitation is increased to hold up the voltage of the generator, the excitation of the motor would also be increased. The motor would thus tend to take leading current and act similarly to a synchronous condenser in regulating the voltage of the incoming transmission line.

Parallel Operation

By parallel operation of frequency changer sets we mean that the motors of the sets are connected to and driven from the same source, and the generators are connected to and feed the same system; or in other words, the sets are electrically locked together on both ends. The motor and generator of each set are, of course, mechanically locked together by the shaft. From the above you will note that parallel operation means that the sets must be paralleled on both ends and not merely paralleled on the motor ends while the generators feed different systems.

After starting by any of the methods outlined, and synchronizing on the motor end, the generator of the set may not be in the correct phase relation for paralleling with sets already running. In some cases, to secure the proper phase relation at both ends of the set, synchronizing lamps and a voltmeter are made use of. In other cases a special double synchronism indicator with two hands on the same dial is used; but the most practical way is to use two standard synchronism indicators, one for each end of the set. When starting a set which is to operate in parallel with sets already running, it should be started up from the low frequency end, as this will give the better chance of the other end coming to speed in the proper phase relation, as will be explained later. In the case of 25-60 cycle 300 r.p.m. synchronous motor sets, the 25 cycle motor is started up by means of a compensator or low voltage transformer taps, and after synchronous speed is reached the 60 cycle end has one chance in five of being in the correct phase position for paralleling with the other sets already running. If started from the 60 cycle end there is one chance in 24 of the set coming right on both ends, and it may be necessary to slip a maximum of twenty-three poles to bring the sets to the correct phase position. When started from the 25 cycle end, the 60 cycle synchronism indicator shows whether or not the phase relation is correct.

If the phase relation is incorrect, as it will be four times out of five, there are two methods of obtaining the correct relation. In the first method the motor circuit is opened and the set begins to slow down. Both synchronism indicators begin to revolve, the 60 cycle indicator making 2.4 revolutions for each revolution of the 25 cycle indicator. There is one instant when the hands of both indicators will pass the synchronizing point at the same instant, thereby indicating the correct phase relation of both ends of the set. When this takes place the circuit of one machine is closed, and the circuit of the other end of the set may be closed at leisure, and when this is done the set is in parallel with the sets already running and will take its proper share of the load.

The synchronizing point referred to above will not be at the top of the dial on the synchronism indicator connected to the generator of the incoming set, but its location will depend upon the load which is being carried by the generators of the sets already running. The rotors of the loaded synchronous motors have a constant angular lag behind the revolving position in space of the three-phase currents in their stators. The amount of this angular lag depends upon the load which is on these machines. There is also an angular lag, or phase displacement, of the terminal voltage of the loaded generators behind their generated e.m.f. Consequently the e.m.f. of the generators of these loaded sets is behind the e.m.f. of the generator of the incoming unloaded sets by a constant time lag which depends on the amount of load of the loaded sets. This means that the hand of the synchronism indicator on the generator of the incoming set, which is unloaded, will stand (when synchronism is reached) not at the top of the dial but ahead, or approximately in a position which the operators refer to as "quarter past" if the running sets are fully loaded. This point, ascertained by experiment, is the synchronizing point referred to above in the two-synchronizer method; that is, the circuit should be closed at the moment when the synchronizer connected to the motor circuit is passing the top of the dial and the synchronizer connected to the incoming generator is passing the synchronizing point, which may be quarter past at full load, or half of that angle at half load. As soon as both circuits are closed, the incoming machine takes enough load to make its displacement angle equal to that of the running machines, which angle is somewhat decreased by the transfer of a portion of their load to the incoming machine.

With machines of comparatively large angular displacement, the phase displacement may be so great as to cause an undesirably large rush of current at the moment of connecting an incoming machine on the system. This may be obviated by several methods. One is to provide an artificial load consisting of water boxes or iron rheostats for the incoming machine; another method is to connect the incoming generator to the busses through a reactance or resistance with several taps, so that it may be made to take up a part of the load on the system gradually and thus reduce the angular displacement between this machine and those already running before finally cutting out the resistance and throwing the machine fully in parallel.

In the second method of obtaining the correct phase relation the motor is left connected to the busbars while the field is reversed (to "slip" a pole) as many times as may be necessary to obtain correct phase relation. The synchronism indicator connected between the busbars and the incoming generator will show whether the phase relation is correct for parallel operation; but for any one of the other four possible positions of phase relations, the indicator will show one of the remaining four points, which may be marked 1, 2, 3 or 4, indicating the number of times that the motor field should be reversed if this method is used for changing the phase relation. This may be done by using a double-pole double-throw field reversing switch connected in the synchronous motor field. At each reversal the motor is slipped back one pole at a time, until the generator is in the same phase relation as the machine already running. If the generator has the proper phase relation when the set comes to synchronous speed, it will not be necessary to slip poles on the motor. As this chance is only one in five, as stated before, it is usually necessary to reverse the motor field two or three, or in extreme cases four times in succession to obtain the correct phase position. After this position has been obtained, the set may be thrown in and will take its portion of the load.

The exact position of the correct phase relation point, as well as the other points Nos. 1, 2, 3 and 4 showing the number of times that the motor field should be reversed, depends upon the extent to which those machines already running are loaded. If they are running at no load, the correct position for the generator synchronizer of the incoming machine is the top of the dial. If they are running at full load it may be as much as quarter past or 20 minutes past, and the points 1, 2, 3 and 4 will be moved around accordingly.

It is not a difficult matter for the station operator to make up a movable card dial which may be set for different values of the load and will indicate the position of the proper synchronizing point and the points 1, 2, 3 and 4 on the synchronism indicator for each value of load. The operation of starting and placing a set in parallel with sets already running is therefore as follows: throw the motor on the compensator or transformer tap and when the motor has reached synchronous speed close the field circuits of both motor and generator. Unless the generator comes to synchronism in the proper phase position, the field of the synchronous motor should be reversed until the synchronism indicator shows the correct position for parallel operation. Then the motor should be thrown on full line voltage, which is done by oil switches, usually electrically or mechanically interlocked to prevent the motor from being thrown on the compensator and full line voltage at the same instant; then connect the generator to the busbars, which will complete the operation. The above method may be used with sets of any combination of poles, speed or frequency. However, with sets in which the ratio between generator poles and motor poles is a whole number, the generator phase position must be correct. In some combinations of poles, field reversing switches on both motor and generator are used, as this reduces the number of times that the motor field must be reversed in order to bring the generator to the proper phase position. Table I shows the different combination of sets that should be furnished with one or two field reversing switches, and also gives the degree of chance that the generators will come right when started by synchronous motors.

Where either direct current or induction starting motors are used, both ends of the set may be phased in at the same instant, or one end only may be synchronized by the usual method, and the other end phased in by reversing the motor field switch until the generator is in the proper phase position.

Where machines are provided with direct-connected exciters and one exciter becomes reversed, it may interfere with synchronizing this machine with the others. Where the sets are excited from the same bus, the reversal of exciter polarity will give no trouble, as the fields of all the sets will reverse at the same time. The generator of the incoming set, before it is phased in, has a terminal voltage which is in advance of the generators operating under load; therefore, at the instant of connecting the incoming generator to the busbars, it has a tendency to take more than its portion of the load momentarily. In actual practice this is not generally found to be serious and may be eliminated in several ways as already pointed out. An incoming generator with the proper excitation will cause a minimum disturbance on the system, which should cause no appreciable flicker in the lights at the instant of synchronizing. By changing the excitation of motor or generator, or both, some change in the division of the load between the sets may be gained; however, this method should not be used, as it causes leading or lagging current which increases the heating of the machines. By increasing the field of the synchronous motor for a given load, the angle of lag will be less; therefore increasing the motor field tends to make the set take more than its proportion of the load.

Requirements for Proportional Division of Load

For parallel operation it is not necessary that sets be identical in construction, or of the same capacity. Two identical sets operating in parallel will carry the same load if each is provided with the same field excitation. Where a set has a motor or generator with closer regulation than the machines of another set, the set with the closer regulation will take more than its proportion of the load. The closer the machines regulate with a given load, the smaller the angle between the voltage on open circuit and the voltage under load; therefore the set of closer regulation will take more load, increasing this angle, while the other set will take less load, decreasing the angle. The sets will divide the load in such proportion as will make the angle the same for both. Under this condition the division of load is stable. If the set with the closer regulation is adjusted to have the same phase position as the other machines, it will take more than its rated proportion of the load. It is a simple matter to change the phase relation so that when running with other machines under full load the incoming machine will not take more than its share of the load. However, when operating under light or no-load this would cause the generator to lag behind the others and its action would be reversed, that is, the generator would tend to run as a synchronous motor.

Induction Motor Sets

For successful parallel operation of induction motor frequency changer sets, it is advisable that the motors be of the wound rotor type with an external adjustable resistance in the rotor circuit so that all sets will have the same slip at different loads in order that the generators will have the same frequency under any conditions. Where a manufacturing company is called upon to furnish an induction motor set to operate in parallel with sets of different capacities and manufacture, it is not only necessary that they furnish a starting resistance for the rotor circuit for bringing the set to speed, but in addition to this, there should be furnished a synchronizing resistance designed for continuous operation, which will allow slight variations in speed of the set when operating at a given load or variable loads. From this it will be seen that under certain conditions some of the sets may be operated with the rotor circuit short-circuited, while other sets should have a resistance permanently in the rotor circuit, as stated, to obtain the same per cent slip or to give the same generator frequency. When an induction motor set is first placed in parallel with other sets, it is necessary to determine preferably by experiment, the amount of resistance to be placed in the rotor circuit for a given load. The slip on all sets will vary practically the same for all loads and, therefore, it is not necessary to adjust the rotor resistance for variations in load. If one induction motor set is operated alone, it is of course advisable to short circuit the rotor circuit. It is impossible to operate an induction motor set and a synchronous motor set in parallel, because as the load increases the speed of the induction motor set will decrease, and thus the synchronous motor set will take more than its share of the load. On account of the variable generator frequency of induction motor sets due to the motor speed varying with the load, synchronous motor frequency changer sets are in general preferable. A notable installation of this kind, however, is at the Brooklyn Edison Company, where 1000 kw. and 500 kw. induction motor sets of different manufacture operate in parallel.

TUNGSTEN LAMPS OF HIGH EFFICIENCY

By Irving Langmuir and J. A. Orange

Research Laboratory, General Electric Company

This article is a portion of the A.I.E.E. paper mentioned in the editorial note accompanying the article on "The Nitrogen-Filled Lamp," published in the October issue of the Review. The new lamp, as is now well known, consists of a tungsten filament enclosed in a bulb filled with an inert gas, such as nitrogen, at about atmospheric pressure. The highest efficiencies with satisfactory life (0.4 to 0.5 watt per candle, 1500 hours) are obtained from filaments of relatively large diameter, requiring currents of 10 amperes or more. Many lamps taking 6 to 7 amperes have been made for 110 volts that have burned at 0.6 to 0.7 watt per candle efficiency with a life of more than 1000 hours. The article gives a very interesting discussion on the design of filaments, bulbs, lead-in wires and supports of various types of nitrogen-filled lamps. The advantages of the nitrogen-filled lamp are mentioned and some remarks included on the light distribution and methods of photometry.—Editor.

In a previous publication there has been outlined the principles upon which radical improvements in the efficiency of tungsten lamps may be based.*

It was there shown that the desired improvement can be obtained by preventing evaporation of the filament or by preventing blackening of the bulb. By the introduction of considerable pressures of such gases as nitrogen or mercury vapor into the lamp the blackening can be practically avoided and the evaporation of the filament reduced very considerably.

By making use of these principles we have been able to construct practical tungsten lamps which, starting at an efficiency of about 0.40 watt per candle, have run over two thousand hours, the average efficiency during life being better than 0.5 watt per candle. It should be pointed out at the outset, however, that such a degree of improvement as this has been reached only in lamps taking large currents.

In this present article we will describe the methods by which these results have been attained.

The early experiments with lamps containing nitrogen at atmospheric pressure were made with ordinary single loop filaments of 0.005 and 0.010 inch diameter placed in long heater lamp bulbs. These lamps were set up on life test at such a voltage that the temperature of the filament was 2850 deg. K.†

In order to compare these with ordinary lamps, similar lamps with evacuated bulbs were set up on life test with the filaments at the same temperature.

The nitrogen-filled lamps with the filaments 0.005 inch diameter gave an efficiency of 0.65 watt per candle and had a life of about 90 hours, whereas those with the larger filaments (0.010 inch diameter) gave an efficiency of 0.56 watt per candle and a life of about 300 hours. The bulbs opposite the filaments remained clear, although a slight brown deposit of tungsten nitride collected in the upper part of the bulbs. The candle-power of these lamps remained above 80 per cent during their entire life, failure being due in every case to breakage of the filament after this had decreased considerably in diameter.

The vacuum lamps, on the other hand, gave an efficiency of 0.41 watt per candle, but the bulbs blackened rapidly, the candle-power falling to 80 per cent in about 40 minutes. Since the filaments of the vacuum lamps burnt out after 2 to 5 hours, whereas those of the nitrogen lamps lasted 50 to 100 times as long, it is evident that the rate of evaporation of the tungsten is materially reduced by the presence of the nitrogen.

These results indicated clearly the desirability of using a filament of large diameter. The larger filaments gave not only a better efficiency at any definite temperature, but also a much longer life. Thus doubling the diameter increased the efficiency from 0.65 to 0.56 and increased the life from 90 to 300 hours. The improvement in the efficiency, as was pointed out in the previous article, is due to the relatively greater heat loss by convection from small wires. The life of the filament is determined largely by the loss of tungsten from the filament by evaporation and has been found to be dependent on the *relative* decrease in diameter caused by this evaporation. If the rate of evaporation per unit area from large and small wires were the same, the lives of various filaments run at a given temperature would be roughly proportional to their diameters. However, as the evaporation of tungsten in nitrogen is largely a diffusion process, it probably obeys laws similar to those of conduction or convection of heat from a wire; that is, for wires of small diameter, the actual amount of

* [illegible] Methods of Preventing [illegible] A.I.E.E. [illegible]
[illegible] General Electric Review, [illegible] 688.

† [illegible] Kelvin [illegible]

tungsten evaporated would be nearly independent of the size of the wire. The rate of evaporation *per unit area* would thus be approximately inversely proportional to the diameter. The relative lives of very small wires in nitrogen are therefore nearly proportional to the squares of their diameters.

Design of Filament

These results were decidedly encouraging, for both efficiency and the life of the lamps can be improved by increasing the diameter of the filament.

It is, however, not desirable to use filament of very large diameter if similar results can be obtained with smaller ones. The current taken by a filament increases approximately with the three-halves power of the diameter. Thus, for wires of the sizes used in the preceding experiments, the currents needed to maintain a temperature of 2850 deg. were approximately:

DIAMETER		CURRENT
Inches	MM.	Amp.
0.005	0.127	3.0
0.010	0.254	8.5
0.020	0.508	24.0

Unless very low voltages are used, the power consumed with the larger wires is so great that only very high candle-power lamps can be made.

Therefore it was of vital importance to increase the effective diameter of the filament without decreasing its resistance, and various methods of doing this were tried.

This result may, for example, be obtained by using a tubular filament. The method which has thus far proved most satisfactory, however, is to wind the filament into the form of a tightly coiled helix.

The use of a helically wound filament presents several very interesting features. The life of ordinary single loop filaments is limited by the irregularities in diameter which develop after a considerable amount of tungsten has evaporated. These irregularities, after they first appear, tend to magnify themselves very rapidly, on account of the tendency for the current to overheat any spot which becomes thinner than the rest of the filament. The overheating increases the rate of evaporation and rapidly causes failure.

In the gas-filled lamps, however, when helically wound filaments are employed, a new factor is introduced which entirely counteracts this tendency to overheat in spots. In designing the filaments of these lamps, it is evidently desirable to wind the filament on as large a mandrel as possible, in order to obtain the advantage of the large diameter. Since tungsten is a relatively soft material at the operating temperature of these lamps, too large a mandrel should not be used, as otherwise the weight of the filament pulls out the helix very materially in a few hours, and the heat lost by convection may thus become greater than if a helix of smaller diameter had been used. In actual practice the filament is designed so that the amount of sagging during life will be perceptible, but not enough to cause too great a change in the characteristics of the lamp.

If, during the life of the lamp, any part of the filament should, for any reason, evaporate more rapidly than the rest, so that the filament becomes somewhat thinner, this portion will have less mechanical strength than the rest and will therefore sag more rapidly. The helix will therefore open out wherever the filament becomes thin or becomes overheated. This will cause increased heat loss both by convection and radiation, and thus prevent local overheating or spotting.

The use of helically wound filaments increases the life of the lamp many times beyond the life that would be obtained with a straight filament running at the same efficiency. This is especially true of the smaller sizes of wire.

Besides the helically wound filament, various other forms have been tried, and, for special purposes, many of these have decided advantages.

Design of Bulbs and Location of Filaments

In the ordinary evacuated lamp, the choice of a suitable bulb is a comparatively simple matter. It must be of convenient size and shape, and provide sufficient room for the proper mounting of the filament. Furthermore, it must have as large an inside surface as possible, so that the density of the deposit of evaporated tungsten will be small. It is also desirable to have the bulb at a sufficient distance from the filament and so related to the power input into the lamp that the bulb does not become overheated. This latter is not only desirable from the view point of safety (in case of lamps for domestic service), but because it is difficult to remove water vapor so thoroughly from the bulbs that the life of the lamps will not be greatly shortened by an overheating of the glass.

In the nitrogen-filled lamps, however, several other factors must be considered, especially in the lamps of high candle-power.

In ordinary lamps about 20 per cent of the energy radiated from the filament is intercepted by the glass and causes heating of the bulb. In the nitrogen lamp, beside this radiated heat, there is an additional amount of heat carried to the bulb by convection—an amount varying with the type of lamp and ranging from 6 to 40 per cent of the total input. The convection currents carrying this relatively large amount of heat travel vertically upwards from the filament and strike a relatively small area of the bulb, which thus tends to become greatly overheated. Unless special precautions are taken, this overheating will cause the liberation of enough water vapor to cause attack of the filament and consequent blackening of the bulb. It is thus highly desirable, in ordinary cases, if small bulbs are to be used, that the filament should be placed in the lower part of the bulb. This has the further advantage that it allows sufficient surface of glass in the upper part for the deposition of the tungsten nitride.

Fig. 1. High Efficiency Nitrogen-Filled Lamp for Low-Voltage Circuit

For a similar reason it is generally desirable, although not necessary, to make the bulbs with their height considerably greater than their horizontal diameter.

By special design of the bulb, satisfactory lamps have been made with bulbs of only one-half to one-third as large a volume as that of evacuated lamps of the same wattage. This means that for bulbs of the same volume the nitrogen lamps give roughly from five to ten times the candle-power of evacuated lamps. The bulbs of such lamps naturally run much hotter than those of ordinary lamps. The upper parts of the bulbs are often 100 to 200 deg. cent. or more, while the lower parts are sometimes much cooler than this, although closer to the filament.

Several special varieties of heat-resistance glass have been used for the bulbs, making considerably smaller ones possible, as well as rendering it easier to get rid of water vapor. Transparent quartz bulbs have been tried, but do not seem to have sufficient advantage over some of the special glasses to offset their present high cost.

Lead-in Wires and Supports

For some of the larger size lamps which take heavy currents (20-30 amperes) it has been necessary to devise special types of lead-in wires. Platinum has been discarded entirely, even in the smaller sizes. Several types of heavy current leads have been successfully used. Most depend on the use of special alloys which have the same coefficient of expansion as the glass. Bulbs of special glasses into which tungsten or molybdenum wire can be sealed directly, have also been used.

In many of the larger lamps the lead-in wires pass through the lower end of the lamp. In this case they can be made short. In others, however, the leads are brought in from the top. This requires more care in the construction of the seal if it is exposed to the heat from the convection currents. Screens are sometimes used to protect the seal or other glass parts from direct contact with the convection currents, and to reduce convection.

Various Types of Nitrogen-Filled Lamp

We have seen that at constant temperature, both the efficiency and the life improve as the diameter of the wire is increased. With very large wires (0.020 to 0.040 inch diameter) which take 20-60 amperes, the efficiency may reach 0.40 watt per candle and probably even better, and yet give a life over a thousand hours. It will probably be worth while, in some cases, to use nitrogen in low-current lamps, even if an efficiency no better than that of vacuum lamps is obtained, in order to gain certain other advantages of the nitrogen-filled lamps, such as better color of the light, higher intrinsic brilliancy, etc.

The principal limitation of the new type is therefore that of current. There is no practical upper limit to the current, provided the voltage is not lowered to keep constant power consumption.* With increasing current, larger and larger filaments are used and the efficiency that may be practically reached, increases towards the limit of 0.20 watt per candle, which is fixed by the melting-point of tungsten. Unless special expedients are employed, the cooling effect of the leads lowers the efficiency of the lamps by an amount that is inversely proportional to the voltage and nearly independent of the size of the wire or the current strength.

With voltages of 20 volts or more, this effect is not serious, but for voltages as low or lower than 10 volts, it may become very important.

For the particular type of nitrogen-filled lamp which has at present been furthest developed, it may be said that a life of over 1500 hours is obtained at efficiencies better than 0.50 watt per candle only in large units taking over ten amperes. Lamps running at 0.6 to 0.7 watt per candle have been made in units taking at least 5 amperes.

No serious difficulty has been met in making high-voltage lamps. In nitrogen at atmospheric pressure there is no tendency toward arcing, even at 250 volts. Many lamps taking 6 or 7 amperes at 110 volts have been made up and run at 0.6 to 0.7 watt per candle, with a life of over 1000 hours.

A number of special types of nitrogen-filled lamps have been made and tested. Among these the most interesting, for the present, are perhaps the following:

1. *Large Units of Very High Efficiency (0.4 to 0.5 watt per candle with a life of 1500 hours or more).* These take currents of 20 to 30 amperes and (except in units over 4000 candle-power) are therefore best run from a-c. circuits by means of small transformers or auto-transformers giving a voltage depending on the size of unit desired. Thus, with 30 volts and 25 amperes, the power would be 750 watts and this, in a lamp of say 0.45 watt per candle, would give 1670 candle-power. Higher or lower candle-power may be obtained by using other voltages. Typical lamps of this kind are shown in Figs. 1 and 2.

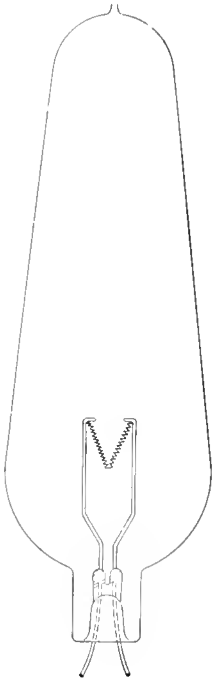


Fig. 2. High Efficiency Nitrogen-Filled Lamp for Low-Voltage Current

2. *Small Units of Low Voltage.* These take currents of ten amperes or less and voltages as low as four or five volts. The efficiencies with 1000-hour life range from 0.6 to 1.0, or even 1.25 watts per candle, according to the current used.

These lamps are adapted for series street lighting on 6.6-ampere circuits (at 0.6 to 0.7 watt per candle), for stereopticon lamps, automobile headlights and in general wherever a source of high intrinsic brilliancy, steadiness and white color is needed.

*As an example, a lamp taking 60 amperes and giving 6600 candle-power at 0.40 watt per candle has been successfully run.

3. *Lamps to Run on Standard Lighting Circuits (110 volts).* Large units of this type (several thousand candle-power) have efficiencies of 0.5 watt per candle or better. With smaller units the efficiency is ordinarily not so high.

A lamp of this type is illustrated in Fig. 3. The leads may be brought in from the top,

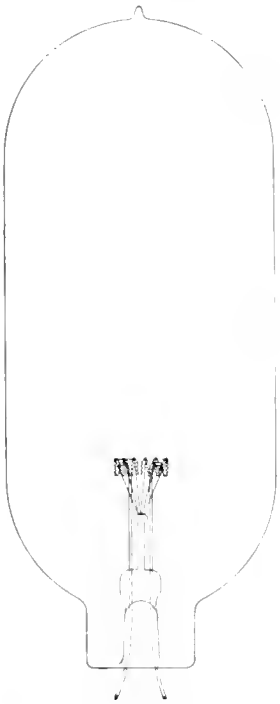


Fig. 3. Nitrogen-Filled Lamp for 110-Volt Circuit

in which case they are preferably made longer so that the filament remains in the lower part of the bulb.

Special Advantages of the Nitrogen-Filled Lamps

Besides its high efficiency, the features of the new lamps which may, at least for certain purposes, prove of advantage, are:

1. *Color of the Light.* The temperature of the filament being 400 to 600 deg. higher than that of ordinary lamps, causes the light to be of a very much whiter color, so that it comes closer to daylight than any other form of artificial illuminant except the d-c arc and the special Moore tube containing carbon dioxide. The color is almost exactly like that which can be had for a few minutes by running an ordinary tungsten at [illegible] double its rated voltage.

Work is at present under way to develop special color screens which, when used with this light, will give a true daylight color (corresponding to the radiation from a black body at 5000 deg. C.). From measurements with the spectrophotometer, it can be calculated that the screens which will accomplish this purpose will absorb from 65 to 75 per cent of the light, so that the net efficiency will be about 2.0 watts per candle for a pure daylight color. At present, to accomplish this purpose with ordinary tungsten lamps, screens must be used which absorb so much light that the net efficiency is between 10 and 12 watts per candle.

2. *High Intrinsic Brilliancy of the Filament.* At the operating temperature of the nitrogen-filled lamps the intrinsic brilliancy of the filament is about 1200 candle-power per sq. cm. In ordinary tungsten lamps, on the other hand, running at about 1.25 watts per candle, the filaments have a brilliancy of only about 150 candle-power per sq. cm. The brilliancy of the filament of the nitrogen lamp is thus about eight times that of the ordinary lamp.

This feature, combined with the high degree of concentration preferably used, renders these lamps particularly useful for projection work, such as for headlights or for stereopticons.

3. *Constancy of Characteristics During Life.* It is often possible to so design these lamps that their ampere, volt, and candle-power characteristics remain practically fixed during the greater part of their life. In any case, however, since there is no deposit on the bulb to cut off the light, the candle-power practically never falls below 75 per cent (this decrease sometimes being due to sagging). The lamp usually fails by the breakage of the filament with the candle-power well above 80 per cent of its original value.

Appendix I

Light Distribution of Nitrogen-Filled Lamps. In the preceding paper, wherever efficiencies of lamps have been given, they are expressed in watts per horizontal (international) candles measured in the direction perpendicular to the plane of the filament if this is in the form of a single loop.

Careful measurements have shown that with helically wound filaments the distribution of light in a horizontal plane is almost perfectly uniform, therefore the efficiencies that have been given may be considered to represent also watts per mean horizontal candle.

The spherical candle-power of many of the lamps have been measured. The ratio of mean spherical to maximum horizontal (practically mean horizontal also) candle-power has been found to average about 84 per cent for the lamps made with single loops of helically wound wire.

It is possible to design the filaments of nitrogen-filled lamps so as to give a maximum of candle-power in a given direction. This is being done in stereopticon lamps.

Appendix II

Method of Photometry for Nitrogen-Filled Lamps. The usual practice in dealing with incandescent lamps is to determine volts, amperes and candle-power either at a predetermined value of one of these quantities or else at a predetermined efficiency by the "cut and try" method. In the case of a lamp which prevents so many variables as does the nitrogen-filled lamp, however, it is more systematic to regard temperature as the fundamental variable.

The method that has been adopted for these lamps is not essentially novel, although it does not appear to be as well known as it deserves to be.

First: The temperature has been defined by the equation

$$T = \frac{11230}{7.029 - \log H}$$

where T is the absolute temperature and H is the intrinsic brilliancy of the filament in international candle-power per sq. cm. (projected area).*

Second: A most useful criterion in practice for equality of temperature of tungsten filament is that of color-match.

A little practice with the Lummer-Brodhun photometer enables one to judge equality within about 5 deg. if the illumination is good. The most convenient way of setting up temperature standards is to select a number of well-seasoned lamps of high-voltage type in which the anchors are tightly pinched onto the filaments so as to prevent variable cooling effects at the contact. It is best to standardize these, not on a basis of candle-power and filament dimensions, but by the aid of a special lamp and diaphragm as shown in Fig. 4. This lamp is arranged at one end of the photometer with the diaphragm in front of and at a known short distance from it. The filament is preferably stout (say 10-mil or 0.025-cm.) so as to admit of good micrometer measurements.

The diaphragm enables one to disregard the end portions of the filament and select a known length of the part which is at uniform temperature. Of course a simple geometrical correction based on the position of the screen is necessary.

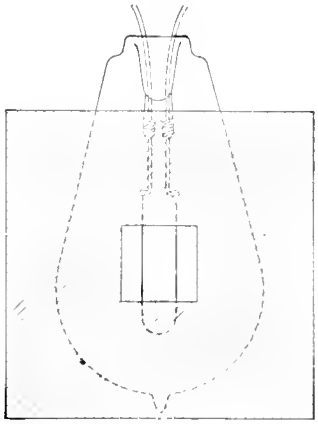


Fig. 4. Lamp and Screen Used for Calibration of Blue Glass

It is thus possible to set up the special lamp at any temperature desired by getting the appropriate candle-power per sq. cm. from the filament. The standard lamps are brought to color-match with this arrangement and in this way a set of lamps with known relation between voltage and effective temperature is obtained. The life of the ordinary standard lamps would be very short indeed if they were run at the same temperature as nitrogen-filled lamps. For this work, therefore, the standards cannot be used directly as color standards. For this reason a most important accessory is introduced in the form of a set of special blue glasses. It is not easy to get a blue screen which will perfectly facilitate color-match of tungsten filaments at different temperatures, but a special blue glass has finally been obtained which answers exceedingly well.

Four distinct screens of different intensity are used, each carefully finished as a uniform plate, and any or all of these may be combined with a tungsten filament run at any temperature and the result will color-match correctly against other tungsten filament at a higher temperature.

* (The derivation of this formula together with a description of other methods of obtaining the temperature of filaments will soon be published, probably in the *Physical Review*.)

It may be shown theoretically and experiment confirms that the following relation holds:

If T is the temperature of a filament which is viewed through screens A, B, C, etc.,

T_1 is the temperature of a filament which matches the above.

Then $\frac{1}{T}-\frac{1}{T_1}=a+b+c$, etc.

where a, b, c, etc. are constants for the screens A, B, C, etc. Thus one only needs to maintain one standard temperature by means of standard lamps and that temperature can be so low that great permanence is insured.

The constants for the four glasses once determined, there are available a number of standard temperatures ranging from 2250 deg. to 3600 deg. K.

By the use of these screens it is an easy matter to set a lamp up at a voltage such that the filament has a standard temperature, say 2850 deg. To do this it is simply necessary to adjust the voltages so that the color of the light from the lamp is the same as that which comes from the standard lamp when viewed through one of the special blue screens.

Since the efficiency in vacuum is very simply related to the color of the light, this method of photometry gives a very simple and direct way of knowing the exact effect which the nitrogen has on the efficiency of the lamp.

PHASE BALANCER FOR SINGLE-PHASE LOAD ON POLYPHASE SYSTEMS

By E. F. W. Alexanderson

Consulting Engineer, General Electric Company

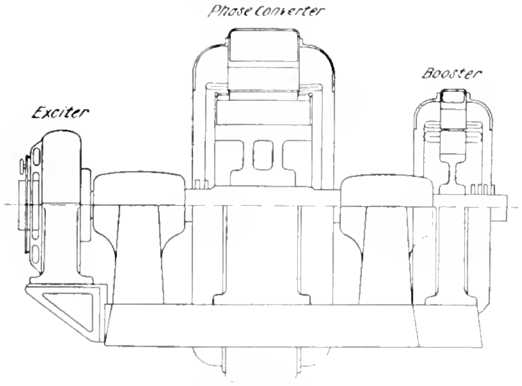
The demands for single-phase power from polyphase systems often reach such a point as to produce serious heating of the generators and troublesome unbalancing of the voltage. Especially is this true when single-phase power is supplied for traction purposes or for electric furnaces. The author describes a machine that has been developed to counteract these undesirable influences, the function of which is to absorb the unbalanced component of the load and redistribute it to give a resultant balanced polyphase load. The phase balancer consists essentially of a synchronous condenser provided with a polyphase booster connected in series with it, but in such a manner that its phase rotation is in the opposite direction to that of the synchronous condenser. —Editor.

The present practice in power station operation has been built up almost exclusively on the use of polyphase generation and supply. Whenever it is required to furnish single-phase power, a number of difficulties arise which make necessary departures from the ordinary power station practices.

The principal difficulties are the heating of the alternators on unbalanced load and the unbalancing of the voltage. A polyphase alternator of the slow speed salient pole type can be used for single-phase as well as for polyphase load, although its output is reduced with single-phase load; whereas a high speed turbo-generator which is ordinarily used for polyphase operation is entirely unsuitable for single-phase operation. The voltage on a polyphase power system is almost always controlled by voltage regulators in the power stations, and also eventually in various points in the distribution system by means of synchronous condensers with regulators. The regulator which controls the field of the alternator (or synchronous condenser) is actuated by the voltage of one of the phases, and the other two phases will maintain a constant voltage only under the condition of balanced load.

If single-phase power is needed in large quantities, for instance for traction purposes, this power can be generated in a power house designed specially for the purpose; but in so doing there are lost the advantages of being able to interchange power with existing systems, and the possibility of securing lower cost of power generation in a large system. The same problem of single-phase power supply arises in connection with electric furnaces, where the load is fluctuating between different furnaces, so that it is not possible to balance the load between the phases of a polyphase system without getting momentary excess load on one phase or the other.

In order to meet these new requirements of single-phase power supply in connection with existing polyphase power systems, a machine has been developed which may be called a phase converter or phase balancer. The machine is of a general type of synchronous condenser and has the function of either converting a single-phase load into a polyphase load, or what is really the same thing, absorbing the unbalancing component of a power system with mixed load and redistributing it so as to give a resultant balanced polyphase load. The use of the phase balancer in this latter way has the advantage over the use of single-phase alternators in that the additional cost of single-phase power house equipment and lower efficiency of generation



Outline of Phase Balancer Set

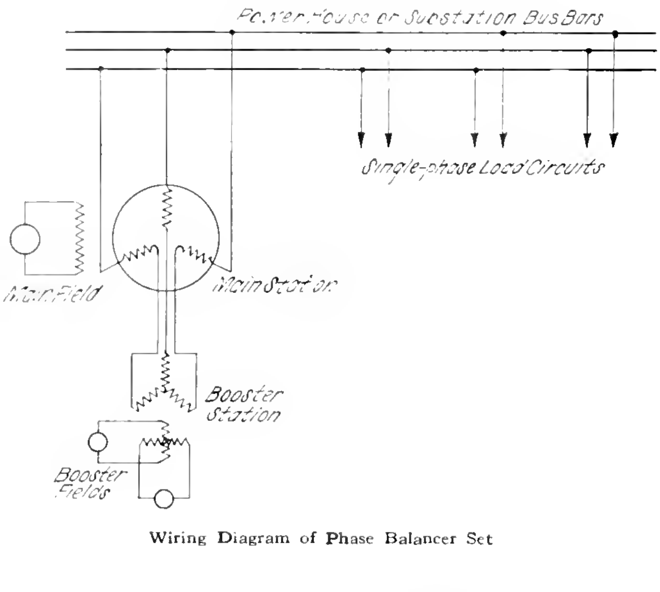
applies only to the momentary difference between the peak loads on the different phases. A large and diversified single-phase load can be better balanced than a small load, and an increase of single-phase load beyond a certain limit does not necessitate any additional installation of balancing machines.

Theory of the Phase Balancer

Various problems and phenomena in connection with single-phase alternating currents can be conveniently investigated, by assuming that a single-phase current or single-phase field can be resolved into two polyphase components with opposite phase rotation. These methods have been used by several investigators for explaining the functions of a single-phase induction motor. It is also convenient for explaining the phenomena in a single-phase alternator and the action of the squirrel cage, which it has been found necessary to use in such machines.

The single-phase armature reaction is looked upon as being resolved into two polyphase currents having opposite phase rotation. Thus, it can be seen how one of these components can be counter balanced by currents induced in the squirrel cage, while the resulting armature reaction is the same as the armature reaction of polyphase load with the same total kv-a. output, or one-half as much current in each phase. While this method of investigating these phenomena is purely artificial, it is often of value for finding solutions for new problems, because the theory of a uniformly rotating field armature reaction or polyphase current is comparatively simple and is well understood by electrical engineers in general.

An unbalanced load on a polyphase system is the combination of a true polyphase load with a single-phase load, and is considered very undesirable because it introduces disturbances in the functioning of almost all apparatus connected to a polyphase system, which are designed for balanced current and balanced voltage only. When it becomes necessary to deliver unbalanced, single-phase load from an ordinary polyphase system, a problem is presented which, for a satisfactory solution, requires the introduction of some new features. A complete understanding of the problem requires some new conception, outside of the well known laws for polyphase currents and apparatus, and this is a case where the artificial conception is of value: to consider the single-phase current as having two component parts of equal and balanced polyphase currents with opposite phase rotation. With this conception, it also becomes clear how an unbalanced load can be corrected. The single-phase component of the



Wiring Diagram of Phase Balancer Set

unbalanced load is resolved into its polyphase constituents, one of which has the same rotation as the system and thereby becomes a part of the polyphase load, the other having opposite phase rotation. If, therefore, some means are provided for supplying to a polyphase system a current or voltage with opposite phase rotation which neutralizes the corresponding component of the unbalanced load, it is evident that the result is a complete correction of the unbalancing.

Construction of the Balancer

It is well known that any induction motor or synchronous motor with squirrel cage has a tendency to maintain an approximate balance of voltage in a polyphase system to which it is connected. The machine generates a counter e.m.f. which is balanced, and any departure from a corresponding voltage on its terminals will cause a current to flow. If this departure is positive in one phase, and negative in the other, the result is that the machine absorbs the power of one phase and delivers it into the other. If the machine has no impedance an infinitely small departure would cause a sufficient current to flow to rebalance the load and the terminal voltage would remain balanced. From this consideration, it is obvious that it would be possible to introduce an e.m.f. in series with each phase which would overcome the impedance of the winding and thereby force a current to flow of the same phase and magnitude as the current that would flow if the impedance was zero as assumed above. The theory of the two polyphase components of the single-phase current gives a convenient method of analysis by which these correcting e.m.f.'s can be found. The currents that should flow in the phase converter are evidently the polyphase components of the single-phase load which have opposite phase rotation, and this consideration indicates immediately the solution of how these currents can be produced. The correcting current being a balanced polyphase current, it is evident that the voltage drop in the winding due to this current must be a balanced polyphase voltage and that this voltage drop can be neutralized by introducing a polyphase e.m.f. by a booster connected in series with the windings of the main machine. If the only object of the phase balancer is to correct the unbalancing in current and voltage which are due to single-phase load in some other part of the system, it would only be necessary to use a machine of the induction type with a squirrel cage and to direct-connect to it a polyphase booster with sufficient capacity to overcome the impedance drop in the windings of the main machine. If the single-phase load were of a definite and known power-factor, the booster might have a single field of the ordinary kind; however, if the power-factor of the load fluctuates at the same time as the current, means must be provided for changing the phase, as well as the strength of the e.m.f. introduced by the booster. This is done by providing the booster with a quarter-phase field winding and two separate sources of excitation.

If the regulation of the balancer is to be automatic, the two booster fields are controlled by two voltage regulators adjusted so as to maintain the equality of the two phases with the third. The voltage of the third phase is then controlled by the main power station regulator working on the generator fields.

Application of Balancers to Substations

The use of the balancer is not limited to power stations and it can be used to advantage in any place where with the present practice synchronous condensers are used, provided that the load in the distribution center supplied by those condensers is apt to be unbalanced. A phase balancer installed in this way performs all the functions of a synchronous condenser, and in addition to this corrects the inequalities between the phases so that the main transmission line and the power house may carry a balanced load at unity power-factor. The fact that the phase balancer has essentially the same construction as the synchronous condenser, with the addition of a small series booster, will probably make it worth considering in many cases where synchronous condenser substations are to be installed: whether it would not be economy to equip some of the machines in a substation as phase balancers so as to have provision for taking on single-phase or unbalanced polyphase load to such an extent as there may be a demand.

The same consideration applies to the substation as to the power house, i.e., that the capacity of the balancing machinery does not increase beyond a certain limit when more single-phase load is taken on, because the load becomes more balanced as it becomes more diversified, and it is probable that substations as well as power stations of considerable capacity will need only a small percentage of balancing machinery; whereas without such machinery it is not possible to take on single-phase load even in small quantities without interfering with polyphase operation.

LOYALTY IN BUSINESS LIFE

By Chas. L. Clarke

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From time to time we have published articles in the Review that have been useful in directing one's conduct toward another in everyday business life. The present article by Mr. Clarke is a helpful addition to those that have been previously published. Mr. Clarke, having been in the General Electric Company's organization since its early days, is in an excellent position to speak from a wide store of experience. The author shows that loyalty must include loyalty to the system of management, loyalty within the system, and loyalty irrespective of the system.—Editor.

The general subject of loyalty in business life should always be of interest because it concerns certain relations between men that vitally affect their material interests. It is specially worthy of earnest consideration by the younger men, whose business careers still lie in the future, and whose habits of mind and dispositions have not become so firmly set that they should have much difficulty in subjecting themselves to a fair self-examination in the light of reason, and, if necessary, gain thereby with sensible exercise of will such control over adverse inclinations, when present, as will naturally cause them to be loyal to their business associates on every occasion. The younger men might here note the words of the immortal Franklin, who made the appropriate remark, through the sayings of "Poor Richard," that " 'Tis easier to prevent bad habits than to break them."

It must be admitted that the subject of loyalty is a delicate one to deal with, when presented, as in this instance, to one's business brethren. But here, again, heed Poor Richard's injunction: "Love your enemies, for they tell you your faults;" although it may be admitted that human nature is so constituted that sometimes a friend is not so easily forgiven as are enemies for doing this kindness.

The attention given the subject here will be distinguished more by what is omitted than by an exhaustive presentation of its many sides. And it is left to the imagination and experience judiciously to read between the lines to supply the missing links, and make such personal application of the whole as self-examination and conscience may direct; for, in matters pertaining to loyalty each individual must shape his own course, as he is the maker of his own destiny. No one can supply the deficiency of another in this essential for a helpful attitude toward those joined in effort for a common good.

It is unnecessary to comb the dictionaries for scholarly definitions of the term "loyalty," or to find out what "business life" means. Normally constituted persons will doubtless substantially agree to the general proposition that *loyalty in business life is the faithful endeavor successfully and justly to perform an assigned task or duty of lawful nature, with which two or more persons are concerned, relating to some mutual material advantage measurable in dollars and cents.*

Further, for the purpose of keeping consideration of the subject within reasonable bounds, that we may not become lost in the mazes of a philosophical dissertation, and fail to make such practical application of its leading principles as may be advantageous to ourselves, let it here be restricted to loyalty in duties required to carry on the affairs of a corporation, which are apportioned to employees in accordance with a system of management organized for orderly and profitable conduct of business.

The loyalty, then, that should subsist in a corporation is:

First: Loyalty to the system of management, as organized, and not, necessarily, as one may think it should be, and would like to see it organized. The system is impersonal, and comprises a code of corporation business rules and regulations, sanctioned by law and effective thereunder. It is the guide-post which points the directions in which employees should go in the line of efficient duty; if not thus guided and obedient thereto they would soon become lost in confusion. The rules and regulations of a corporation are the underlying means by which duty is assigned and directed, and anything less than faithful effort to observe them is disloyalty to the whole business in hand and to every one whose welfare depends upon its success.

Second: Loyalty within the system to the persons in whom is vested the authority to manage the details pertaining to the assignment and direction of duties. Those in authority are absolutely dependent upon the loyalty of others under them for the business success of a corporation, and they could accomplish nothing without it no matter what their own ability might be. The higher the plane of authority on which they stand, the wider becomes the scope of the undertakings for which they are responsible; the greater are the trials they have to bear, and the severer is the tax on their patience, resourcefulness, common sense and endurance to keep even themselves in every way loyal to the trust imposed upon them under the system. Thus they need the loyal support of every one else to a special degree.

Third: Loyalty within the system between those whose authority or duties are practically co-extensive. Here there should be unreservedly faithful co-operation, absence of petty jealousy, undue self-seeking, overreaching, bickering and backbiting, which interfere with efficiency and can prove serious forms of disloyalty, and are liable, even if the seed be sown by only one person, to produce much harm and with certainty prove the truth of Poor Richard's adage, that "A quarrelsome man has no good neighbors."

Fourth: Loyalty, irrespective of the system, between all employees of whatever grade, based upon mutual respect, general good will, pride in connection with the organization and with associates, and a sincere desire to help to the best of their ability to promote success.

It is not easy for every one, and, at times, not even for those most experienced and disciplined, always to be loyal to every duty. Sometimes its performance, as the saying is, "goes against the grain," in which case such adjustment to conditions should be made that "chips do not fly."

At other times its performance may seem unnecessary, or the wrong way of getting at a desired result. And these are times when loyal patience is called for, patience to wait for time to tell one whether after all he may be mistaken, or to correct a method, if later found not the best one to pursue. While it is easy to be patient under accustomed circumstances, it becomes more difficult of exercise under trying conditions, when most required, in which connection it should be helpful to remember that Poor Richard said: "What signifies your patience if you can't find it when you want it."

Temperamental peculiarities seem to make it practically impossible in some unfortunate instances for loyalty willingly to exist, the misfortune being mainly harmful to those thus afflicted, for they are either certain to be kept outside the pale of organized business, or to be bound hand-and-foot by limited duties and restricted authority so that they lose opportunity for achievement and advancement that might be theirs. And Poor Richard again spoke, and said: "There was never a good knife made of bad steel."

Then there are some whose characteristics only occasionally cause them to clash with the business system or with their co-workers, and become disloyal by not taking up and endeavoring to perform an alloted duty in line with the directions of their superiors. The effect is disturbing, so much so as to have a correcting influence on men of intelligence toward lessening or preventing repetition of the mistake. If they prove to be men in positions of authority, Poor Richard here advises them: "He that cannot obey cannot command."

Sometimes the cause of opposition to authority and orderly compliance with a business system proceeds not so much from temperament as from specialization, to the neglect of the everyday concerns of life. While there has been development in a particular direction to an unusual degree, advancement in other ways, essential to constitute the normal practical man, is wanting. It is true, the specialist and his calling may be such boon companions that there is intense satisfaction in the partnership. Nevertheless, when it leads to a life so self-centered that the outside world—in which he would naturally prefer to include the corporation from which his subsistence comes is largely unknown or quite forgotten, the points of business contact and resulting pressure of duty, which must exist at times, are apt to be resented as an intrusion and infraction of an imagined right simply to be let alone and not be bothered. Or he may not only be specialized so highly, but so self-exalted, perhaps over some truly noteworthy achievement, as to arrogate to himself special rights superior to the system, and consider himself not accountable to his immediate superior, but somehow entitled to sit at the right of the throne and otherwise do about as he pleases. He is likely to have what he chooses to call his "self-respect" easily injured by his superiors acting under the compelling requirements of business, but closer examination would often discover that only his conceit has been pricked. A real or imagined injury to one's self-respect is no excuse for non-performance of duty. Even should the injury be real, the act of the offender, which would constitute disloyalty on his part, conveys no right to retaliate by being in turn, disloyal; there are obviously other and proper ways of mending the fault.

It behooves such a person, when he feels that he is being imposed upon by the system, to realize with Poor Richard that "It is the easiest thing in the world for a man to deceive himself," and try to discover whether this may be the fact in his case, and ascertain, if he be after the truth, that his first duty is loyalty to the system whatever it may be at least as long as he chooses to rely upon it for his bread and butter.

Jealousy, which in its different manifestations may be given various names but smells no sweeter therefor, is, perhaps, the most frequent cause for lapses in loyalty. It is generally of the petty, evanescent sort, and fortunately, rarely manifests itself in the region of large responsibilities. Every one knows the cure, namely, get over it; toward the accomplishment of which end the realization that all must loyally work together, if the payroll is regularly to be met, should help.

The speaker will not trench upon the ground preempted by those engaged in the profession of healing bodily ills, further than to say that he has often noted instances where the question, whether a man would prove loyal or not for that day or longer, was sure to depend upon the state of his digestion and thus his nerves. For such a condition of affairs there is no legitimate excuse. Ill health and nerves, short of derangement, will not interfere with loyalty, if the innate disposition is in that direction, or if experience has taught one wisely to control an antagonistic nature. And in any case, it is profitable to realize that, while incapacitating disability is no excuse for refusing, or grudgingly and inefficiently, to perform one's duty, nevertheless, it properly justifies obtaining reasonable release therefrom.

Finally, there is the cranky man, who gets at odds with the system and with his associates on the most unlooked for occasions and for inexplicable reasons. His misfortune is inability to control impulse by exercise of will power, and he should make a special study of ways and means to cure the defect. Often he is mostly of good steel; the knife passes inspection and is placed in stock although the defects are recognized, but it will not, to his detriment, be rated A-1.

Do not let those that are disposed to chafe under the impersonal, impartial working of a business system, peevishly fall into the error of imagining that it was designedly created for their personal discomfort, as some appear to do. If, now and then, its application by a superior seems in some respects not just as it should be and disposes one to be disloyal, take Poor Richard's hint that "There is a time to wink as well as to see." Before we are over winking the incident is past and forgotten. Moreover, do not overlook the fact that superiors in authority generally have to do by far the greater part of the total winking, to the comfort and benefit of uneasy ones under them.

Whether the writer has appropriated the privilege of presenting some business principles, we may say maxims, that might, more properly, have issued from those here in authority cannot be stated; possibly they have already expounded similar principles before our advent. Or, it may be, they have deemed it a better plan to let individuals work out their own salvation through experience acquired from hard knocks, in spite of the fact that, if analyzed to a conclusion, they will ordinarily be found to have a reactance quality, producing more or less of a hitch in the orderly flow of current affairs.

Some may have adopted this policy on the principle that a knock now and then may make the recipient, who invites it and is really worth keeping, wiser and hence more valuable. If such has been their policy, they may be quite right. Large manufacturing corporations today have generally adopted the policy of inaugurating special educational courses, at no inconsiderable expense, calculated to improve certain grades of service; and it may not prove a bad investment to foot the bills involved in maintaining a School of Hard Knocks, for inculcating and disseminating among naturally able employees, who may, unwittingly or in a temporary fit of perversity, have gone wrong, a correct understanding of the practical laws concerning the art of rendering their relations with business associates of maximum efficiency through loyalty.

By this time the reader may be wondering whether to plead guilty or not guilty. This is entirely unnecessary; no indictment has been found; the writer has filed no bill of complaint, or even expected to tread on anybody's toes, and undoubtedly has not done so. Although loyalty has been the subject under consideration, antithetically, disloyalty has necessarily been referred to. But there is no occasion for pessimism; human nature is more inclined to the virtues than to the wrong; and let it be known that loyalty in business is the rule and disloyalty is the rare exception, so rare in fact, and out of the normal, that for this very reason, it arrests immediate attention, and all the more so because of the always painful disturbance its occurrence produces in the customary, orderly progress of affairs and relations between men.

The stronger the effort made by all within the various departments of this great organization to constitute themselves a brotherhood of open-minded, open-hearted, mutually helpful men loyal to one another and especially so to their respective chiefs, the nearer will be the approach of the departments to ideal efficiency in performing the functions assigned to, and expected from them.

Poor Richard here speaks for the last time and pertinently suggests that "You may talk too much on the best of subjects," which, with the feeling that enough food for profitable thought has already been presented, will bring us to a close.

FLUORESCENT LIGHT

A Lecture Delivered By

W. S. Andrews
Consulting Engineering Department

This address is confined entirely to that branch of luminescence called radio-luminescence. After describing the production of fluorescent light by a substance, a number of the common elements are named whose compounds possess this light-giving property. It is then shown that such compounds, the light from each of which possesses an intrinsic predominating color, can be made to produce light of a useful color, in a few cases closely approaching daylight; the substance being placed in a tube with a gas furnishing a complementary color and subjected to the influence of an electric discharge. The remainder of the paper is given over to a description of a number of very interesting experiments concerning the properties of the light emitted by various fluorescent and phosphorescent substances. Mr. Andrews speaks with authority, since for the last 15 years he has been interested in the study of fluorescent and phosphorescent phenomena, and has for the last few years devoted a large part of his time to the development of the subject from the utilitarian standpoint.—Editor.

Prof. Wiedermann applied the general term "luminescence" to light produced independent of incandescent heat. It has been divided under several headings according to the origin and nature of the light. Thus, we may observe chemi-luminescence in the glow of phosphorus in the dark, and we may see an example of animal or biological luminescence in the light of the firefly and the glow-worm. Professor Bancroft, however, states his belief that all luminescent phenomena are caused by chemical reactions, although as a matter of fact it may be difficult to prove this in every case.

The particular branch of the general heading under present consideration is "radio-luminescence," which applies to light that is emitted by certain substances under the stimulation of other light, or, in some cases, of electric radiations, such as cathode rays, etc. Under this heading we find the transient effect known as "fluorescence," which, if it persists after the exciting cause is cut off, is termed "phosphorescence." These two effects are so closely allied that it is almost impossible to draw any clear dividing line between them, because, not only are they both of similar origin, but whereas the after-glow in some substances may persist for many hours, in others it may die out in a very small fraction of a second, so that it can only be detected by means of a phosphoroscope, and then in many cases even these refined observations fail to show any visible after-glow.

A substance may be termed fluorescent when, under proper stimulation it emits light of some predominating color, irrespective of the frequencies of the incident waves by which it is excited, although, in general, these incident waves are of higher frequency than those of the predominating fluorescent color. Moreover, the exciting light need not lie within the visible spectrum, for the brightest fluorescent effects are produced by the invisible waves of ultra-violet light.

The term "predominating color" is used, because fluorescent light, when examined through a spectroscope, can be generally split up into a more or less continuous spectrum, a portion of which being more intense than the rest of it, imparts a predominating color when observed by the unaided eye.

The molecular condition of a fluorescent substance appears to influence its properties quite as much as its chemical constitution. Thus, some substances are fluorescent in a solid state and lose this property when dissolved, e.g., bario-plat. cyanide; others in a solid state show no fluorescence, but become so in solution, e.g., many aniline dyes. Some acquire phosphorescence by the addition of gelatine; some require an exceedingly minute but definite amount of another element to develop their luminescence, such as calcium, sulphide, etc., while others again show their brightest fluorescent effects when chemically pure, e.g., calcium tungstate.

Five of the metallic elements are remarkable for the fluorescent and phosphorescent properties shown by some of their compounds, and it is a curious fact that these five elements are found in consecutive order in the second group of Mendellèef's table of the "Periodic Law," as follows:

Calcium,	atomic mass	40.1
Zinc,	atomic mass	65.4
Strontium,	atomic mass	87.5
Cadmium,	atomic mass	112.4
Barium,	atomic mass	137.4

The variety of different fluorescent colors shown by some of the compounds of calcium and zinc, may be seen in the following short list, to which many additions might be made:

Calcium sulphide	+Mn	yellow
Calcium sulphide	+Cv	blue
Calcium carbonate	+Mn	red
Calcium tungstate c-p.		blue
Zinc oxide	+Mn	red
Zinc sulphide	+Mn	green and yellow
Zinc silicate	+Mn	green
Zinc tungstate c-p.		Light blue.

When electricity is passed through a vacuum tube containing a gas at a pressure of about 0.5 to 5 mm. of mercury, varying with the nature of the gas, light is produced in the tube, but a part of the energy is expended in invisible radiation, so that the efficiency of the tube as a light producer is reduced in proportion to the amount of energy thus wasted. By introducing a suitable fluorescent material into the tube, some of this invisible radiation will be absorbed and transformed into visible light, thus increasing its luminous efficiency. The noble gases, neon and helium, produce a luminescence in which the red and yellow rays predominate. By selecting fluorescent substances predominating in the green and blue rays, a combination may be effected to produce a close approximation to white light, in addition to improving the efficiency.

When the gas pressure in a tube is reduced to a few microns, the passage of electricity ceases to show visible light to any appreciable extent, but cathode rays are produced in abundance, and these rays are powerful excitants of fluorescence in many substances. As before stated, however, these fluorescent preparations usually show some predominating color, thus making them unsuitable for useful lighting when separately employed. Corrective combinations may be made, however, and certain substances have been found to fluoresce so nearly to a white light that by a small correction a luminescence closely approaching daylight may be obtained. The spectra of such combinations also resemble that of daylight in being continuous.

I shall now have the pleasure of showing you a few experiments illustrating some of my preceding remarks.

To begin with, here is a tube which is divided into three chambers by glass partitions. One end chamber is exhausted to a low vacuum, say, about 3 mm., the center chamber to a higher vacuum of about 0.1 mm., and the other end chamber is exhausted to about 0.001 mm. On passing a high potential current through this tube, we note that the low vacuum chamber glows with a red light, the middle chamber shows a bluish light, while the other end chamber glows with a fine apple green color. In this last chamber, the passage of current does not color the gaseous column, as in the other two—the green color being entirely due to the fluorescence of the glass under bombardment by cathode rays. There is thus illustrated in one tube the three principal visual effects of passing current through a glass chamber under different conditions of vacuum, but it must, of course, be understood that these changes take place gradually with change in vacuum and that they merge into each other by imperceptible degrees.

Here we have another tube exhausted to a high vacuum and containing a screen painted over with calcium tungstate. This shows a bright blue fluorescence under the bombardment of cathode rays. Here again are tubes containing respectively, screens painted over with zinc oxide, sulphide, silicate and tungstate, which, as you will see, respond to excitation of cathode rays, according to the colors before mentioned, namely, red, yellow, green and a very light blue. Finally, here is a tube containing cadmium tungstate, which shows an almost snow white fluorescence.

While on the subject of vacuum tubes, I will show you some containing the noble gases at low pressure. Here is a tube charged with argon at a pressure of about 5 mm. You will note that its luminescence is very weak, which is one of the peculiar features of this gas. Here is a tube containing helium at about the same pressure. Notice its bright rosy luminescence. I now show you another helium tube containing a screen painted with zinc sulphide, the green fluorescence of which is intended to complement the pink color of the helium gas and produce a more or less white light. The most efficient of all the noble gases as light producers is neon, but unfortunately it is at present very difficult to procure, so I have here only two tubes containing it. In the tube now before you note the bright reddish orange color of the electric discharge, especially at the two ends of the tube.

I will now connect my last tube, which is made of uranium glass and filled with neon at 4 or 5 mm. pressure. The bright green fluorescence of the glass and the red luminescence of the neon make a pleasing combination.

Turning to the high tension disruptive discharge between iron terminals as a source of ultra violet light for exciting fluorescence, I now show you some cards on which are the words CALCITE, BARIUM SULPHIDE, WILLEMITE, and CALCIUM SALICYLATE printed in block letters that are dusted over with these different compounds in powder. By ordinary visible light you may see that these letters show no color, but when exposed to the ultra violet rays from the iron arc they fluoresce in bright hues of pink, orange-yellow, green and blue respectively. To prove that it is the invisible light of the iron arc that produces the colors, I interpose a piece of thin window glass between the iron arc and the card, when the color at once vanishes and you see the letters as they appear by ordinary visible light. Glass, mica, celluloid and many other substances which are transparent to visible light are substantially opaque to the higher frequency invisible waves in the ultra violet spectrum—while other substances, such as quartz and fluorite are equally transparent to the visible and invisible rays.

A variety of pleasing and spectacular effects can be produced by painting radial lines, curves and circles on disks of cardboard or thin metal and rotating them before the iron arc.

You are all aware, of course, that this disruptive discharge, although to the eye appearing continuous, is really a very rapid succession of sparks oscillating between the two iron terminals, the persistence of vision creating the continuous effect in the eye. It is therefore easy to conceive that if the oscillations of the spark were exactly uniform and coincident with the rotation of the disk, the latter would appear stationary by the light of the spark and that various stroboscopic effects must follow variations from synchronism.

Here is a disk of thin aluminum painted black excepting for two circular rings, which are painted over with calcium salicylate, the disk being attached to the shaft of a small electric motor. I now turn on the iron arc, the disk being at rest, and you see the two rings show up a bright blue on the otherwise black surface of the disk. Now, on starting the motor you see a multiplicity of these blue rings all interlocking with each other and forming a variety of kaleidoscopic patterns governed by the constantly changing ratio between the frequency of the spark and the speed of rotation of the motor.

Time will only permit me to show you one modification of the above, although you can readily see innumerable possibilities for producing changing effects.

Here is a disk which is entirely covered with different fluorescent materials, such as you have already seen, and which is fixed to the shaft of the motor. In front of this fixed disk, I place another disk painted black and having two curved slots in it and which runs loosely on the motor shaft. When the motor is started, the fluorescent disk rotates with it, but the loose disk, being only held by light friction, lags behind in an irregular manner and as we see the fluorescence only through the curved slots in the loose disk, its appearance is constantly changing so that it looks like a wheel of many colors in various and ever-changing patterns.

The phenomena of fluorescence and phosphorescence have been diligently studied by scientists for many years, but principally from an academic rather than from a ulilitarian viewpoint. The speaker believes, however, that as these chemical compounds become better understood, their luminous efficiency will be greatly improved or new ones discovered, so that they will eventually play an important part in the artificial production of light for practical commercial purposes.

APPLICATION OF POWER APPARATUS TO RAILWAY SIGNALING

By H. M. Jacobs

Signal Accessories Department, General Electric Company

There are in general use today three systems of railway signaling, viz., mechanical, electro-pneumatic, and all-electric. Except for a brief explanation of the principles of the mechanical and electro-pneumatic systems, this article is concerned only with the all-electric. On steam roads, direct current for signaling is mostly employed, both rails being insulated from block to block and made to serve as conductors. On direct current roads only one rail is sectionalized in some cases; and where the voltage drop due to the propulsion current is troublesome, special polarized relays are used. On still other d-c. roads, alternating current is used for signal purposes, operating relays that are unaffected by direct current. The most recent practice is to use both rails for propulsion current and a-c. signal current; the rails being sectionalized at block ends and connected by impedance bonds which offer negligible resistance to the propulsion current and sufficient impedance to the signal current. Signals for alternating current railway systems will be described in a subsequent article.
—Editor.

It is not intended in this series of articles to go into details with the various signal systems but simply to trace the development of signaling in a general way showing how the systems have necessarily become more and more complex to afford greater protection and flexibility and to show how power apparatus is becoming more and more essential.

Railway signals are roughly divided into two general classes, viz: block signals and interlocking signals. Block signals are used only on stretches of track where there are no switches or crossovers and serve to limit the spacing between trains to such limits as will afford proper braking distance for the heaviest trains running at maximum speed.

Interlocking signals are used where there are switches, crossovers and junctions, and in addition to showing whether or not the oncoming train may proceed, they also indicate the route and the speed at which it may proceed The signals, like the switches, are controlled by the tower operator. They are also "block" signals in that they are so related to the block signals outside of the interlocked territory that the movements of the latter are dependent on them. The whole track is therefore sectionalized into blocks, the interlocking territory being one block where there are switches, crossovers or junctions, or combination of same, while the other signals are for blocks on the straight track.

In modern signal practice signals are located at the entrance to each block to indicate the condition in that block and usually in the block ahead. These signals are usually either "three-position upper quadrant" or "two-position lower quadrant semaphores." On three-position upper quadrant signals the arm in the horizontal position indicates "danger," or that the adjacent block is occupied; 45 degrees above the horizontal indicates "caution," or that the adjacent block is clear, but that the following block is occupied; and the vertical position indicates "clear," or that both blocks are unoccupied. Therefore the "caution" signal indicates to the engineman that he may proceed through the adjacent block under control, prepared to stop at the next signal. On two-position lower quadrant signals the arm in the horizontal position indicates "danger," and 60 degrees below indicates "clear."

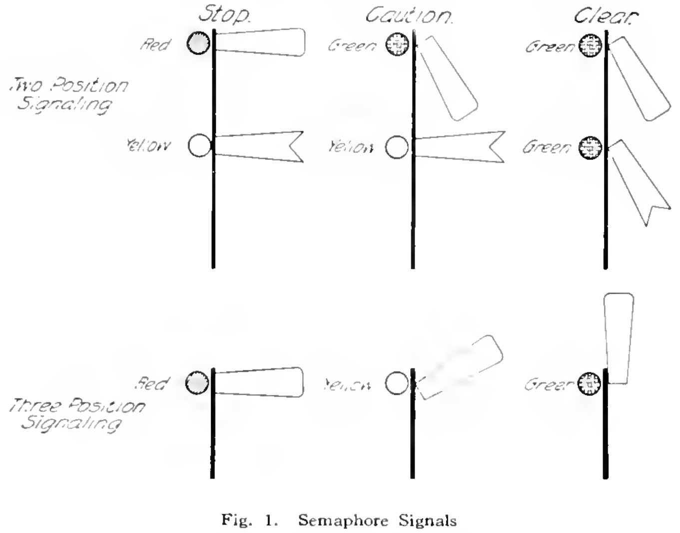

Fig. 1. Semaphore Signals

In two-position signaling, two arms or blades are required, the upper arm or "home" blade indicating the condition of the adjacent block and the lower arm or "distant" blade the condition of the following block. These blades are therefore termed respectively the "home" and "distant" signals.

Fastened to the semaphore arm is a spectacle carrying roundels or colored glasses obscuring a lamp so that different colored lights are displayed at night, corresponding to the various positions of the arm. In two-position signaling the "home" blade displays red for "danger" and green for "clear," and the "distant" blade displays yellow for "caution" and green for "clear." In three-position signaling the one light shows red, yellow or green to indicate respectively the danger, caution or clear positions. These colors are standard with the majority of roads. Fig. 1 illustrates the various indications.

Fig. 2. Mechanical Interlocking Signal Plant

One of the first questions which may arise in the reader's mind regarding two-arm two-position signaling is whether the distant blade may indicate "clear" while the home blade on the same signal indicates "danger," but the circuits are so arranged that such an indication is not possible. On second thought the reason for this is obvious.

The primary object of railway block signaling is to facilitate traffic by informing the engineman as to the condition of the track ahead. Railway signaling is of English origin and it is interesting to note that the first idea of operating a number of signals and switches from one location was for the purpose of saving labor of switchmen. The first machines, therefore, simply concentrated in a single frame the theretofore widely separated switch and signal levers, thus saving switchmen labor and making possible the passage of a train through the territory without coming to a stop.

Signaling was practically unknown in this country until the early seventies. Some roads devised and built signals of their own to meet certain special needs; but real interlocking was not introduced until 1874, when the Pennsylvania Railroad installed an English Saxby & Farmer plant at East Newark, N. J., the machine being imported from England and installed by English mechanics. This same year an experimental installation was made at Spuyten Duyvil Junction, New York City. Three years later several machines were installed by the Manhattan elevated lines of New York City.

Manually operated interlocking plants can operate through a restricted territory only, since the signals are operated by wires or pipes and the switches by pipes. Therefore, for precisely the same reason that signals first came into use in England, viz., the saving of labor, it was desirable to further extend the territory controlled from the tower, and the railroads turned their eyes toward power operation to replace the manual operation to switches and signals. Among the first installations of this character was a rather crude machine installed in Philadelphia in 1876, followed later by a hydraulic plant at Wellington, Ohio, in 1882, and two years later by the first hydro-pneumatic plant at Bound Brook, N. J., on the Central Railroad of New Jersey. From 1884 to 1891 eighteen of these hydro-pneumatic plants were installed on six different roads; but, as the system developed many serious defects, these inventors devised an electro-pneumatic plant, which was installed in Chicago in 1891. In the hydro-pneumatic machines all of the switches and signals were operated by valves in the interlocking machine, which admitted air to and released it from a normal and reverse pipe filled with water in summer and a non-freezing solution in winter, the water operating an auxiliary valve near the mechanisms. In the electro-pneumatic type of machine the air pipe runs directly to the switch and the air is admitted to the normal and reverse valves on the switch by electromagnets controlled from the interlocking machine. This system is in use at all great terminals throughout the country with but very few exceptions, and is also used to a large degree at isolated points. It is particularly attractive for congested terminals with heavy and frequent traffic where the simplicity and speed of operation obtained in this system are a necessity.

additional labor of manual operation with the shorter blocks, provide a means of operating the signals by the trains themselves. Various schemes were tried, but the most satisfactory one produced and that which forms the basis of all the automatic signaling today employs the d-c. track circuit.

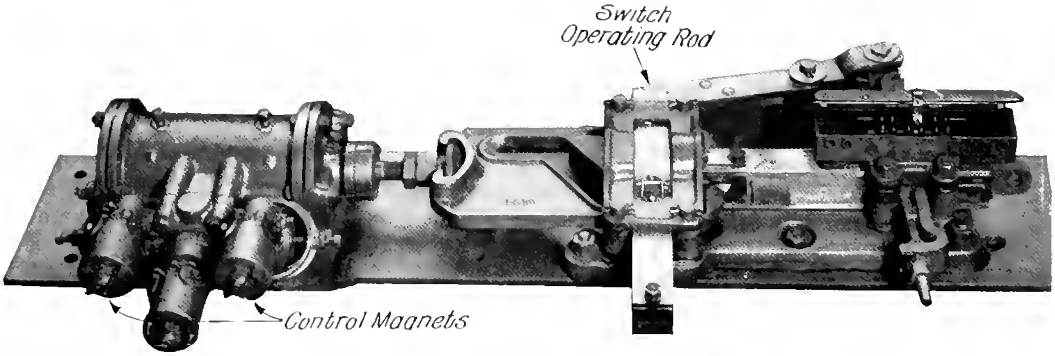

Fig. 3. Electro-Pneumatic Plate Switch and Movement

Following this came machines worked wholly by electricity, and this development kept pace with the development of the electric motor; but they did not come into very general use until 1900. Today there are but three systems in general use, viz., the mechanical, the electro-pneumatic, and the all-electric.

A train order signal is ordinarily used to stop trains for the delivery of written orders, which would normally proceed on their time schedule. The idea of block signaling arose by making use of this signal to hold a train at one station until telegraphic advice was received from the next station to the effect that the preceding train had passed. Special telegraphic instruments were then devised to indicate "line clear" or "line blocked." This necessarily delayed traffic on roads where the stations were far apart and certain slow speed trains were permitted to proceed with caution after fast trains, thus giving rise to "permissive signaling." To save the delays in traffic it became desirable to shorten the blocks as much as possible, and, to minimize

An insulated rail joint was installed on both rails at each block section, a battery being connected across the rails at one end and a relay for closing the power circuit to the signal at the other.

By referring to Fig. 5 it will be seen that

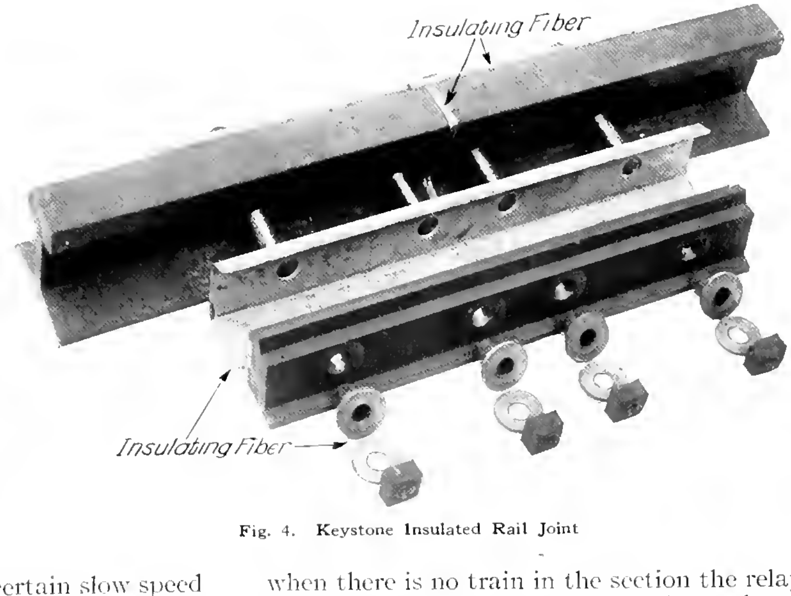

Fig. 4. Keystone Insulated Rail Joint

when there is no train in the section the relay will be energized and the circuit made to hold the signal clear; but when the section is occupied the rails are short circuited by the train, the relay is deenergized, and the signal circuit opened, allowing the signal to come to danger by gravity. All signal circuits work on the closed circuit principle so that a broken rail or a defect in the signal control circuits will bring the signal to danger position.

Signaling electric roads presented a different problem from that of steam roads, for the return propulsion current passes through the rails and the rails therefore cannot be sectionalized. On elevated roads where the supporting structure can furnish a return many times the conductivity of the rails, it was possible to give up one rail exclusively for signal work. This was sectionalized in the customary manner and insulated from the supporting structure, giving a circuit arrangement as shown in Fig. 6.

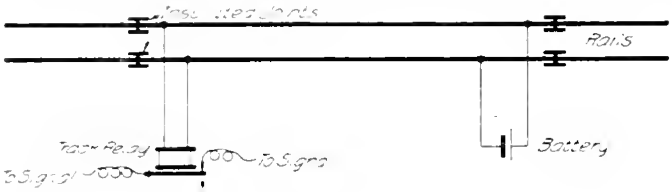

Fig. 5
Diagram Showing Connections Between Battery, Track, and Track Relay

This arrangement was undesirable in some cases because of the excessive voltage drop produced by the propulsion current, which affected the action of the signal relay. This effect was offset to a certain degree by using polarized relays which would not respond to the propulsion drop, and the first installation involving this safety feature was made on the Boston Elevated. The propulsion drop was very small, owing to the fact that the supporting structure carried the major portion of the propulsion current and that the block sections were necessarily short on account of the frequent train service and short spacing between trains. The signals themselves were electro-pneumatic.

Sometimes the direction of flow of the propulsion current would reverse in some sections owing to shifting of the load between the three power houses along the right of way, rush traffic, poor bonding of the rails, or imperfect contact between car wheels and rails, and it was necessary to install a polarized relay at both ends of a block section connecting the signal control circuits through the contacts of both relays in series.

To overcome the disturbing effect of the propulsion current, the introduction of alternating current to operate the signal circuit, using selective relays which would not respond to direct current, offered a satisfactory solution. This system was first installed on the North Shore railroad in California with great success under most trying weather conditions. A single-phase 2300 volt, 60 cycle pole line was strung along the right of way and a transformer installed at the exit end of each block section, stepping down to a low voltage for the operation of a selective relay located at the entrance end at the signal, which was operated from a storage battery. The road was originally a narrow gauge steam road, but standard gauge electric service was added, using one rail common to both gauges. This common rail was used as the block or signal rail and the return propulsion current flowed through the two remaining rails.

Shortly after this the New York subways installed the single rail a-c. track circuit system of signaling, similar to that on the North Shore, one rail being used for the propulsion current and the other sectionalized for signal current. Transformers delivered current at 10 volts to the leaving end of each track circuit and vane type a-c. relays were installed at the entrance end, while series resistances were connected between each relay and the rails to prevent excessive heating due to excessive flow of propulsion current as a result of the direct current drop in the return rail. As a further protection for the relay, an impedance coil was connected to shunt out direct current from the relay. The arrangement is shown in Fig. 7, the transformer and top resistance being connected to the rear block; while the relay, other resistance, and the reactance were connected to the block ahead for which the signal indicates.

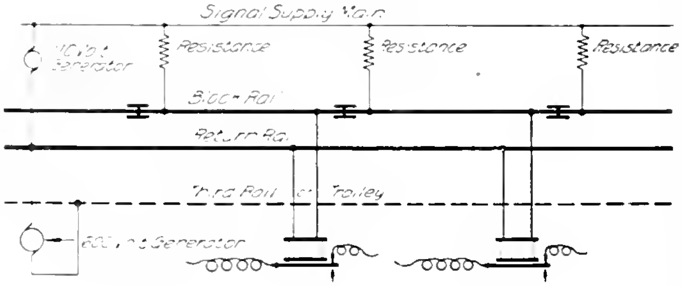

Fig. 6. Connections for Block System

To give some idea of the rigorous requirements fulfilled, it should be noted that during rush hours 150 trains per hour pass

96th Street. The system comprises approximately 500 track circuits, 700 signals, and 40 interlockings. The average length of block is 820 feet, which is one and one-half times the full speed braking distance of trains, the short length blocks being necessary on account of the very heavy traffic conditions, undoubtedly the heaviest of any road in America.

The necessity of giving up one rail of each track exclusively to signaling purposes was finally removed by providing the track circuits with impedance bonds, thus making possible the use of both rail for propulsion current and signal current. Both rails were sectionalized by insulating joints at the block

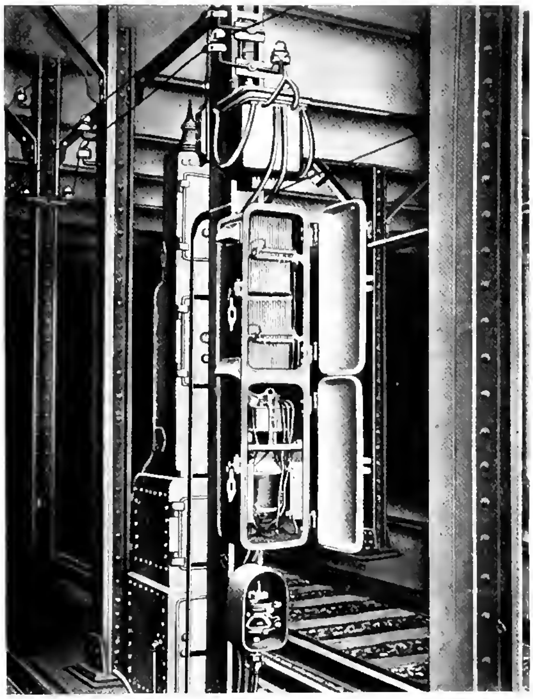

Fig. 7. Typical Instrument Case, New York City Subway

ends and the impedance bonds connected across the joints as illu rated in Fig. 8. These bonds were so wound with heavy copper wire as to provide a negligible resistance to the flow of the direct propulsion

Fig. 8. Impedance Bonds

current and at the same time offer an impedance to the passage of the alternating signal current.

This scheme was first applied as an initial installation on the East Boston tunnel section of the Boston Elevated under Boston harbor, where 14 track circuits were installed. This gave such satisfactory results that the scheme was applied on a large scale on the electrified lines of the Long Island Railroad. Following this in rapid succession, each being on a larger scale than the former, came the West Jersey and Seashore Railroad between Camden and Newfield, N. J., the Hudson and Manhattan; New York Central Electric Zone and Grand Central Terminal; Pennsylvania Terminal, New York; and the electrified lines of the Southern Pacific in the San Francisco district.

When the New York, New Haven, and Hartford Railroad electrified portions of the system for 11,000 volt 25 cycle a-c. propulsion, it became necessary to design an impedance bond and selective relay that would differentiate between the 25 cycle propulsion and the 60 cycle signal circuits. Up to that time, the propulsion current had been direct. A similar installation on the New York, Westchester, and Boston, a heavy suburban road taking power from the New Haven system, was made in 1911 and will be more fully discussed in a subsequent article, as will also a-c. signaling in general.

THE COMMUTATOR AS FREQUENCY CHANGER

By Dr. H. Meyer-Delius

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This is the first of a series of articles by Dr. Meyer-Delius for the Review on polyphase commutator motors, and for the sake of a better understanding of the phenomena peculiar to such motors this paper is devoted to a discussion of the commutator as a frequency changer. Two quarter-phase machines, identical in all respects save that one is provided with a commutator and the other with slip rings, are taken for illustration. It is first assumed that the rotors are blocked and the stators excited from a polyphase line of constant potential and frequency, the voltage and frequency across the brushes on the commutator and across the slip rings being remarked. The rotors are then allowed to revolve at half synchronous speed and the voltage and frequency again investigated. Direct current is then impressed on the revolving rotors and the resulting action discussed; a slightly different commutator machine being assumed in this case. Other conditions of excitation are considered and the involved phenomena pointed out in each case.—Editor.

The commutator is the well known attribute of the d-c. machine. Conditions at the a-c. commutator, especially the polyphase commutator, appear to be more complicated than those at the d-c. commutator. The reason is that in the d-c. machine, with its constant current and steady field in only one axis, not all the properties of the commutator show up as prominently as they do in a-c. polyphase commutator machines. We will therefore consider the actions of the commutator as a frequency changer, as it will be of assistance when dealing with polyphase commutator machines.

Assume two machines as shown in Fig. 1 and Fig. 2, both having a quarter-phase winding in the stator, as have normal induction motors. Let both machines have a rotor with a regular d-c. winding, closed on itself; the only difference being that in one machine the rotor winding is connected to a commutator as in a d-c. machine, and in the other four equally spaced points of the rotor winding are connected to four collector rings as in a quarter-phase induction motor. On the commutator four equally spaced brushes are bearing to take off the current. Both rotor circuits may be open at first.

If we connect the two stator windings to a polyphase line of constant potential and frequency, a field will be excited in both machines which revolves with a constant speed. At standstill there will be no difference between the two machines, an equal potential of the impressed frequency appearing between the brushes of the commutator and between the slip rings. Now let us turn both rotors with a certain speed, say half the speed of the field. The potential between the slip rings is now half of the standstill potential, and the frequency is half of the impressed line frequency, because the speed of the rotor relative to the speed of the field is cut in half.

Let us now consider the commutator machine under the same conditions. The potential between two diametrically opposite commutator bars is apparently exactly the same as the slip ring potential of one phase in the other machine; that is, the amplitude and frequency are just half of the standstill values. Suppose there are 16 commutator bars. Between each couple of diametrically opposite bars exists the same potential of the same frequency, the difference between them being only the time phase. Since we have eight couples for half of the circumference, we get eight sine waves as indicated in Fig. 3.

The rotor revolves with half the speed of the field. The frequency of the rotor e.m.f. is half the line frequency; therefore, the rotor makes one revolution during the cycle of the rotor e.m.f. The brushes, which are supposed to be very thin, remain in touch with one segment one sixteenth of one revolution and then slide over to the adjacent bar with which they are connected for the second sixteenth, and so on. We obtain as brush potential the broken line in Fig. 3. The dotted line gives the ground sine wave of this curve. It shows the exact double frequency of the rotor frequency; thus we obtain the line frequency. Normally the commutator has many more bars than we have assumed, and the brushes are wider, covering one or more segments. The brush tension is accordingly much more uniform, and the higher harmonics may be neglected without practical fault.

We note that the amplitude is not changed by the commutator, only the frequency is changed to the line frequency. It is easy to see that this is the case for all speeds. The reason for the difference between the rotor frequency and the stator frequency is the turning of the rotor. Since the brushes slide over the commutator at the same relative speed as that at which the rotor revolves, this difference in frequency is just made good for the brush potential. The result is that the brush tension frequency of any commutator motor is always the same as the stator or line frequency.

This is the well known main property of the commutator and is beyond any consideration in d-c. machines; that is, the brush tension is always a d-c. tension corresponding to the d-c. excited stator, although the actual rotor frequency may be any high frequency.

We have seen that the commutator acts as a pure frequency changer, with respect to the brush potential, and we will now consider how it acts when current is flowing through the brushes into the armature. At first thought it would seem as though the commutator should work in exactly the same manner with respect to the current as it does with respect to the voltage; that is, change the current passing through the brushes into the rotor winding from a current of the line or stator frequency to a current of the rotor frequency. This is, however, not strictly true.

Let us take the machine of Fig. 4, which is a quarter-phase machine. The rotor and

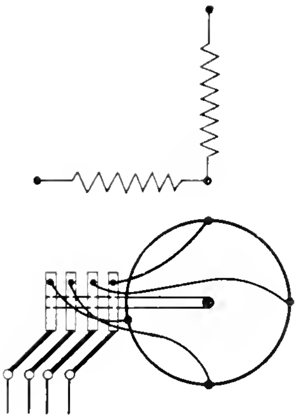


Fig. 1

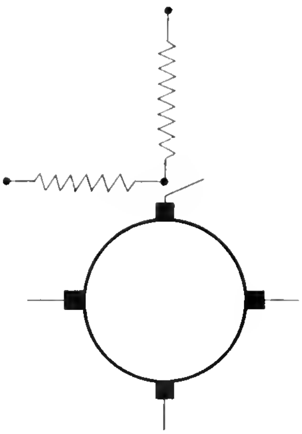


Fig. 2

commutator are those of the motor of Fig. 2. Each phase has on the stator a compensating winding, such as is sometimes used on d-c. machines when extremely heavy commutating conditions prevail. The compensating winding is an exact duplicate of the armature winding and entirely neutralizes the armature field along the circumference. There may be provided interpoles excited by the same current to secure sparkless commutation.

We will send a direct current through phase I and leave phase II open, in this way imitating one momentary condition of the quarter-

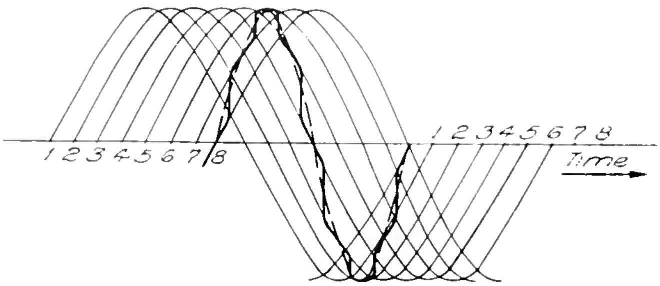


Fig. 3

phase current where phase I has its maximum value and phase II is just zero.

After passing through the compensating winding the current enters the positive brush I, then divides into two branches, each carrying half of the brush current. These unite under the negative brush I to flow back to the line. If we follow one armature coil on its way around for one turn of the rotor and mark the current it carries at each moment, we obtain the diagram of Fig. 5. On leaving the positive brush the coil carries a constant current until it reaches the negative brush. While passing under the latter brush, the current rapidly changes direction, building up to the same value as before; this condition of affair holding until the coil reaches the positive brush again, where the current is reversed to the first value. The current changes its strength only in the short intervals during which the coil passes under a brush, and is constant in the main periods between. This constant current is part of the outside current, which is a direct current in this case. It would be against the law of continuance, if in a part of this circuit (the armature) the outside direct current should disappear and an alternating current of the rotor frequency flow instead.

Though the outside direct current is flowing in the revolving armature, the armature field is not revolving, but is steady in space, which of course is necessary if a useful constant torque is to be exerted between the direct current excited, steady stator field and the armature. This is effected entirely by the commutation zones, or during the short intervals in which the armature coil is passing under the brushes.

Of course, the armature coils in which the constant outside current is flowing carry

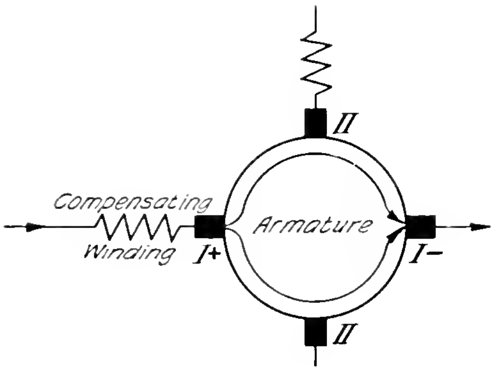


Fig. 4

their own flux around with them as they revolve. But in one commutation zone the arriving coils are continually deprived of their current, and in the other commutation zone the leaving coils are loaded with the same amount of current as is taken away at the previous zone. The result is that the sum of the ampere-turns of all the armature coils is steady in space.

A slip ring machine would effect the same results in an entirely different way. Take for instance an alternator of the old type, where the d-c. excited poles are outside on the stator and the alternating current is produced in a wound armature with slip rings: The armature current is a plain uniform polyphase current of sine shape. The frequency is exactly the frequency corresponding to the speed of the alternator, so that the armature field remains steady in space, just as in our commutator machine.

Let us now consider what is the result of this difference in the shape of the armature current of the commutator machine and the slip ring machine. Take again the quarter-phase commutator motor of Fig. 1. Phase I again carrying direct current and phase II being open. The compensating winding neutralizes the armature field entirely; there remain only the leakage fluxes across the slots over the teeth and around the end connections. As soon as the current in one coil changes its strength, a reactance voltage will be produced by these leakage fluxes. For this voltage we get the diagram of Fig. 6.

While the coil is under brush I+ a high reactance voltage is set up by the above leakage fluxes, since the current changes rapidly. As soon as the coil leaves the brush, the reactance voltage becomes zero. It keeps zero until it reaches the negative brush I and so on. This voltage is the well known reactance voltage in the short circuited coils, which is the cause of sparking at the brushes unless it is properly balanced by auxiliary means, as for instance an interpole field. With an interpole field the reactance voltage between the tips of the brushes can be reduced practically to zero. The peaks in the commutation zones disappear and the reactance voltage is zero all around the armature.

Compare with this state of affairs the conditions in the above old type alternator. Suppose the same leakage fluxes should appear there as in the commutator machine. Since the current in the armature changes uniformly with the rotor frequency, a uniform reactance voltage of sine shape will be produced which is proportional to the leakage fluxes and the full rotor frequency. The current and leakage reactance voltage of one armature coil of the commutator machine and slip ring alternator are shown for comparison in Fig. 7. The dotted curves belong to the commutator machine, the full drawn curves to the slip ring machine. By assuming both machines alike and producing the same total armature ampere-turns, it is apparent that the sine wave of the alternator current is the ground sine wave of the armature current of the commutator machine. It can also be shown that assuming the same leakage fluxes, the sine wave of the alternator leakage voltage is the ground sine wave of the leakage voltage curve of the commutator machine, because the frequency of commutation is just as much higher as the time is shorter during which it is produced. The shaded areas in the above diagram are therefore equal. The difference between the two machines is not numerical, but lies in the shape of the curves. In the commutator machine all the reactance due to the frequency of rotation is concentrated in the commutation zones, while all the other armature coils carry the outside current of the line or stator frequency.

For the sake of simplicity we have so far taken the stator current as direct current, but having seen the principle of the commutator, it is easy to consider what happens if the direct current is replaced by an alternating current.

Let us take again the machine of Fig. 4, in which we sent a direct current through phase I, phase II being open. We will vary the strength of the direct current slowly. The armature ampere-turns, before steady, will vary proportionally to the variation of the outside current, and if we apply an alternating current of certain frequency, the armature AT will pulsate with the same frequency. The speed of the rotor has nothing to do with this pulsation. Before the armature carried direct current, now it carries the alternating current of the line frequency. Before, the constant armature current did not produce any reactance voltage with the leakage fluxes across the slot, over the teeth and around the end connections. Now the alternating current develops with the above leakage fluxes a reactance voltage, which appears between the two brushes of the phase. This leakage reactance voltage is independent of the speed of the rotor, and is only proportional to the impressed frequency and the intensity of the armature current. The same holds for phase II. The armature AT of this phase pulsate also with the line frequency, independent of the rotor speed. Therefore, if we apply a normal quarter-phase current of certain frequency to the two phases of the machine, the two pulsating armature m.m.f.'s at right angles in space produce a resultant m.m.f. which revolves with the line frequency independent of the rotor speed. Just as found for single-phase current the armature leakage reactance for polyphase current is also independent of the rotor speed. The armature, even when turning at its synchronous speed, has the full leakage reactance as at standstill.

So far we have assumed that the reactance voltage set up in the coils short circuited by the brushes during the commutation was balanced by a rotational voltage in an auxiliary interpole field. Thus the resultant voltage between the tips of each brush was zero. But such an auxiliary field of just the right strength and phase is not always available. With some motors it would be too complicated a matter and too expensive to apply properly excited interpoles; with others the brushes are shifted to obtain speed variation, the commutation zones moving

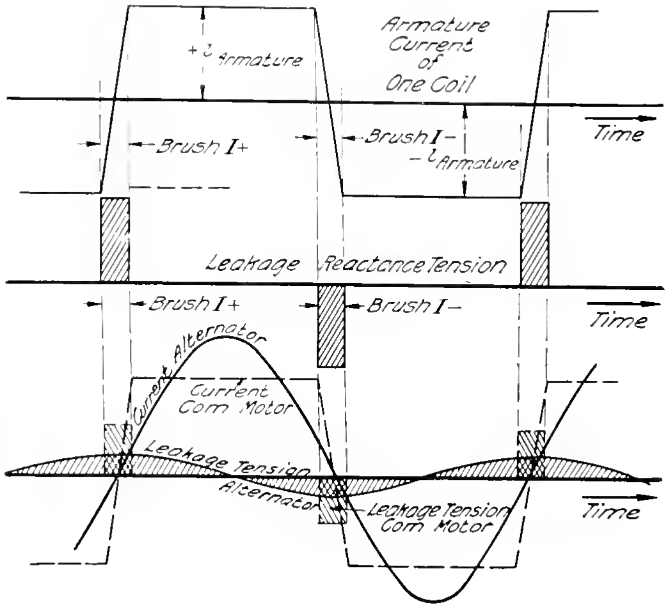


Fig. 5

Fig. 6

Fig. 7

along with the brushes, and interpoles are impossible. With the latter motors, other voltages which help the commutation and balance the reactance voltage more or less, are induced in the short circuited coils by the main field. The balance is not exact, sometimes the commutating voltage being too small, sometimes too large; the unbalanced voltage causing an additional current in the short circuited coils. In such motors hard carbon brushes are mostly used, and with these the larger part of the resistance of the commutation circuit lies in the contact surface of brushes and commutator. Therefore the larger part of this unbalanced voltage appears between the tips of each brush. One look at Fig. 4 shows that between the brushes of phase I lie the brushes of phase II. Therefore an unbalanced voltage of this sort between the tips of the brushes II add or subtract from the leakage reactance voltage of phase I. The unbalanced voltage is, of course, more or less proportional to the speed of the rotor, and for this reason the total reactance voltage of phase I is not quite independent of the speed, as we have found before for perfect commutation. Since the unbalanced voltage actually appearing between the tips of brushes II is largely dependent on the contact resistance of carbon to copper—a varying feature even for one motor—it seems hardly possible to give any figures for this influencing factor. Tests on the same machine made on different days showed considerable difference in this respect. With properly corrected commutation, however, the unbalanced voltages are practically zero. Thus, as we have seen, the leakage reactance of the armature is constant and entirely independent of the rotor speed.

To further illustrate the difference between a slip ring and commutator armature we will connect the stators of the two machines shown in Figs. 1 and 2 to a three-phase line of constant voltage and frequency and connect the slip rings and the brushes of the commutators to two quarter-phase resistances. Both machines will run as induction motors. We will load both mechanically, so that they run at half synchronous speed. We have seen that there appears at both the slip rings and commutator brushes a voltage of half the standstill voltage of the rotor, the only difference being that this voltage has half the line frequency at the slip rings and full line frequency at the commutator. The result is, that currents of the same intensity flow through the two resistances, absorbing the same amount of energy. But the current in the resistances of the commutator motor is of line frequency, while the current of the slip ring rotor is of a frequency equal to half the line frequency. Owing to the leakage fluxes across the slots, over the teeth and around the end connections of the rotor winding of the latter machine, there are reactance voltages in the secondary circuit proportional to the leakage fluxes and to half of the line frequency. There exist in the commutator motor practically the same leakage fluxes across the slots, and over the teeth and the end connections of the rotor winding; but as we have seen above, the current in the rotor winding has the full line frequency. Thus there appear in the commutator rotor reactance voltages of double the amplitude of those in the slip ring motor. Actual tests show that the commutator motor with the above connections has a poorer power-factor and overload capacity than the normal slip ring induction motor.

With the slip ring motor, the difference in frequency of the current in the resistances makes it impossible to return this energy to the line, unless auxiliary means are provided. It must simply go to waste in the resistances, which in our case means an efficiency less than 50 per cent.

In the commutator motor the current in the resistances is of the line frequency. It can be transferred to the line without difficulty, for instance, by means of a transformer. The poor efficiency of the slip ring motor at half speed is raised to the efficiency of a normal motor. This is the main advantage of the commutator motor over the induction motor.

The result of the above considerations is shortly:

Regarding the brush potential, the commutator acts as a straight frequency changer, so that at the brushes the potential produced by the main field in the armature is always of the stator or line frequency.

The actual armature current, except for the current in the few coils passing under the brushes, is the unchanged outside current of the stator or line frequency. The change of the line or stator frequency to the rotor frequency is effected only by the commutating zones. The leakage reactance potential of the armature current is therefore (correct commutation assumed) proportional only to the intensity of the current and the impressed line frequency, and is independent of the speed of the rotor.

The frequency of the armature AT in the stator is entirely independent of the speed of the armature and always the same as the stator or line frequency.

A GRAPHICAL STUDY OF THE RESISTANCE DIVISIONS FOR SERIES MOTOR OPERATION

By E. R. Carichoff

Railway Equipment Engineering, General Electric Company

The object of this article is to present a graphical method which will simplify the apportioning of the amounts of resistance that should be connected to the various points of a series motor controller in order to insure its best operation. A clear description of the method of laying out the diagrams is given along with a mathematical proof of their correctness. The usual superiority of graphical methods over arithmetical ones is brought out more forcibly in connection with the application of series-parallel operation.—Editor.

When a series motor is to be started and accelerated on a constant potential circuit, by means of a controller with a given number of steps, it is necessary to divide the starting resistance in a certain manner in order to have uniform changes in the current as the controller is advanced from point to point. Some more or less mathematical methods for determining the relative values of resistance for each point of the controller have been published, but as these are quite complicated it appears that there is need for a graphical presentation of the relation between current, speed, and external resistance of a series motor connected across a constant potential circuit.

In Fig. 1 let S_1 represent the speed of a series motor, having no external resistance, connected across a constant potential circuit when a current I_1 is flowing in the motor. The ordinate of S_1, i.e. OS_1, is the measure of the speed. Let R_1 satisfy the equation $\frac{V}{I_1}-r$, where V is the line voltage and r is the internal resistance of the motor. R_1 is then evidently that value of external resistance which would limit the current to I_1 when the motor is blocked. Set off OD equal to R_1 on the abscissa axis and join the points S_1 and R_1 by a straight line. Then it is evident that with any given external resistance in the circuit as represented by OR the speed will be represented by the value OS when the current I_1 is flowing, the value of this speed being the length of the ordinate from the point R to the line S_1 R_1.

In Fig. 2, S_1 is the speed taken from a motor curve with a current I_1 in the motor, S_2 is the speed corresponding to a current I_2 in the motor, $R_1=\frac{V}{I_1}-r$, and $R_2=\frac{V}{I_2}-r$. A horizontal line b is drawn from the point S_2 to cut the line I_1, and from the point of intersection a vertical line c is drawn cutting the line I_2. Then the horizontal and vertical lines d, e, f, and g are drawn until there exists, as shown, a set of unequal right angle triangles entirely filling the space between the lines I_1 and I_2. Now if the motor is started with a current I_2, through an external resistance R_2, and the current is allowed to decrease in value, the speed will be S_4 when the current has fallen to I_1. Then if the external resistance is instantly reduced to R_3 the current in the motor will increase to I_2; and when the current falls to I_1 the speed will have increased to S_3. Instant decrease of the resistance to R_4 will cause the current to increase to I_2; and when the current falls

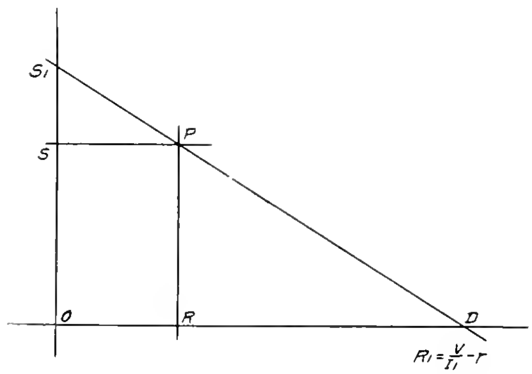


Fig. 1. A simple diagram showing the relation between the Current, Speed, and External Resistance for a Series Motor

to I_1 the speed will be S_2. When R_4 is removed the current rises to I_2 and falls to I_1 at a speed of S_1. Thus it is seen that R_2, R_3, and R_4 are the external resistances which, with suitable pause between the change from the higher to the lower, will cause the current to vary between the values I_2 and I_1. The required time intervals between the changes are evidently proportional to OS_4, S_3-S_4, and S_2-S_3, and it is obvious that a current limit control with resistances proportioned as above will operate in the manner described.

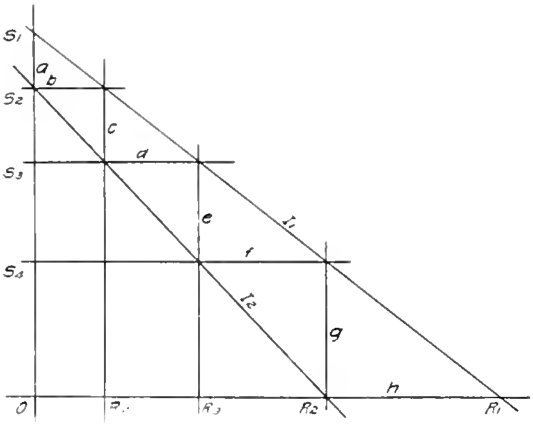


Fig. 2. A Completed Current-Speed-External Resistance Diagram for a Series Motor

If the differences between the vertical lines and the differences between the horizontal lines be denoted by the small letters a, b, c, d, e, f, g, and h, the relations below may be deduced by proportion.

$$b = a \times \frac{R_1}{S_1} = (S_1 - S_2)\frac{R_1}{S_1}$$

$$c = b \times \frac{S_2}{R_2}$$

$$d = c \times \frac{R_1}{S_1} = b\frac{R_1\,S_2}{S_1\,R_2}$$

$$e = d \times \frac{S_2}{R_2}$$

$$f = e \cdot \frac{R_1}{S_1} = d\frac{R_1\,S_2}{S_1\,R_2} = b\left(\frac{R_1\,S_2}{S_1\,R_2}\right)^2$$

$$g = f \cdot \frac{S_2}{R_2}$$

$$h = g \cdot \frac{R_1}{S_1} = f\frac{R_1\,S_2}{S_1\,R_2} = d\left(\frac{R_1\,S_2}{S_1\,R_2}\right)^2 = b\left(\frac{R_1\,S_2}{S_1\,R_2}\right)^3$$

It is seen that second horizontal interval may be obtained by multiplying the first horizontal interval by the factor $\frac{R_1\,S_2}{S_1\,R_2}$, the third is equal to the second times the same factor, and the fourth is equal to the third times this factor also. The sum of the blocks of resistance form the total resistance, therefore,

$$R_1 = b + b\frac{R_1\,S_2}{S_1\,R_2} + d\frac{R_1\,S_2}{S_1\,R_2} + f\frac{R_1\,S_2}{S_1\,R_2}$$

or

$$R_1 = b\left[1 + \frac{R_1\,S_2}{S_1\,R_2} + \left(\frac{R_1\,S_2}{S_1\,R_2}\right)^2 + \left(\frac{R_1\,S_2}{S_1\,R_2}\right)^3\right]$$

This equation may be solved by assuming a constant value for I_1, a number of values for I_2, and plotting the different values of R_1 as ordinates of a curve having the various values of I_2 for abscissas. Then the ordinate which equals the value of R_1 required has for abscissa the required value of I_2 which satisfies the equation. This solution of the above equation was given by Carichoff and Pender in the GENERAL ELECTRIC REVIEW, July, 1910.

The difficulty in laying out the steps as shown in Fig. 2 is that, when the lines $S_1\,R_1$ and $S_2\,R_2$ are drawn for two assumed values of current and corresponding values of speed from the motor curve, the line h will fall either above or below the line OR_1 and another line S_2R_2 will have to be drawn and the steps drawn in again. Probably several trials may have to be made before the triangles can be drawn to fill exactly the space between the two lines representing the two currents I_1 and I_2.

Fig. 3 shows the process for determining the resistance steps of a four-point starter; Table I shows the values from which the motor curve was plotted and the various lines drawn, as well as the necessary calculations. A line for 60 amperes and a line for 95 amperes were drawn to resistance scale A

TABLE I

$V = 600$ Volts; Res. of Motor; $r = 0.7$ ohm

Speed Miles per Hr.	Current Amperes	$\frac{V}{I}$	$\frac{V}{I}-r$	Factor	Speed—Two Motors in Series	$\frac{V}{I}-2r$
18.75	50	12	11.3			
17.4	60	10	9.3		8.05	8.6
16.3	70					
15.4	80	7.5	6.8			
14.8	90	6.65	5.95			
14.2	100	6	5.35			
15.08	85	7.07	6.37			
14.45	95	6.32	5.62			
14.7	91	6.6	5.9	1.333		
15.02	86	7	6.3		6.7	5.6

from the points 17.4 and 14.45 respectively on the ordinate axis, which latter represent the car speeds when driven by the motor with those current inputs and without external resistance. It will be seen that the fourth horizontal line falls below the datum line and crosses the 60-ampere line at a value 10.8 which is greater than 9.3. Then lines corresponding to 60 and 85 amperes were drawn to resistance scale B. Here it is seen that the fourth horizontal line is above the datum line and crosses the 60-ampere line at a value 7.2, which is less than 9.3. Just below the motor curve the point 10.8 (resistance) and 95 (current), and the point 7.2 (resistance) and 85 (current), were joined by a straight line LM. In this line the resistance point 9.3 (from Table I for 60 amperes) corresponds to a current value of 91 amperes. Then lines corresponding to 60 and 91 amperes were drawn to resistance scale C and the fourth horizontal line is seen to fall on the datum line as required.

The value of resistance for the first point on the controller is 5.9, that for the second point is 3.36, and that for the third point is 1.44.

The factor $\frac{R_1S_2}{S_1R_2}$ is equal to 1.333 and the smallest horizontal interval is 1.44, the next is 3.36−1.44 or 1.92, the next is 5.9−3.36 or 2.54, and the next is 9.3−5.9 or 3.4. These values show that any interval is equal to the next smaller times the factor as stated above.

In Fig. 4 lines were drawn for 60 amperes and 86 amperes in a single motor connected across the line (voltage 600), using the data given in Table I. The 60-ampere line cuts the vertical axis at the speed value 17.4 and cuts the horizontal axis at the value of $\frac{V}{I}-r$, equal to 9.3 on scale B. The 86-ampere line cuts the respective axes at the values 15.02 and 6.3.

When the motors are connected in series across the line without resistance the speed with 60 amperes in the motors is 8.05 (see Table I) and the value $\frac{V}{I}-2r$ is 8.6 (see Table I). When the current in the motors is 86 amperes the speed is 6.7 (see Table I) and the value $\frac{V}{I}-2r$ is 5.6 (see Table I). With these values two lines are drawn to read on scale A. Horizontal and vertical lines are drawn as before between the lines of current. Now if the motors are started in series with a resistance of 5.6 ohms the initial current will be 86 amperes. As the motors accelerate the current will fall, and when it falls to 60 amperes if the resistance is suddenly reduced to 3.2 ohms the current will rise to 86 amperes. The next resistance point is 1.4 ohms, and the intervals are 2.4, 1.8, and 1.4 ohms.

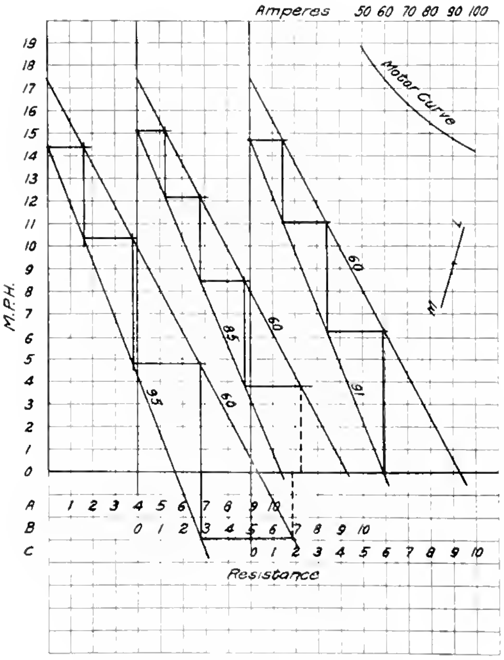


Fig. 3. Diagram showing the method of adjusting the current limit to satisfy assumed conditions

Now suppose the controller is arranged to disconnect one motor and leave the other in circuit with a resistance across the line preparatory to connecting the motors in parallel. At the speed of 8.05 a resistance of 2.9 ohms in series with one motor across the line will permit 86 amperes to pass. When the other motor is connected in parallel the resistance should be cut to 1.45 ohms $\left(\frac{2.9}{2}\text{ ohms}\right)$ so that each motor will take 86 amperes. The next resistance point for a single motor is 1.3 which should be halved for two motors in parallel. The correct resistance values for the series steps then are 5.6, 3.2, and 1.4; and the correct resistance values for transition and the parallel steps are 2.9, 1.45, and 0.65.

If 3.2 is used for transition the current at that time will not quite reach 86 amperes. On the other hand, if 2.9 is used for the second series point the current on that step will rise

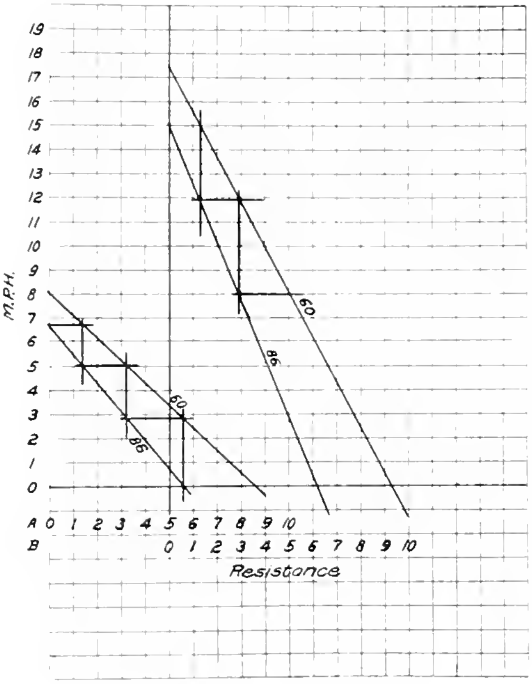


Fig. 4. Diagram for Series-Parallel Operation

above 86 amperes, so that it is well to use 3.0 as a compromise value between 3.2 and 2.9. The second parallel point 1.45 differs very little from the low series section 1.4 which may be used instead, and the low parallel point 0.65 may be obtained by a tap in the 1.4 section.

The compromise values for series are then 5.6, 3.0, and 1.4, and for transition and parallel are 3.0, 1.4, and 0.65. This arrangement of resistance is suited to the K-10, 11, 12, and 36 controllers if the controller is not stopped on the first parallel notch which has the resistance value 3.0. If a pause is made here the motors will take about half current each, so it would seem better to pass over this notch on the controller. On the other hand, if a lower value than 3.0 is used in order to increase the current in the motors on the first parallel point, this same low value would be used for the second point series, on which point the current would rise above the value 86.

Suppose a case where the torque required on a grade is not less than that given by 60 amperes in both motors, obviously a pause on the transition resistance 3.0 would permit the motors to slow down, and when the next step is taken excessive current would flow.

By looking at Fig. 2 it will be seen that the interval of pause on each step represented by *g*, *e*, and *c* are unequal and, when no current limiting device is used, the current will ordinarily not be held within the limits I_1 and I_2, unless as on a street car the operator has become very sensitive to the change of acceleration and advances the controller as prompted by this feeling. Any attempt to employ equal intervals of time between steps will result in an increased difference between the maximum and minimum current on each step as the controller is advanced.

LATEST PRACTICE IN STREET RAILWAY LAMPS

By J. L. Staley

Harrison Works, General Electric Company

The replacement of the old carbon filament lamp by the drawn-wire mazda lamp has been as successful on trolleys and trains as it has in stationary installations. In the beginning of this article, the reasons are considered which brought about the re-equipment. The size, construction, and rating of the new lamps which have been designed to replace the old are then described. The remainder of the article explains how it is that although a replacement, lamp for lamp, will result in a marked improvement both as regards light distribution and current economy, the greatest benefit will be derived from the use of fewer lamps of larger capacity carefully located and backed by well-chosen reflectors.—Editor.

Before attempting to describe the present practice in street railway car illumination it is useful to make a brief review of past practice. In the past, 64-watt carbon lamps of approximately 16 candle-power, operating at an efficiency of about 4 watts per candle were commonly used. These were 105 to 130-volt lamps operated five in series on circuits of 525 to 650 volts. Three, four, and five circuits, of five lamps each were commonly used, the number of circuits depending on the size of car, the various forms of grouping and general arrangement, such as clusters of fives or double rows of single lamps.

The 42-watt lamp of approximately 10 candle-power was used by a few railways, while the 114-watt lamp, giving approximately 32 candle-power, was sometimes used where more illumination was required, or where it was felt that the saving in the number of sockets employed would justify a larger lamp.

The carbon street railway lamp, however, had certain limitations. It was found that, with the increase in street railway schedules due to the growth of any community, there was at certain rush hours a drop in voltage, which, with carbon lamps, made a very marked decrease in resultant illumination. While these rush hour periods were of short duration, they unfortunately occurred at a time when street railway companies were attempting to serve the greatest number of people. During these rush hours the motors were operating satisfactorily, although not quite as efficiently, and as speed was not so important at this time, the railway companies did not feel justified in increasing the feeder capacity to take care of lighting alone. There was therefore need for a lamp of better regulation, that is, one which would maintain more nearly constant candle-power over a wide range of voltage. See Fig. 2.

Aside from the fact that more nearly constant illumination was desirable, the increase in the standard of illumination throughout the country in all places where artificial illumination was used, such as the home, factory, office, street, etc., made it also desirable to increase the illumination in the car. That is, illumination which a few years ago was considered adequate, today would not meet with public approval.

Fig. 1. Interurban Car Illuminated by Mazda Lamps

The inherent regulation of the mazda lamp, i.e., increase in resistance with increased voltage tending to check an increase in current, together with its high efficiency showed that this class of lamp was almost ideal for street railway service. It only remained to prove the ability of this lamp to stand up under railway operating conditions.

There have been four mazda lamps standardized for regular street railway service, as shown in the table on the following page.

The 23-watt lamp was primarily designed for the replacement, lamp for lamp, of 64 and 42 watt carbon lamps. When replacing the former, it gives a slight increase in candle-power at normal voltage, but a steady candle-power over a wide range of voltage, thereby giving sufficient illumination at under-voltage where the illumination by the carbon lamp is not sufficient under these conditions. The 23-watt lamp also effects a considerable saving in current, amounting in some cases to one kilowatt per car

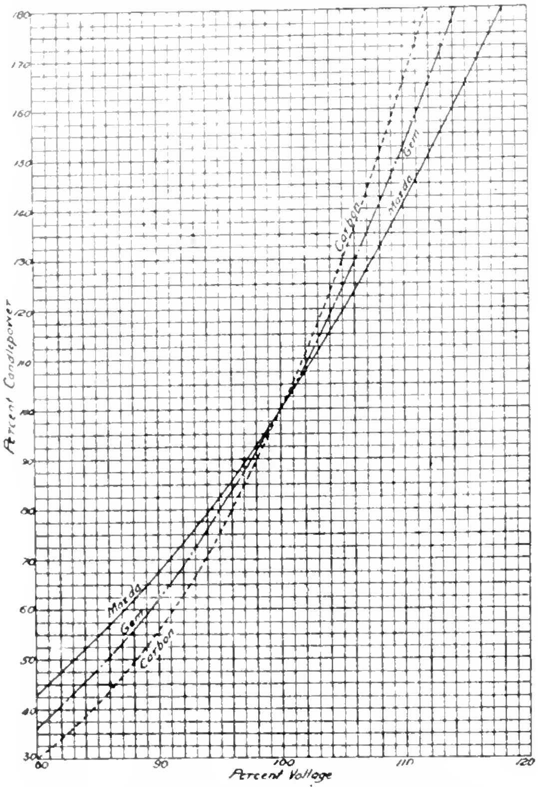


Fig. 2. Curves Showing Variation of Candle-Power Due to Voltage Variation for Carbon, Gem and Mazda Lamps

MAZDA LAMPS FOR ELECTRIC STREET RAILWAY SERVICE

Description	Voltage Groups	Nominal Watts	Efficiency W.P.C.	Diam. Bulb in In.	Overall Length in In.
Straight side	105				
	110	23	1.34	$2\frac{3}{8}$	$5\frac{1}{4}$
	115	36	1.34	$2\frac{3}{8}$	$5\frac{1}{4}$
	120	56	1.20	$2\frac{5}{8}$	$5\frac{1}{2}$
	125	94	1.20	$3\frac{1}{16}$	$7\frac{1}{8}$
	130				

The 36-watt lamp is designed for replacing, lamp for lamp, the 64-watt carbon lamp, and, while affording a decided increase in the illumination of the car, still effects considerable saving in current.

The 56-watt mazda lamp is intended primarily for use with Holophane reflectors, using only two circuits of lamps. The features of this system will be discussed later.

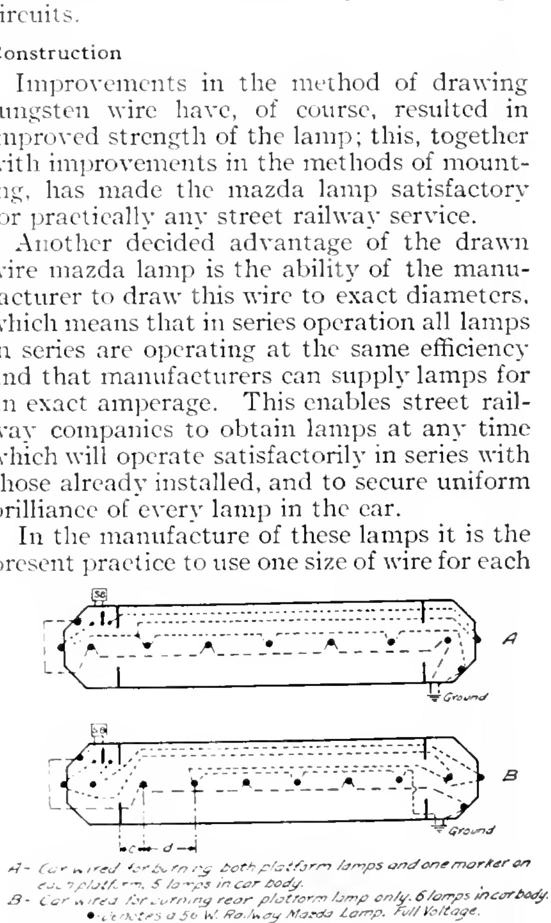
The 94-watt lamp was also designed for use with reflectors, and is generally used in single circuits.

Construction

Improvements in the method of drawing tungsten wire have, of course, resulted in improved strength of the lamp; this, together with improvements in the methods of mounting, has made the mazda lamp satisfactory for practically any street railway service.

Another decided advantage of the drawn wire mazda lamp is the ability of the manufacturer to draw this wire to exact diameters, which means that in series operation all lamps in series are operating at the same efficiency and that manufacturers can supply lamps for an exact amperage. This enables street railway companies to obtain lamps at any time which will operate satisfactorily in series with those already installed, and to secure uniform brilliance of every lamp in the car.

In the manufacture of these lamps it is the present practice to use one size of wire for each



Spacing	Length of Interior of Car Body e						
	e = 28 ft	e = 30 ft	e = 32 ft	e = 34 ft	e = 36 ft	e = 38 ft	e = 40 ft
a	2 "	3 "	2 "	3 "	2 "	3 "	4 "
b	6 "	6 "	7 "	7 "	8 "	8 "	8 "
c	$1\frac{1}{2}$ "	$2\frac{1}{2}$ "	$2\frac{1}{4}$ "	2 "	3 "	$2\frac{1}{2}$ "	$2\frac{1}{2}$ "
d	5 "	5 "	$5\frac{1}{2}$ "	6 "	6 "	$6\frac{1}{2}$ "	7 "
[illegible]	in all cases where practical						

Fig. 3. Wiring Diagrams

size of lamp, regardless of the voltage; that is, the filament diameter is selected for lamps of a certain wattage rating at 115 volts and the filaments are cut longer or shorter, depending upon the voltage desired. This means that the wattage of the lamp would be slightly higher for higher voltage, and slightly lower for lower voltage; but this variation is not objectionable, as is shown in the following specifications for the 23 and 36 watt lamps:

NOMINAL CANDLE-POWER AND NOMINAL WATTS FOR STREET RAILWAY SERIES MAZDA LAMPS

	23 WATTS 0.209 AMPERE		36 WATTS 0.335 AMPERE	
	Nominal C-P. for Group	Nominal Watts for Group	Nominal C-P. for Group	Nominal Watts for Group
105 volts for use 5 in series on 525 volts	16.4	21.95	26.3	35.18
110 volts for use 5 in series on 550 volts	17.2	22.99	27.5	36.85
115 volts for use 5 in series on 575 volts	17.9	24.04	28.8	38.53
120 volts for use 5 in series on 600 volts	18.7	25.08	30.0	40.20
125 volts for use 5 in series on 625 volts	19.5	26.12	31.3	41.88
130 volts for use 5 in series on 650 volts	20.3	27.17	32.5	43.55

Street railway mazda lamps are operated at somewhat poorer efficiency than lamps for regular multiple service, due chiefly to the fact that the cost of current is low and fairly long lives are justified.

An interesting point in connection with the operation of mazda lamps is that, when a failure occurs due to breakage of the filament, these lamps often re-weld themselves due to the vibration of the car. Although when this occurs it slightly changes the total resistance of the circuit, the efficiency at which these lamps are rated takes care of the slight increase in current which might result.

Systems

Practically all street railway cars found in operation a year or so ago were operating bare lamps, no attempt being made to re-distribute the light or prevent the glare of the filaments. Distribution was obtained by distributing a great number of small units rather than by re-directing the light from a few larger ones. Companies wishing to take immediate advantage of the characteristics of mazda lamps have replaced their carbon lamps, lamp for lamp, with mazda lamps. Of course, this represents a much smaller initial investment and presents an opportunity to immediately test out the new lamp. A better practice, of course, would be to re-wire the cars, using a smaller number of units with proper reflectors. A wiring diagram

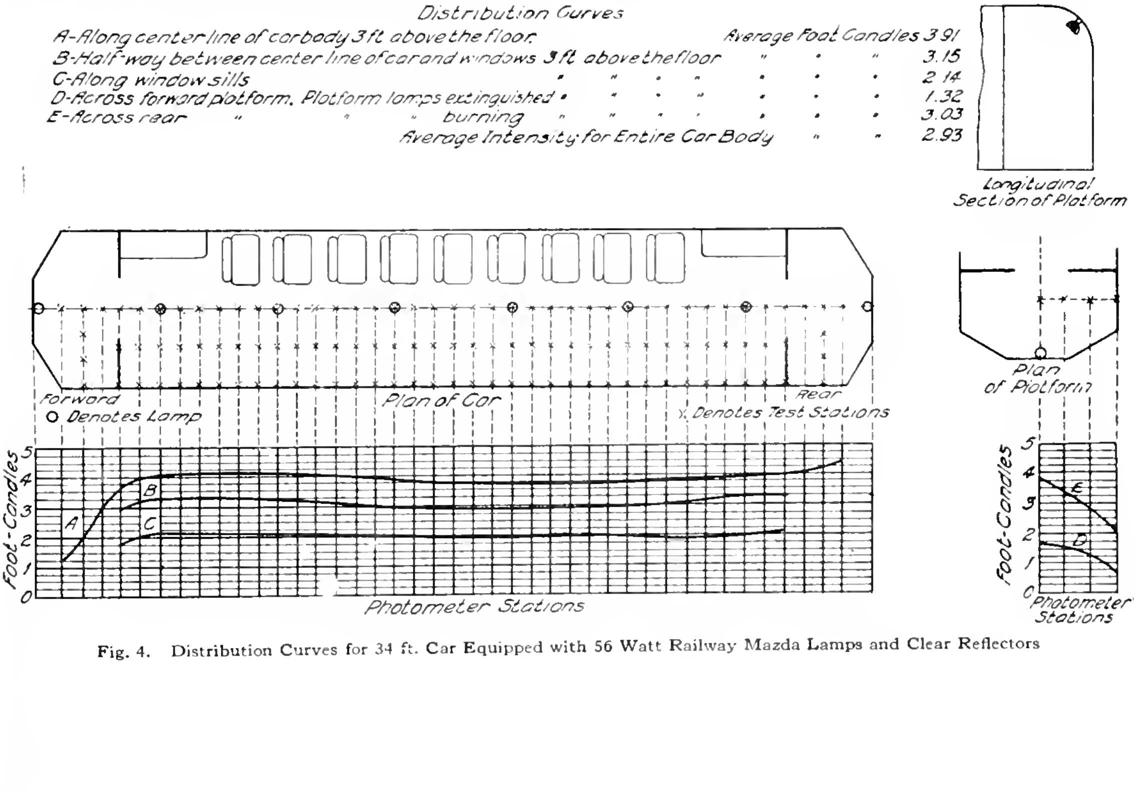


Fig. 4. Distribution Curves for 34 ft. Car Equipped with 56 Watt Railway Mazda Lamps and Clear Reflectors

of a re-equipped car is shown in Fig. 4, together with tests of illumination at different stations throughout the car.

It is seen that this illumination, while not only considerably higher than that of carbon lamps originally installed, is very uniform throughout the car. In this system, alternate lamps only are in the same circuit, so that the failure of one circuit still leaves better illumination than that given by the carbon lamps.

There are a great many varieties of circuits installed in present equipments, such as the joining of two circuits of four lamps each through the headlight, which requires the latter to be double the wattage of the lamps in the interior of the car. Some systems also have lamps of half the wattage in the sign boxes and markers. There is no reason, however, why all these systems cannot be equipped with mazda lamps.

SWITCHBOARD FOR 2400 VOLT D-C. RAILWAY SERVICE

By A. C. Finney

Switchboard Engineering Department, General Electric Company

This article describes the switchboard equipment that was designed and built for the 2400 volt d-c. electrification of the Butte, Anaconda & Pacific Railroad. The arrangement is similar in most respects to standard 1200 volt practice, the principal difference being in the provision of additional insulation and clearances to care for the higher potential. Every precaution has been observed to protect the operator from contact with any live part; and to further prevent any possible chance of injury to the attendant the circuit-breakers are mounted to the rear of and above the main panels, instead of at the top of the main panels, as is customary on 1200 volt boards.—Editor.

Several years ago designers of apparatus for electric railway operation took a bold step forward in breaking away from the long existing standard of the 600 volt trolley and inaugurating the use of a 1200 volt d-c. circuit. It remained until a recent date, however, for the next important step to be taken in the upward direction, consisting of the pioneer installation of 2400 volts d-c. on the Butte, Anaconda & Pacific Railroad. The general underlying principles and requirements indicating the economical sphere for 2400 volt service are broadly covered in the article by Mr. Hobart appearing in the July and August numbers of the Review. As an essential item in providing this 2400 volt service, we now wish to mention a few problems that were encountered and solved in the design of the switchboards for the Butte, Anaconda & Pacific Railroad.

The first installation consists of two substations, the switchboards for which are in the main identical. In each station the switchboard is required to control two 1000 kw. motor-generator sets, each consisting of a synchronous motor driving two 500 kw., 1200 volt d-c. generators, which are connected in series to give 2400 volts, and which derive excitation at 125 volts from separate exciters. The a-c. control for these sets is not at all unusual, being along standard lines for remote control switching; but for controlling the d-c. end of these machines, the equipment involves a number of features which are new [illegible] we believe, may warrant more [illegible]

In working out the design of a switchboard of this character, a number of problems present themselves for solution. In the first place, in addition to taking care of the proper control of the machines, the switching apparatus must be so arranged as to allow convenient operation of various feeders required for the usual system with grounded negative and sectionalized trolley. Secondly, automatic protection must be provided against various sources of trouble outside of the switchboard, the most important of which result from overloads and short circuits on either machines or feeders. Then there is always the chance of motoring and a possibility of over speed with machines in parallel on the d-c. end in case the circuit is opened on the a-c. machine. It is also desirable to open the circuit in case of drop in voltage below a certain point. These all correspond to similar requirements in the case of the customary 600 volt machines. In addition, however, for these higher voltage sets it was considered desirable to make provision against an abnormal rise in generator voltage in case the load were suddenly removed.

The third class of requirements in this design related to the elimination of the possibility of trouble within the switchboard itself or between its component parts. To insure proper and continuous service, all live parts, busses and connections must be protected against accidental grounds and short circuits; and it is also of the greatest importance that the switchboard operator be kept entirely free from jeopardy of life or limb which might be incidental to the handling of these circuits.

A general idea of the manner in which some of the above problems were solved may be gained by a glance at the accompanying illustrations. From the reproduction of the wiring diagram (Fig. 1) it will appear that the main connections in general follow standard railway practice in use for the lower voltage switchboards. This naturally follows from the fact that the main switching requirements are similar. It is in the detailed design of the various apparatus to perform the functions indicated that we find the main departures from previous standards.

After settling on the system of connections and class of apparatus necessary for conveniently carrying out the given switching requirements, it is most important to make sure that no possible source of trouble in any of the circuits is left unbridled. In this case the chief automatic provision against these difficulties outside the switchboard, centers in and about the circuit breakers. It will be seen from the views of the switchboard that these circuit breakers, as well as the lever switches, follow the present 1200 volt practice in using operating levers and connecting mechanisms to avoid danger to the operator. It was at first believed that the standard 1200 volt practice could also be followed in locating the circuit breaker itself at the top of the panel. Actual experience in the handling of direct current circuits at 2400 volts and above, however, soon indicated that the process of opening a heavy overload or short circuit just above the head of the operator might at least be rather disconcerting, if not actually dangerous. It was, therefore, decided to go a step further and locate the circuit breakers and switches on separate panels back of and above the main switchboard, the operating mechanisms having a design somewhat similar to the usual arrangement adopted for hand operated oil switches. This allows the possibility, if desired, of using a little more space for the circuit breaker and switch panels than for other corresponding panels in the switchboard, but a large difference is not desirable, and the arrangement is simplified by using panels of the same width. In the switchboards illustrated, the circuit breaker and switch for each circuit are mounted on a panel four inches wider than the corresponding panel in the main board.

The circuit breaker proper as furnished on these boards is the result of long continued and exhaustive tests and experimenting to obtain a device which would be quick in action and would effectually open its full rated load at a pressure considerably above the 2400 volt circuit on which it was to be

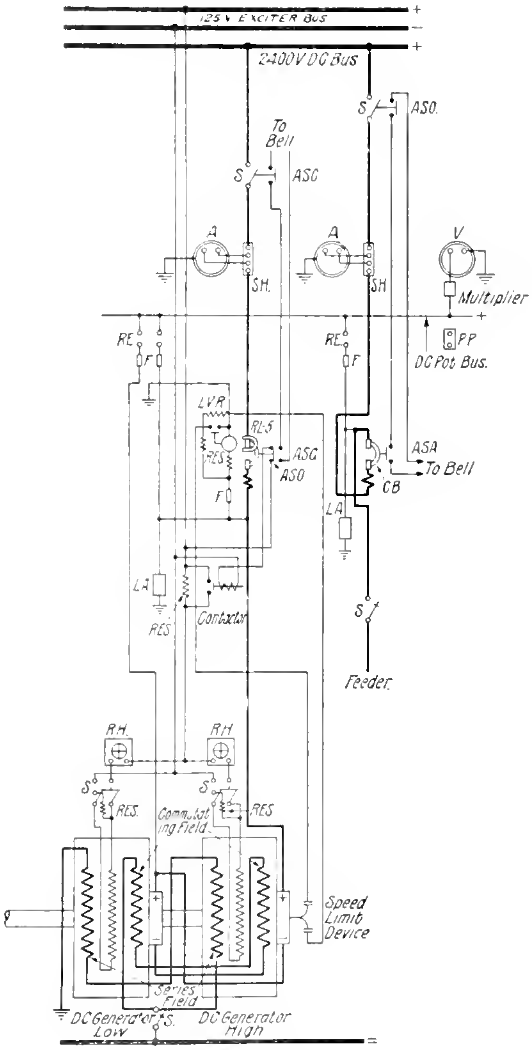


Fig. 1. Diagram of Connections, 2400 Volt D-C. Switchboard

used. The strikingly unusual feature in the appearance of this circuit breaker is the magnetic blowout arc chute, which was evolved from a careful study of the nature of the arc and after numerous tests under actual short circuit conditions.

Both the circuit breakers and lever switches are mounted on their panels by means of insulators and are otherwise so arranged that the panels need not be depended upon for full

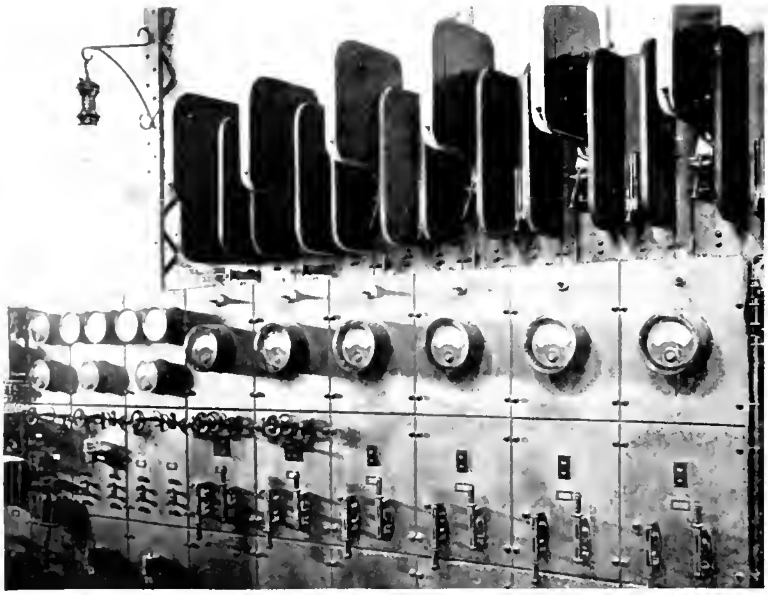


Fig. 2. 2400 Volt D-C. Switchboard Showing Circuit Breakers Mounted Above and to Rear of Main Panels

insulation. For this reason, natural black slate has been considered acceptable for the circuit breaker panels as well as main panels of this switchboard.

Supplementing the protection against overload and short circuit afforded by the circuit breaker proper, we find here, as on lower voltage equipments, the usual low voltage release which is short circuited by the speed limit device on the machine, reverse current relay, and bell alarm switch. The low voltage release and reverse current relay are operated on 2400 volts through high resistances, and are carefully insulated from the circuit breaker, so that the speed limit device on the machine may be kept at ground potential. A light connecting mechanism operated by a pull button on the switchboard is used for lifting the low voltage release by hand or for hand tripping. The bell alarm connections and arrangement follow the standard 1200 volt practice, the bell circuit being closed by the opening of the circuit breaker, and opened again when the main switch is opened.

To obviate the possibility of an abnormal rise in voltage when the generator circuit breaker opens, a resistance is connected in series with the field circuit. This resistance is normally short-circuited by a contactor operated through an auxiliary switch on the circuit breaker. The tripping of the circuit breaker opens the contactor circuit, thereby cutting in resistance in the field and accomplishing a quick reduction in voltage.

Insurance against internal trouble on this switchboard has been largely a matter of attention to small details in design. Ample clearances have been allowed for all current carrying parts. The main busses are carried high up back of the circuit breaker panels and are further protected by an asbestos lumber roof running up at an angle from the top of the circuit breaker panels to the wall back of the board. This, while preventing foreign material from falling on the busses and connections, will also act as a barrier to stray arcs, should any such developments occur at the circuit breakers. All potential leads and busses are supported on insulators, and the flexible shunt leads are carried in fiber tubes, in turn mounted on insulators.

The final test of serviceability for a switchboard of this type is to put ourselves in the

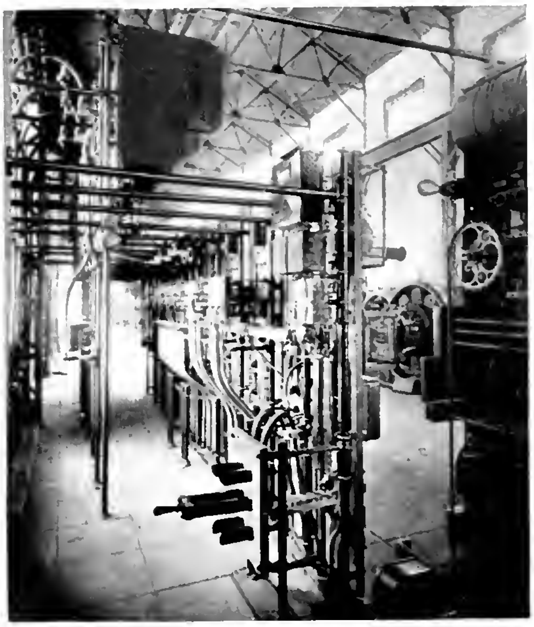


Fig. 3. Back View of Switchboard of Fig. 2

place of the operator and judge whether we could take care of all necessary operations and emergencies without fear of personal danger. It may be of interest to note a few of the measures which have been taken for the safety of the operator of this board.

In the first place, no high voltage live parts are exposed on the front of the panels. All the circuit breakers and switches, as before noted, are removed from the switchboard. Wood rods are used for connecting up the operating mechanisms, so that the handles are fully insulated. The ammeters are enclosed in insulating covers, and the voltmeter on the swinging bracket is connected on the grounded side of the circuit, its separate resistance being on the positive side. The entire framework of the switchboard is grounded, but an additional precaution is taken in covering all supporting bolts on the front of the panels with insulating caps. Even on the back of the board no live parts are exposed in any location that would allow accidental contact with the operator. The shunt and potential leads are well insulated and are carried overhead, and even the studs of the potential receptacle have been covered with a fiber box.

Fig. 5. A 2400 Volt D-C. Switchboard showing two generator and four feeder panels

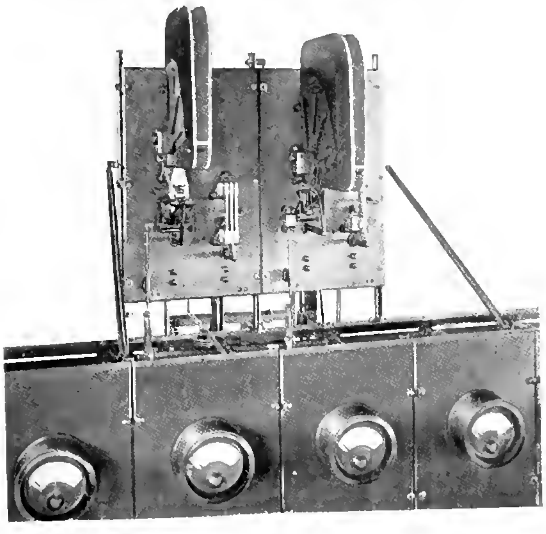


Fig. 4. Top of 2400 Volt D-C. Switchboard showing Location of Circuit Breakers and Lever Switches

From the foregoing description of the 2400 volt d-c. switchboard as furnished to the Butte, Anaconda & Pacific Railroad Co., it may well be imagined that a very considerable outlay in development has been involved and the best thought of a large number of men in the organization has been incorporated in this work, but all this finds ample compensation in the reports of the uniformly satisfactory operation of the finished product as installed. It is probably a little early yet to prophesy anything for the future, but it may be possible that this development is merely a step in the direction of still higher voltages for direct current operation, which will bring with them unexpected difficulties to be again overcome with renewed interest.

SOME SPECIAL APPLICATIONS OF DIRECT CURRENT VOLTAGE REGULATORS

By H. A. Laycock

Voltage Regulator Department, General Electric Company

The principal value of this article lies in the educational information it disseminates regarding the general usefulness of the automatic voltage regulator. As examples of the versatility of the device, some eight of its special applications are described in detail accompanied by diagrams. A concluding statement is made to the effect that an automatic voltage regulator can be successfully applied to almost any proposition involving varying factors, one of which it is desired to hold constant.—Editor.

Introduction

The application of an automatic voltage regulator to an alternating-current or a direct-current generator, for the sole purpose of maintaining an unvarying voltage, is doubtless familiar to everyone. It is safe to say, however, that but few realize the broad scope of application of the regulator to special conditions. As regards these special conditions, it may be said in general that in a circuit where the constancy of some factor is sought, the inherent principle of the regulator can almost always be applied to some controlling portion of that circuit in such a manner as to secure the desired result.

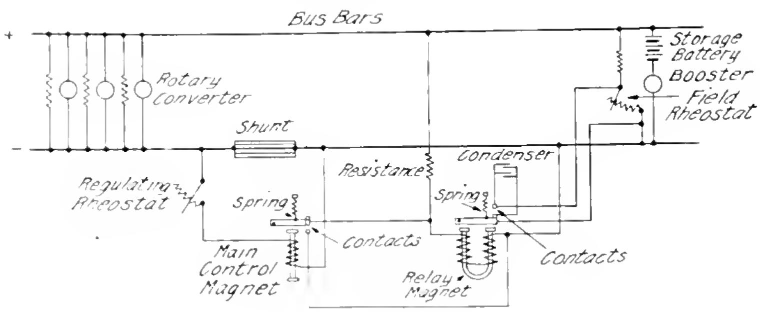


Fig. 1

It is not the intention of this article to attempt to cover the field of special application of regulators, but to present and explain a few of the most commonly encountered special applications to direct-current circuits. In order to more easily follow the operation of the regulator under special conditions, its action upon the apparatus which it regulates and the effect of the inherent characteristics of that apparatus upon it will be very briefly reviewed.

It is generally known that the automatic type of voltage regulator when used to maintain constant voltage accomplishes its purpose by the rapid control of the generator excitation, this being the result of a rapid automatic opening and closing of a short circuit around the field rheostat of the exciter or generator. This rapid "make and break" is made by two relays which are part of the device, one being connected across the generator and the other in series with it. The rapidity with which regulators operate depends entirely upon the characteristics of the generator regulated. For instance, if a generator is designed with very high magnetic saturation, the time required for this generator to build up its voltage, by increasing the field strength, may be considerably longer than would be practical for good regulation; but should this generator be designed with low saturation, the time in which the fields will respond to the action of the regulator will be such that perfect regulation will be obtained

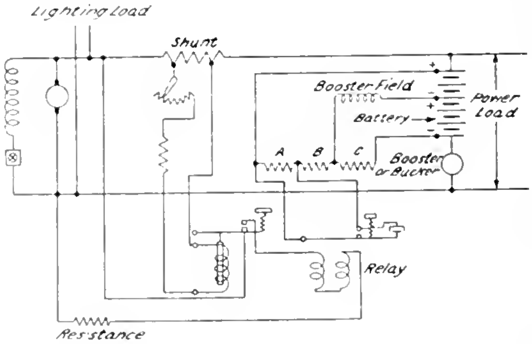


Fig. 2

even when the entire load is suddenly thrown on or off the generator. Thus it will be seen that the perfect regulation of all direct-current plants is dependent entirely upon the characteristics of the generators. For instance, for plants having a heavy elevator load and only a small percentage of lighting load, the generators must be more or less specially designed in order to obtain the best regulation, although a very great improvement can be produced in the case of standard generators. In order to explain the operation of automatic voltage regulators, in connection with their application to a few of the systems most commonly used, the following description will be taken up in sections.

Voltage Regulation of Rotary Converter with Floating Storage Battery

Fig. 1 shows a regulator as connected in circuit with rotary converters. These converters being of limited capacity, a storage battery is placed across the busbars. Connected in series with the storage battery is an ordinary shunt-wound booster. If the load demanded by the system exceeds the total capacity of the rotary converters, the battery supplies the excess current automatically. The rheostat in the booster field, being automatically controlled by the regulator, causes the battery to discharge in accordance with the current flowing through the line shunt, which is also connected to

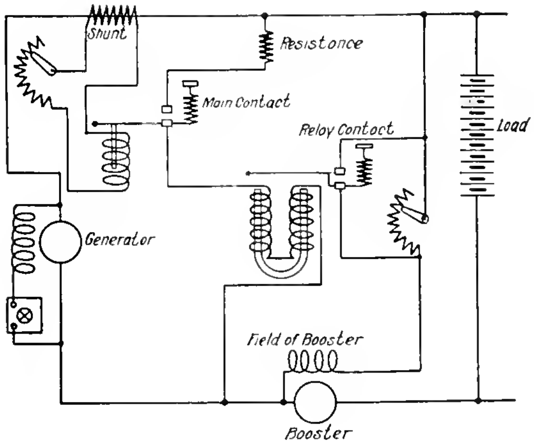


Fig. 3

the regulator. Should the current be low, i.e., a light load prevail the field of the booster will be weakened and the battery consequently charged.

Voltage Regulation of Generator with Storage Battery on Mixed Loads; Booster in Series with Battery

Another application of a similar outfit, Fig. 2, is made in connection with the ordinary standard generator used in supplying a mixed power and lighting load, such as prevails in

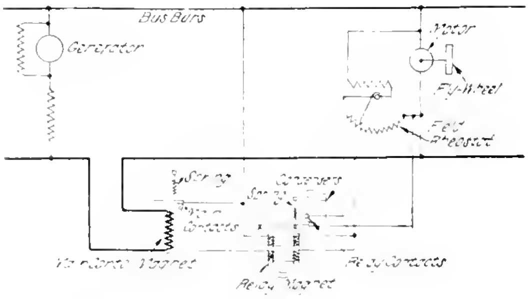


Fig. 4

office buildings, apartment houses, etc. The lighting and power loads are segregated, and the separate lines caring for each are connected to the generator bus, the lighting load connection being the closer to the armature. Connected between the positive and negative bus, at a position between those where the lighting and power loads are tapped in, is a storage battery with a booster in series. This is a small booster which operates in either direction and has its field separately excited from the storage battery, the center point of which is brought out in order to obtain a positive direction of current flow through the field for boosting, and a negative direction of flow for bucking the battery voltage.

The connection of the regulator in this case is such that when the current is high the resistance which is connected to the regulator is short circuited. This resistance is marked *A* and contains for example 150 ohms; the resistance between *A* and the booster field is marked *B* and contains 5 ohms; the resistance between the booster field and the other side of the battery is marked *C* and contains 10 ohms.

Should the current exceed the normal value for which the regulator is set, the short-circuiting connections around the resistance *A* will be opened. As *A* is a comparatively high resistance, the current will flow from the middle point of the battery through the fields of the booster to the negative end of the battery. The polarity of the booster will now be such, under these conditions of excitation, that it will add the voltage of the booster to that of the battery, and consequently allow it to discharge into the

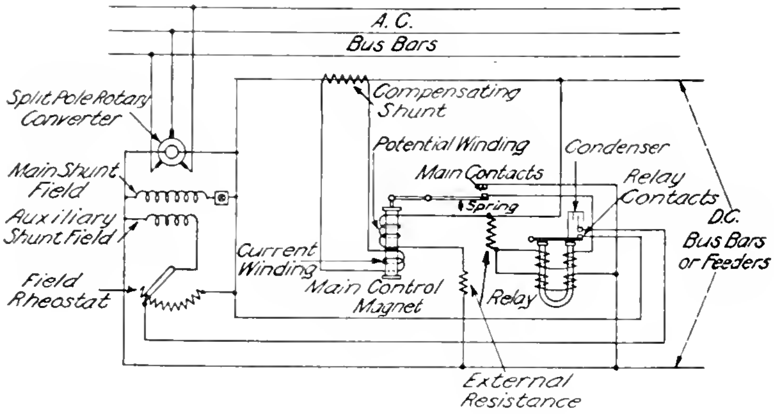


Fig. 5

line. Should the line current become low this resistance A is short circuited, and, since the resistance of B is one half that of C, the current now reverses in the field and flows in the opposite direction, or from the positive end of the battery to its middle point. The booster now bucks the e.m.f. of the battery, thus allowing generator current to flow through and charge it. An arrangement of this kind only requires a booster of the same capacity as the battery.

Voltage Regulation of Generator with Storage Battery on Mixed Loads; Booster in Series with Generator

For the same general layout shown in Fig. 3, which differs from the preceding only in the location of the booster in series with the generator instead of the battery, the application of a voltage regulator again allows the use of a shunt-wound booster. As the booster is arranged to operate in the one direction only, i.e., to raise the voltage, its capacity must be greater than if the previous arrangement were used, meaning, of course, additional cost as the booster must be of the same capacity as the generator.

Voltage Regulation for Control of Flywheel Equalizer Set

Where a dynamic battery, i.e., flywheel and motor, is used for supplying energy at peak loads, Fig. 4 shows a simple arrangement for accomplishing its regulation. The equalizing set shown in this diagram happened to be small enough to allow the total current to flow through the current coil of the regulator. For larger sets a line shunt is used, as shown in Figs. 1, 2, and 3.

Should the current here increase above normal value, the action of the regulator is to close the shunt circuit across the motor field rheostat. The motor, having stored up energy in its flywheel, now becomes a generator and delivers energy to the line. As flywheel sets are only designed to deliver a certain amount of energy for a given time after the load has been taken off, the reverse action of the regulator soon takes place, i.e., the shunt across the rheostat is opened and the resistance cut back into the field of the direct-current machine, the latter becoming a motor and driving the flywheel which again stores the energy for the next peak.

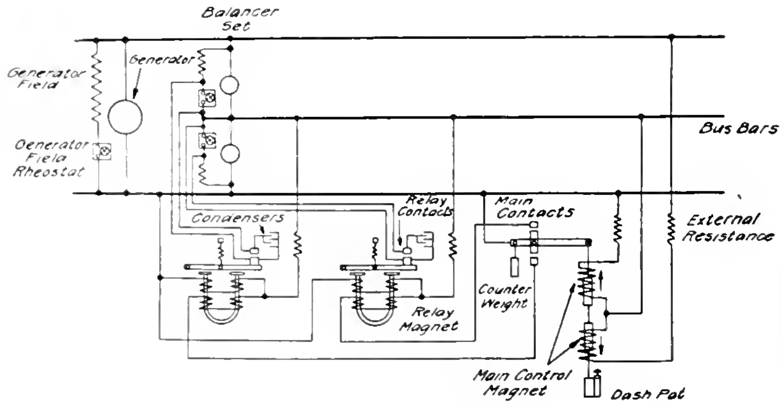


Fig. 6

Voltage Regulation of Split-Pole Converter

Fig. 5 shows the connections of a voltage regulator when applied to a split-pole rotary converter. One field of the rotary with its rheostat is connected permanently across the direct-current busbars, while the second field is controlled by a standard form of regulator. The winding of the second field is so designed that it has complete control from the minimum to the maximum overload excitation demanded by the rotary.

Voltage Balancing on Edison Three-Wire System

There are a great number of Edison three-wire systems using, for instance, 250-volt generators with a balancer set for deriving the neutral. It often happens that the power load is connected between the neutral and outside, and to meet this condition the regulator shown in Fig. 6 has been designed. This regulator, it will be noticed, contains two coils, one being connected to each side of the three-wire system. Balanced between these coils is a double set of contacts which, when closing the circuit of one set of relays opens the circuit of the other set at the same time. Should the voltage tend to go down on one side of the neutral and up on the other, the operation of the regulator at

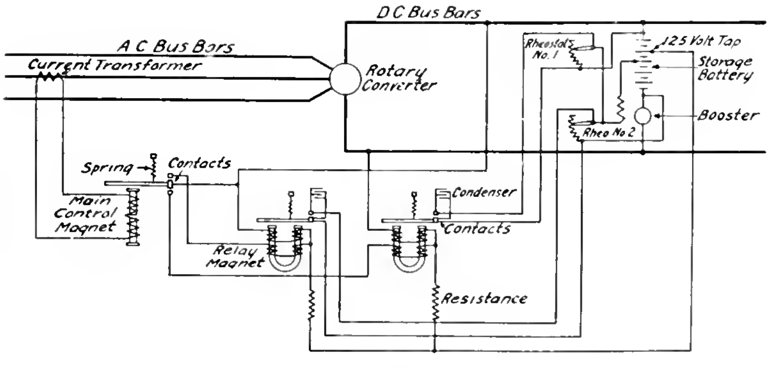


Fig. 7

once cuts resistance into the field of one balancer and out of the field of the other, thus providing a very quick action; and the resulting shift in the motor-generator character of the balancer set holds a balanced voltage under all conditions of load. By bringing pressure wires back from the center of distribution, the voltage can be more nearly balanced over the whole system.

Load Regulation (Constant Output from Rotary Converter with Floating Storage Battery)

Fig. 7 shows the method of applying a regulator to hold constant output on the direct-current side of a rotary converter. This arrangement was adopted for the benefit of a

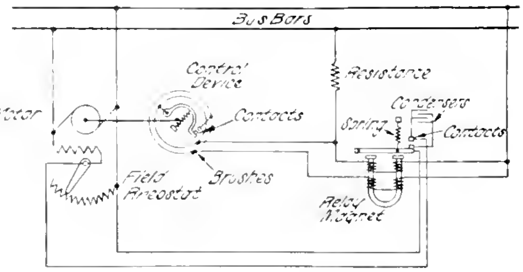


Fig. 8

customer who was buying power and paying for a certain amount, whether he was using it or not. Under these conditions when an overload is experienced on the rotary a very high charging rate is maintained, and when light load takes place the consumer receives no rebate. In order to carry the peak loads, a storage battery is employed across the direct-current end of the rotary, and at times of light load the storage battery is automatically charged by the rotary, thus keeping the rotary output almost constant.

The regulator in this case, being connected through a current transformer to the alternating-current bus, holds a constant alternating-current input on the converter by requiring the booster to either discharge the battery under peak loads, or to charge the battery under light loads. This action is accomplished by a double set of contacts on the main control magnet of the regulator which closes two relays across one of the booster rheostats while the shunt circuit around the other booster rheostat is left open. The booster, as it will be noted, is separately excited from the storage battery, using the middle point of the battery to obtain a positive or negative connection.

Speed Regulation of Constant Speed Motor

The automatic speed regulation of direct-current motors has been successfully accomplished through the use of the speed regulator illustrated in Fig. 8. The prime mover or governor consists of an arm, weighted in the center, pivoted at one end and equipped with a contact on the opposite end. The arm, due to centrifugal force, causes this contact to close against a stationary contact which is insulated from the movable contact, both of which are connected to a pair of collector rings. The current for the relays or secondary device is taken from these collector rings by a pair of brushes. As the speed of the motor increases the movable arm causes the contact to close, thus completing the short circuit around the motor field rheostat which gives the motor full field and causes it to drop its speed.

Opposite the weight on the movable arm is a spring which can readily be adjusted for a very wide range in speed. When the speed of the motor tends to drop below its normal value the spring overpowers the weight of the movable arm, causing the contacts to open and thus cutting the resistance into the motor field rheostat, which tends to speed up the motor quickly. This cycle of operation is repeated at a very high rate of vibration, thus overcoming both hunting and sluggishness in regulation. In the operation of this device there is absolutely no time element.

For a very small motor where the current in the field is light no apparatus other than the centrifugal governor is necessary, but for a large motor one or more sets of relays are necessary in order to handle the field current of the motor.

The speed regulation that can be obtained with this device depends entirely upon the characteristics of the motor to be regulated. Motors, however, designed with sufficient margin can be regulated well within 1 per cent even though the line voltage varies over a range of 40 or 50 per cent. In other words, any motor can be accurately regulated by this device if it will maintain normal speed with the minimum impressed voltage when the resistance is cut into the field rheostat, and also with the highest impressed voltage when the rheostat is short circuited or the motor has a full field.

Conclusion

From the preceding examples, which describe but a few of the useful applications of regulators, it will be seen that though initially an automatic *voltage* regulator, the field of usefulness of the device is much broader than this name would indicate; in fact there is no end to the use to which automatic voltage regulators can be beneficially applied. A short summary of this article shows that:

Besides its function of maintaining constant voltage, it can automatically divide a fluctuating line load between the direct-current generator (or rotary) and a paralleled storage battery, thus protecting the generator from overload.

It is able to effectively regulate the power input and output of a flywheel balancer set, lowering the peaks of the load on the generating source and thus placing it under a more nearly uniform load.

It can be arranged to assist the balancer set of an Edison three-wire system in dividing the current flowing through it from the neutral in proportion to the load on each side of the neutral, thus facilitating the location of the mid-voltage point.

It renders possible the maintenance of the load on a rotary converter at a constant value when the rotary in parallel with a storage battery is supplying load, thus guaranteeing to a power consumer the full benefit of a flat rate.

It will hold the speed of a motor to within a very few per cent of constant under conditions of varying load and voltage, which is a much more nearly straight line characteristic than can be obtained otherwise.

SCHENECTADY SECTION A.I.E.E.

SEASON OF 1913-14

Opening Address by Dr. E. W. Rice

President, General Electric Company

I regard it as a great honor to be given the opportunity to open this meeting of the American Institute of Electrical Engineers, the first meeting devoted to science to be held in these attractive and healthful quarters, the new home of the Edison Club.

I naturally have a very deep interest in the welfare of our student engineers. I have been "on the test"; in fact, I may say with all modesty, that for a short time I was the "test." I wound, assembled, tested and installed the first arc light machine made by the Thomson-Houston Company some 33 years ago. As our little business grew I needed an assistant, then two or three, and finally there grew up that remarkable institution, "the test." There was little known about electricity in those days, and the little that we boys on the test acquired made us seem very wise to the uninitiated. We soon became known as "experts," a title that lasted for some years and was only abolished when in the course of time real electrical engineers were evolved. We had little to trouble us in those early pre-historic times—only one lone ammeter, a Wheatstone bridge and a galvanometer, all home made, with which to test an occasional arc dynamo and its group of lamps.

We had no electric club house or spacious lecture hall, we did not need them. Those were days of small things; but times have changed and we must adapt ourselves to the new conditions or fail in our duty.

The "students," as they are now more modestly called, number some 500 in Schenectady alone and come from some 80 institutions of learning from all parts of the world. The business has become large and most complicated—specialization has developed into super-specialization. There was a great need for just such an institution as the Edison Club, and of course when formed such a body needed a suitable house. This building was, after careful consideration and the elimination of many plans, duly started and finished.

Let me say right here, speaking for the Company, that in providing the necessary funds for this undertaking we have not regarded it as in any sense a philanthropic measure, but rather as an investment in a wise business proposition, which we believe will prove highly profitable. The returns, of course, will not be in the form of dividends on Edison Club stock—our dividends will be intangible but none the less valuable. Besides, we believe that in a broad sense it is a duty we owe to the city in which our largest works are located, and to the electrical industry at large, to assist in providing the most favorable environment for young electrical engineers upon whom depends the future engineering development of our industry.

This place will become the center of scientific and electrical engineering work in this city, and future leaders in the world's progress electrical will here make their first appearance. It is therefore fitting that this building should be placed in the care of the Edison Club, as upon you young men is the responsibility and privilege of carrying forward the work but barely started by your elders. I am an optimist; all scientific men and engineers are optimists. We do not believe that the day of opportunity is passed, certainly not for those who are fortunate enough to be engaged in scientific and engineering work. Of course, one must be alive and well, and therefore play as well as work. There is an old saying, "Opportunity has long legs and quick motion, therefore embrace your opportunities." It is hoped and expected that this building, properly used, will help you to make the most of your opportunities. Therefore I suggest to the new student and the old engineer, join the Edison Club and the A.I.E.E. Their members will be the leaders in the new competition in co-operation, and will cultivate that thirst for knowledge that does not permit the process of education to stop with the college commencement.

I think I can say without exaggeration that this is a rather important historical occasion. I notice that the lecturer of the evening has chosen for his subject, "The Future of Electrical Engineering."* I regard the choice of subject as significant and appropriate. I believe that in the future we shall hear in this hall the announcement of many fulfilments of the prophesies of this evening. History will be made in this room.

* This address, by Dr. C. P. Steinmetz, will be published in full in an early issue of the Journal of the Franklin Institute. The gist of his remarks will be found in the editorial pages of this issue of the Review.

FROM THE CONSULTING ENGINEERING DEPARTMENT OF THE GENERAL ELECTRIC COMPANY

WHY POWER LIMITING REACTANCES ARE BUILT WITHOUT IRON

Power limiting reactances are used in high power systems in the generator leads, in the busbars, and sometimes in the transformer leads and the feeders, to limit the current which in case of a short circuit may flow, to such values as are not destructive to the apparatus and can safely be controlled by circuit breakers. They are usually rated in per cent. That is, a 5 per cent power limiting (or current limiting, as often expressed) reactance in a reactance, which at its normal rating—as determined by heating, etc.—absorbs a voltage equal to 5 per cent of the circuit voltage. If then a short circuit occurs just beyond the reactance, and the system is so large as to maintain full voltage at the generator side of the reactance, the reactance has to absorb the full circuit voltage, that is, with a 5 per cent reactance, 20 times its rated voltage. The magnetic flux in the reactance—which is proportional to its voltage—then would be 20 times its rated value. If the magnetic circuit of the reactance does not saturate at short circuit, this would give 20 times normal current, or in other words, a 5 per cent power limiting reactance would limit the current to 20 times its normal value. If, however, the magnetic circuit of the reactance would saturate, twenty times normal flux could not be produced, or be produced by currents far out of proportion, that is, at short circuit the 5 per cent reactance would allow many times more than 20 times normal current to flow, or in other words, just when the power limiting reactance is counted upon to protect the system by limiting the current, it fails by saturation.

It thus follows that power limiting reactances must be designed so as not to saturate at short circuit, when full circuit voltage comes across the reactance. A 5 per cent reactance thus must not reach saturation at 20 times its normal flux; a 4 per cent reactance not at 25 times, a 10 per cent reactance not at 10 times normal flux.

If then iron were used in the power limiting reactance, assuming about 120,000 lines of magnetic force per square inch as saturation value, the normal magnetic density in a 5 per cent reactance would have to be below 6000 lines per square inch; in a 4 per cent reactance below 5000 lines per square inch, etc. But with the considerable number of turns of high current, used in such reactances, densities of 4000 to 6000 are easily reached in air, and as the use of an iron core would not permit a material increase of magnetic density—due to saturation at short circuit, as explained above—and would greatly increase the cost by the excessive size of iron core required, and would also increase the losses by the core loss, the use of iron is uneconomical in power limiting reactances, if they are properly designed, that is, designed so as not to fall off in reactance under short circuit, and for this reason iron cores are not used.

There is, however, no theoretical objection to the use of iron, and if a power limiting reactance of for instance 25 per cent were required—limiting the short circuit current and short circuit flux to four times normal—a magnetic density of one-quarter saturation, or about 25,000 to 30,000 lines of force per square inch, would be permissible, and in this case the design may show the use of an iron core economical, especially with low power reactances, as may be used to control small branch lines in transmission systems. However, with the usual power limiting reactance of 3 to 10 per cent, the maximum permissible magnetic density in iron is so low as to forbid its use.

THE LINE INSULATOR

The line insulator is an important factor in determining the success or failure of a transmission scheme; and yet the requirements in present insulator specifications in no way provide for uniform porcelain. Destructive puncture tests are generally made on a few selected units which may indicate a very good insulator, but on account of the great lack of uniformity in most porcelain these tests do not indicate the performance of the bulk of the insulators which are manufactured later and put on the line. Uniformity of the porcelain is one of the most desirable features of a line insulator. Engineers should be made to realize that it is better to pay more at the start for a good insulator than to pay many folds later by the loss of prestige due to poor service, to damaged apparatus, to say nothing of replacement of poor insulators.

An important step in the right direction was made at the recent annual convention of the A.I.E.E. at Cooperstown when, under the High-Tension Transmission Committee, new specifications for insulators were submitted by F. W. Peek, Jr., J. A. Sanford, Jr., and Percy H. Thomas. The first of these was written from the engineering and scientific standpoint, but its recommendations are limited by present commercial possibilities in material, design, etc. The second was from the insulator manufacturer's standpoint; while the third was written as a combination of the first two. A very extensive and interesting discussion took place. The importance of such papers is not so much whether standard specifications are adopted or not, but that they bring facts before engineers, and bring out in discussions the result of experience.

C. P. Steinmetz.

QUESTION AND ANSWER SECTION

The Q. and A. Section has been started with the sole object of increasing the practical usefulness of the REVIEW; and in order that it may be made of real value, we invite correspondence from any of our readers who are looking for information on any technical matter in the field covered by this magazine and which they think we can furnish.

Where possible the answers to such inquiries will be the work of this office; where desirable we shall obtain our authority from that engineering or commercial person in the General Electric Company's organization best fitted for handling the particular subject. We hope our readers will not hesitate to avail themselves of the expert engineering opinion which should be made available through this section of the REVIEW. Information on matters of general importance and interest will be published here; questions of interest solely to the querist will be handled by mail.

Sketches should accompany questions in all cases where this is necessary to give us complete and accurate information on the point at issue. Scale drafts will be made up here from correspondent's rough pencil sketches. Questions must be accompanied with the name and address of the sender, although these will not necessarily be for publication, and should be addressed to the Editor, Q. and A. Section, GENERAL ELECTRIC REVIEW, Schenectady, N. Y.

PARALLELING TRANSFORMERS WITH A SPECIAL CONNECTION

(61) Would you recommend that a group of three single-phase transformers, the high-tension sides of which are connected in Y, be run in parallel with a group of three single phase transformers, the high sides of which are connected in delta? The low-tension windings in each bank or group are connected in delta.

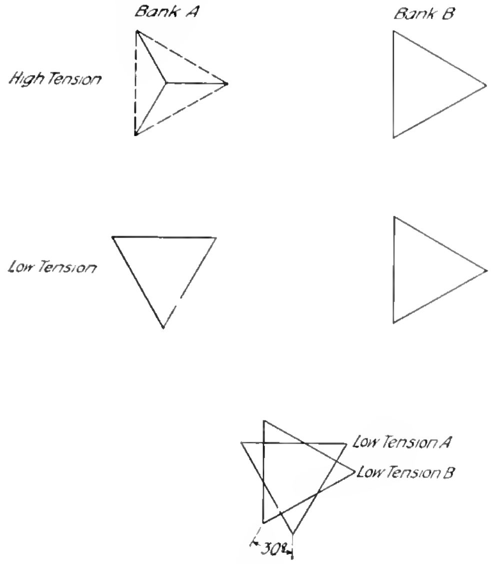


Fig. 1

Such operation is not possible, as will be readily seen from Fig. 1. The low-tension voltages of the two banks are displaced 30 deg. from each other; and, if the transformers are connected in multiple, excessive exchange current will flow to bring the voltages in phase.

W.W.L.

OZONE CONCENTRATION

(62) Is it possible to definitely determine the proper average limit of concentration of ozone in a room; and to develop some test more simple than the volumetric analysis test of potassium iodide, yet sensitive enough to accurately indicate, when in the hands of a layman, when this limit is reached?

Various test-papers have been proposed for determining the amount of ozone in a given sample of air, but these are more or less inaccurate and insensitive, and are subject to error through a variety of uncontrollable causes, such as temperature, humidity, and the presence of foreign substances in the air. A fairly comprehensive discussion of these reagent papers will be found in the book on the subject by Alfred I. Cohn, entitled "Indicators and Test Papers," published by John Wiley & Sons, New York, N. Y.

The proper average amount of ozone for any room is determined from the existing conditions by analogy with previously studied cases. No general rule can be given, but different conditions have been classified by ozone engineers according to their experience, and with suitable information a person experienced in the use of ozone for ventilating purposes is able to predict the amount of ozone for a given case within a reasonable limit of error.

M.W.F.

CORONA

(63) What is the effect of corona on insulation?

The action of corona on insulation is manifested chemically, mechanically, or by heat. The action is different with different insulations. If the corona discharge is only moderate, it is accompanied by the production of ozone from the surrounding air, which may cause chemical action on the insulation by oxidation; if unusually severe, it may cause a chemical combination of the oxygen, nitrogen, and water vapor of the air, forming nitric acid. The production of this latter may in some insulations prove injurious. The mechanical action seems to be of a bombarding nature. In several instances, old style insulation which has been subjected to a severe corona discharge for years has been found to be drilled with minute holes. These holes start on the surface exposed to the air and extend inward through one or more layers of insulation, according to the severity of the discharge and the length of time of its duration. This action is probably helped along by minute intensely heated spots when the "corona needles" start. There may also be trouble due to corona loss heating the whole insulation.

High voltage generators and motors have, for a long time, however, been designed in such a manner that corona will not take place; consequently all the effects mentioned are absent.

F.W.P.

25-CYCLE TRANSFORMERS ON 60 CYCLES

(64) We have a number of 25-cycle transformers ranging from 5 kw. to 500 kw. The smaller sizes are used for distribution purposes and have a ratio of 2200/110 volts, while the larger ones are designed for transmission work and have a ratio of 22,000/2200 volts. If these transformers were to be used on a 60-cycle system, please state: (a) The per cent increase or decrease in their capacity, hysteresis loss, eddy current loss, reactance, and magnetic leakage. (b) How the regulation would be affected. (c) Whether there would be any other change in their performance.

In the following answer it is assumed that the voltage, load, etc., remain the same and that only the frequency is changed, the change being from 25 to 60 cycles.

(a) The hysteresis loss varies as the frequency and the 1.6th power of the flux density; the eddy current loss varies as the square of the frequency and the square of the density. The hysteresis loss forms about 4/5 of the total core loss and the eddy current loss the remaining 1/5. The density varies inversely as the frequency. The joint effect of the increase in frequency and decrease in density is to reduce the 60-cycle core loss to about 60 per cent of the 25-cycle core loss. This will increase the efficiency of the transformer by an amount depending upon the size of the machine and the percentage of the core loss to the total loss. The reactance drop depends on the magnetic leakage and varies directly as the frequency, and is therefore increased 2.4 times by the increase in frequency from 25 to 60 cycles.

(b) The regulation is given by the formula:

$$\text{Per cent reg.} = \text{per cent } IR + \frac{(\text{per cent } IX)^2}{200}$$

As the IX drop has been increased 2.4 times by the increase of frequency, the last term of the above formula has been increased $(2.4)^2$ times, or 5.75 times, and the regulation has been increased to that same extent.

(c) The increase in reactance will decrease the short-circuit current, which varies inversely as the reactance, and this will in turn decrease the mechanical stress due to the magnetic field produced by the short-circuit current, which force varies as the square of the current; i.e., the reactance will be $\frac{1}{2.4}$ times as great, and the short-circuit mechanical stress $\frac{1}{5.75}$ times as great at 60 cycles as at 25 cycles.

As the transformers under discussion are comparatively small and no doubt have large factors of safety in this respect, this item of decrease in mechanical stress will have probably very little weight.

Owing to the decrease in density the exciting current will be greatly decreased, the amount depending upon the particular normal density of the transformer. At the usual densities of operation the 60-cycle exciting current will be probably 20 or 25 per cent of the 25-cycle exciting current.

As the heating of the transformer has been reduced owing to the decrease in core loss, the load may be increased, but by just how much can only be determined by the examination of design or by test as the safe copper density now becomes the limiting feature.

To sum up, the 25-cycle transformer will operate at 60 cycles, carrying rated load, with decreased core loss, increased efficiency, less mechanical stress due to short-circuit current, less exciting current, but with increased reactance drop and increased regulation. The resistance would be decreased to a still greater extent by the use of three-conductor cables. W.W.L.

MULTIPLE TRANSMISSION LINES

(65) In transmitting 1600 kw. at 2300 volts, three-phase, 25 cycle, a distance of one mile, would it not be more economical to use three small lines or circuits of about No. 0000 than one large circuit of 750,000 cir. mil cable? Wires in both cases to be placed 12 in. apart △ shape.

What would be the line drop in the above case when using a 750,000 cir. mil cable and a 95 per cent power-factor?

The question as to the advisability of using three circuits or one depends very largely on the local conditions.

Three circuits require three times as many insulators as one, and therefore cause a greater labor cost in erection. The copper will cost slightly more when obtained in the smaller sizes of cable. Considering line cost alone it would be most economical to use the 750,000 cir. mil cable, with a line drop of 90 volts, or 3.9 per cent drop.

If the load is such that continuity of service is an important factor, two or three lines should be used. By the use of two or more circuits the reactance drop is considerably decreased, and would still be further lessened if a three-conductor cable were used for each circuit. The resistance drop, remaining the same for the same cross-section of copper, does not appear an important factor in this case.

With a low power-factor and 60 cycles there would be a greater advantage in using a number of small conductors from the standpoint of good regulation. F.W.P.

ELECTRIC FURNACE MELTING OF NON-FERROUS METALS

(66) Please furnish references from which information may be obtained regarding the most suitable currents and voltages for melting non-ferrous metals in an electric furnace.

The following is a list of the most recent references on the melting of non-ferrous metals in the electric furnace. With the exception of the article by R. S. Wile, all discuss both cost and power requirements.

"Melting Non-ferrous Metals in an Electric Furnace (copper, monel metal, bronze, etc., on a commercial scale)," Weeks, C. A. Met. Chem. Eng. vol. 9, pp. 383–5, (1911).

"Electric Furnace for Brass Melting," Clamer, G. H.; Hering, Dr. Carl; and also

"Electric Melting of Copper and Brass," Hansen, C. A., American Institute of Metals, Year Book, 1912.

Abstracts, Met. Chem. Eng. vol. 10, p. 702, (1912).

"Electric Melting of Gold Precipitate," Conklin, H. R., Eng. Min. J. June, 1912.

"Electric Furnace for Treatment of Tin Dross, Concentrates, etc. (Tilting Furnace)." Wile, R. S., Met. Chem. Eng. vol. 10, pp. 495–6, (1912).

H.R.H.

BUSBAR MOUNTING

(67) Up to what busbar capacity is it considered good practice to have 4500 or 6600-volt bare copper busbars mounted on open pipe framework construction, and at what capacity is it advisable to have the busses and switch construction arranged in fireproof compartments of either brick or concrete?

It is generally the practice to furnish copper busbars mounted on open pipe framework for 4500 or 6600 volts, where the oil switches used are of the so-called K type; where large capacity oil switches (so called H type) are used, the busses should be separated by means of fireproof compartments. The same practice is to be recommended where the oil switches are furnished in single-pole unit compartments even if they are of the K type. In the latter case, it is largely a question of expense and as to how far the purchaser wishes to go in safeguarding his station against exceptionally dangerous trouble, such as short-circuits of busses, etc. D.B.

D-C. DYNAMIC BRAKING OF INDUCTION MOTORS

(68) Has there been any scheme developed for the dynamic braking of squirrel-cage induction motors by applying direct current to the stator?

We know of no installation which makes practical use of applying direct current to the primary of a squirrel-cage induction motor for the purpose of dynamic braking. In an induction motor having a low-resistance rotor, the braking action which could be obtained by the use of direct current in the stator would not be very effective, because the retarding action is as much dependent on a high resistance in the rotor winding as it is on the magnetizing action of the direct current in the stator. The characteristics exhibited by a squirrel-cage motor having a low-resistance rotor, in stopping from full speed under the action of direct current in the stator, are as follows:

(1) First a very slight torque, probably about 10 per cent of the full-load torque of the motor, would be produced.

(2) This torque would gradually increase as the motor slows down, and at about 1/4 speed would rise to about 150 or 200 per cent of the full-load torque of the motor.

(3) After this it would die down to zero as the motor came to a standstill.

It is thus easy to see that such braking action would not be very serviceable in the majority of applications.

A far simpler method of braking a motor, if space permitted, would be to use a solenoid brake mounted on the motor shaft, which would set and bring the motor to standstill in case the power supply fails or is cut off. R.H.McL.

THREE-WIRE LOAD CALCULATION

(69) Please give a method of calculating the total load on a three-wire generator when the loads each side of the neutral are unequal.

The simplest method of obtaining the result is to determine the sum of the currents flowing through the loads from the positive to neutral line and from the neutral to negative line (in obtaining this amount it will be found that a diagram of connections upon which arrows have been placed illustrating the direction of current flow will be of great assistance), and multiply this by the voltage from line to neutral, which result is the watt-load on the generator. If the equivalent current at the over-all or brush-to-brush voltage of the generator is desired, it may easily be obtained by dividing the watt-load by this over-all voltage.

Example 1. Current in positive wire 400 amp., in neutral 200 amp., and in negative 200 amp. The generator is a 250:125/125 volt machine.

$$(400+200)\times 125 = 75000 \text{ watts or } 75 \text{ kw.}$$

$$\frac{75000}{250} = 300 \text{ equivalent amp.}$$

Example 2. Current in positive wire 300 amp., in neutral 300 amp., and in negative 600 amp. The generator is a 250:125/125 volt machine.

$$(300+600)\times 125 = 112{,}500 \text{ watts or } 112.5 \text{ kw.}$$

$$\frac{112{,}500}{250} = 450 \text{ equivalent amp.}$$

E.C.S.

CHANGING A TRANSFORMER RATIO

(70) On account of a change in local conditions it is desired to change the windings of a 15 kv-a. single-phase transformer, having no taps, from 4000/240 volts to 4000/220 volts. Can not a lead be brought out from the 220-volt point of the winding, and if so how can this point be found?

Not knowing how necessary may be the requirements demanding the change in ratio, attention may be drawn to the fact that perhaps any change at all may be avoided. If the load be one of lamps, new lamps of a higher voltage may be purchased; or if it be a power load it would be quite safe to say that the apparatus would operate sufficiently well, under this slight increase of voltage, as to not make the change worth while.

The changing of the voltage ratio of a transformer by a change in the included turns is out of the question unless done in the factory. The coils of many transformers are not removable without a complete unassembly, and are only accessible over a small portion of their surface. The difficulties presented by the re-insulating of the winding after the tap is located and inserted would be prohibitive to any but a skilled transformer workman.

If the conditions present are such that it would be more preferable to use a voltage practically equal to that desired, although it vary somewhat with the load carried, than the constant high voltage as at present, the following scheme may be applied. Insert a suitable reactance coil in series with either the high or low-tension sides of the transformer. This coil may be so proportioned that it will neutralize that voltage on the low-tension side which is in excess of 220. The size wire to be used in winding the coil should be sufficiently large to carry the full-load current of the winding to which it is connected. If placed in series with the high-tension the voltage drop across it, while carrying full-load current, should be 1600, and, if in series with the low-tension, 96. The method of calculating the necessary reactance coil voltage is illustrated in

Fig. 1. The figures within parenthesis pertain to the use of a reactance coil in the high-tension side and those without to that of one in the low-tension side. The secondary voltage, when such a reactance coil is used, will vary approximately from 240 to 220 with a change from no load to full load.

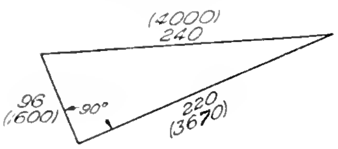


Fig. 1

It would be very advisable, however, in the preparation of a suitable reactance coil, to consult the manufacturers who design and build such apparatus. E.C.S.

ELECTRIC FURNACE

(71) Would it be possible and practical to construct an electric furnace to maintain a temperature of 1000 deg. F. with a 10-inch diameter, 10 foot long wrought iron pipe, using this pipe as the secondary of a transformer whose primary is wound upon the outside? It will be possible to pack the outside of the pipe with heat insulating materials, but the ends must be kept open as a conveyor is to pass through them. If the scheme is practical how can the number of turns in the primary and the required power be calculated?

The use of the pipe mentioned seems to be a good one, but the proposed method of heating it is hardly practical. There is no question, however, but that it may be successfully heated by means of a high resistance wire or ribbon wound around it. A lagging of heat insulating material should be used and will reduce the radiation to a very small amount. It will be impossible, however, to estimate even approximately the amount of power which will be required on account of the lack of any data given as to the kind of material heated in the conveyor and as to its amount per unit of time. The most satisfactory method of arriving at the amount necessary would be to make a rough experiment, using a winding of ordinary iron wire. This wire could not, however, be used permanently, as it is only short lived. Its later replacement by one of the permanent resistance materials on the market (dimensioned so as to absorb the same amount of power as determined necessary by experiment) would produce a furnace which would seem to fulfill the desired conditions. E.F.C.

INDUCTION MOTOR STARTING

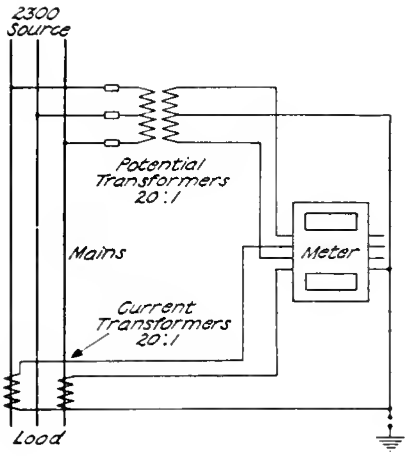
(72) Trouble is experienced in the starting of a 60-cycle induction motor when connected to a transmission line which is otherwise under no-load and which possesses a power-factor of about 80 per cent leading. What is the cause of this irregularity?

The source of the most common difficulty experienced in starting induction motors, where the starting load is not excessive, is the drop of line voltage. It is impossible to predict the amount of this drop without being intimately acquainted with the transmission system, generating system, and the characteristics of the motor itself; but it might be stated that a greater drop would be experienced where the transmission system was under no other load, at the time of starting the motor, than it would if the system were operating under other load. H.M.

TRANSFORMER AND METER PROTECTION

(73) Having a meter connected to a 2300-volt, three-phase line by current and potential transformers according to the accompanying wiring diagram, please state what voltage lightning arresters would be most effective in protecting the measuring apparatus.

Ordinarily a three-phase, 2300-volt electrolytic arrester or a graded shunt multigap arrester on the 2300-volt line at the entrance to the station is sufficient to protect a potential transformer and the meters connected to it. Occasionally, due to



some arrangements of wiring or other local conditions, this is not sufficient and 110-volt single gap arresters are required between the two outside wires on the low-tension side of the potential transformer and ground. The gap in the common ground connection of the meter wiring is contrary to good practice. This point should be dead grounded. J.A.J.

VARNISHED CAMBRIC CABLE IN DUCTS

(74) Are there any objections to the use of 13,200-volt, flame-proof, varnished cambric cable in dry fiber ducts, the ducts being buried in concrete walls or floors?

It is not considered advisable to install a 13,200 volt cable having a flame-proof covering in ducts. If the ducts are drained to a pit so that no water can accumulate in them, then cables with varnished cambric insulation and double weather-proof braid should be used. If it is certain that no water will ever get into the ducts and that the fiber conduits will be practically dry at all times, the flame-proof covering might be used, but it is not nearly as safe. D.B.