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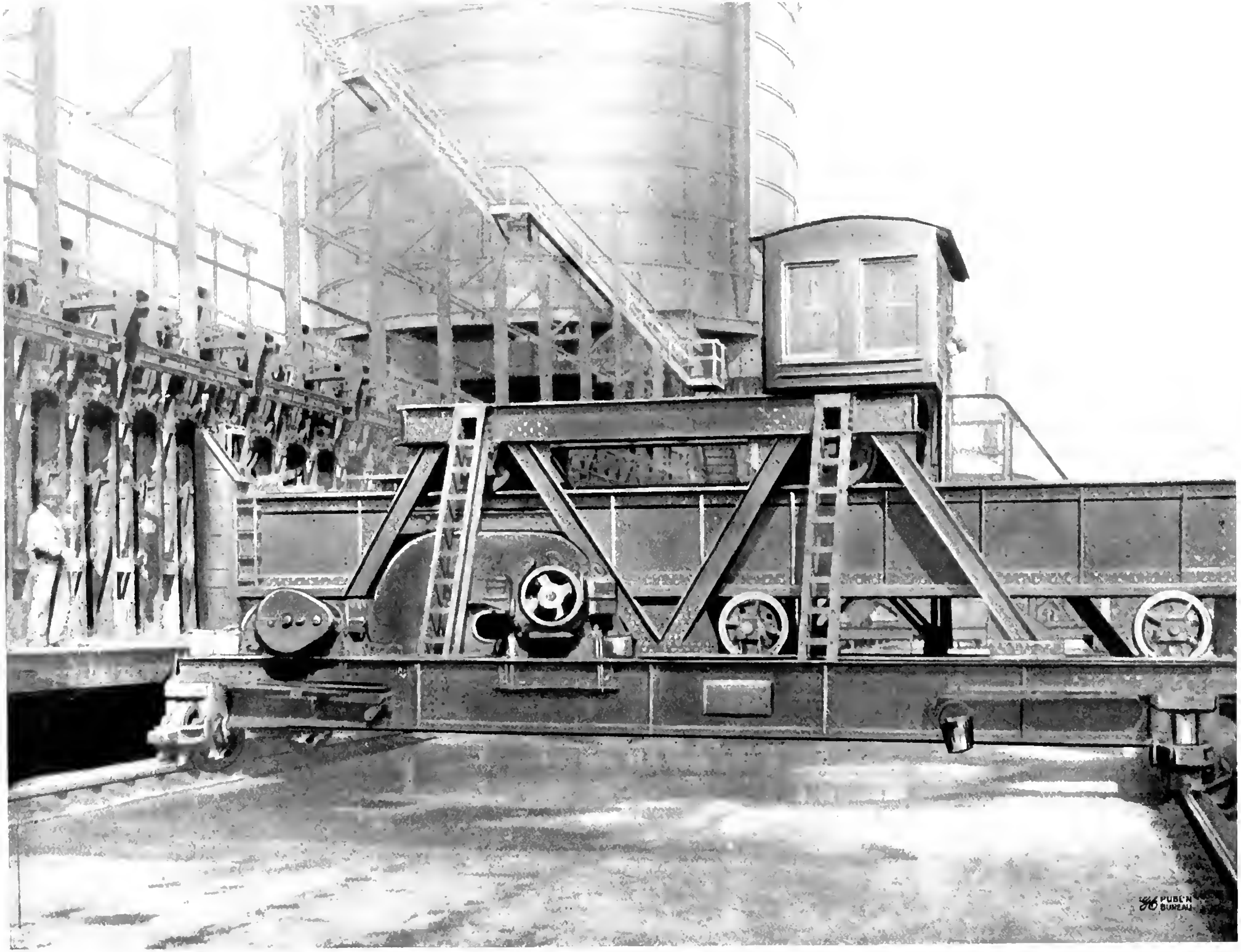

Motor Operated Travelling Coke Pusher at the Plant of the Indiana Steel Company, Gary, Indiana.
(See Page 30)

GENERAL ELECTRIC REVIEW

THE GROUND CONNECTION IN LIGHTNING PROTECTIVE SYSTEMS

Since the early days of commercial telegraphy the question of what constitutes a good ground connection has been a live one; with the most primitive forms of lightning conductors, the earth connection was perhaps the most important part of the outfit; later, in different systems of generating electrical energy, such as direct current 3-wire distribution, alternating current two-phase 3-wire and 4-wire, and three-phase with grounded neutral, an efficient connection with earth has been necessary; and yet it cannot be said that a great deal has been known upon the subject, or that the available data have been collected as thoroughly, and made use of as widely, as one would expect.

Of recent years, since reliable lightning arresting devices have been used for the protection of electrical apparatus from atmospheric lightning and from internal surges, the subject has received more thorough attention from various investigators, the results of which have been published (usually in the proceedings of the engineering societies) from time to time. In the early days of telegraphy, it was the question of earth resistance alone which received attention. By now, however, other properties of the earth connection, of no importance then, have been found to have a bearing on the matter, such as its inductance, and a property which may be called the electrostatic capacity factor or equalizing connection; and it must be borne in mind that in arrester practice a low value of earth resistance is not necessarily the most important factor to be considered.

We are commencing in this issue a paper by Professor E. E. F. Creighton, which will treat the subject of ground connections, as specially applicable to arrester systems, very thoroughly. From the results of tests which have been carried out, in determining more of the nature of the three factors mentioned above, a number of general laws concerning earthing have been established. These laws are concerned with the variation in resistance of the earth, due to depth of pipe, to the specific resistance of the earth, to pipe earths in multiple, to variation in distance between pipe earths, and to change in the diameter of the pipe; with the potential distribution around a pipe earth; the ampere-hour capacity of a pipe earth; the inductance of the earth leads; the electrostatic capacity factor; the algebraic law of separating the resistance of several earths; and methods of measuring resistance of earths. Curves are given showing the results of tests upon which these laws are based. It may be of interest to note that careful tests taken on the earth connection during the past year confirm the results previously published by Prof. Creighton elsewhere (see paper presented before A. I. E. E., June, 1908).

By way of accompaniment to the rapidity with which arresting apparatus and arcing grounding suppressors have been investigated and improved, many have striven after a great elaboration in the matter of the earth connection, neglecting the fact that often elaboration *versus* simplicity is not the same as sufficiency *versus* insufficiency. The result of this has been that various forms of "fancy" grounds have been devised which, while sometimes efficient, have always been excessively wasteful. A simple pipe earth, either singly or in multiple, makes as good a ground connection for arresters as can be required. Detailed instructions are given in this article for making an efficient pipe earth, from which it will be seen that the proceeding is of the simplest.

This paper will be continued, and probably completed, in the February issue of the REVIEW; and will constitute the first of a series of articles which we shall hope to publish in the course of the year, dealing comprehensively with the subject of protection from lightning.

MEASURING THE VELOCITY OF A STREAM OF WATER

Under the heading of "The Diary of a Test Man," we are publishing this month an interesting account of some hydraulic tests which were carried out at the Holtwood Power Station of the Pennsylvania Water & Power Company, to determine the efficiency of one of the 13,500 h.p. water turbines installed in that station. From the electrical measurements the output of the waterwheel end of the turbine-driven set could be calculated; and in order to find the power input to the turbine, it was necessary to know the quantity of water supplied to the turbine through its approaches in a given time.

As a general rule, the most convenient apparatus for measuring the quantity of water in the case of small streams is by means of a weir, placed either above the wheel or in the tail-race. This is particularly the case where systematically repeated readings will be required from time to time. Quantity of water flowing in a given time may also be determined from a knowledge of the velocity of the stream flowing through a known cross-section.

Students of hydraulics will be familiar with various arrangements which may be used for finding the velocity of a stream of water. The use of "floats," either surface or submerged, is a simple method of obtaining the velocity of a natural stream. A current meter is often employed. Several types of current meter are available, but the instrument usually takes the form of an arrangement of vanes, either cup-shaped or helical, which may be lowered into the water. During one half of a revolution the current acts upon the convex side of the vane, and during the other half upon the concave side; and the axis to which the vanes are attached rotates at a speed depending upon the velocity of the stream. An electric make-and-break device may be connected by twin conductors to an observation point; and by this means the number of revolutions of the axis in a given time may be registered, and the velocity determined from calibration charts. The indicating mechanism in such meters must necessarily introduce a complication which is absent in some of the other methods. The Venturi meter again is sometimes used. This apparatus depends on the law, established by Venturi, an Italian investigator, that water, moving in a pipe, may pass from a condition of high pressure and low velocity to a condition of low pressure and high velocity, and *vice versa*, without great loss of energy. In other words, pressure and velocity are mutually convertible. The conversion of pressure and velocity is brought about by a change in diameter of the pipe through which the water flows, pressure readings being taken at two points in the pipe at different diameters. The principle of the Venturi meter has by now received a wide application in large hydro-electric developments as well as in city water-supply systems; and in its commercial forms the meter is arranged to register quantity direct. The use of the pitot tube furnishes yet another means. This method depends upon the principle that if two tubes, both having a right angled bend at the lower end, are placed side by side in a stream, one opening up-stream, and the other opening at right angles to the current or down-stream, the water will rise to a different height in the two tubes, which difference will bear a definite relation to the velocity of the stream. If suitable arrangements are made for reading this difference accurately, and for calibrating the tubes by comparison with a reliable standard, the method is well adapted to uses requiring close accuracy.

All of the foregoing methods may be found in use at various water development works, or at waterwheel testing plants at the present time. The pitot tube method was the one adopted at the Holtwood station; and a brief description of its principle, and the application of the principle in this case, is found in the article to which we have referred. When the method is applied to cases such as the present one, in which the velocity of the incoming water is to be measured immediately in front of the head-gate to the turbine, a more or less elaborate arrangement is required, for mounting the tubes in the stream, rigidly but without materially obstructing the flow, and for transferring these indications to a point where they may be conveniently read by the testing crew. The details of the Holtwood plan will probably be found to be as ingenious as any which have yet been engineered.

Our series of articles on alternating current apparatus troubles will be resumed in the February issue of the Review. Rotary converters will be the subject for treatment.

ELECTRICAL DISTURBANCES AND THE NATURE OF ELECTRICAL ENERGY*

By Charles P. Steinmetz

The distinction between electrical surges or waves of different formation are first outlined and the manner in which such surges may affect the electric circuit illustrated by analogies between the action of electrical waves and the action of waves of the ocean. Light, heat, Hertzian waves and the fields of alternating current systems are shown to be the same phenomenon, differing one from the other only in frequency of vibration. Speculation is made as to what the electric wave is, leading to the contradictory deductions that for certain reasons the luminiferous ether must be considered as a gas of infinitely low density, and for certain others as a solid. The ionic theory is next discussed. It is shown that attempts to prove the correctness of this theory lead to inconsistencies, and in certain cases to contradiction of some recognized law of nature. The address is concluded with the statement that the same thing is true of all theories, which does not mean that these theories are fundamentally wrong, but simply that our present formulations of them are far from final correctness and represent only crude conceptions of the nature of things.—Editor.

To all of us who are interested in the use of electric energy the nature and characteristics of electric energy are of importance; as on their understanding depends our success in the economic use of this energy, and our ability of guarding against the difficulties, troubles and dangers which it may threaten when out of control.

The uses of electric energy are familiar to all of you, and form the subject of numerous papers; the study of the troubles and dangers is in the hands of the Committee on High Potential Disturbances, and therefore only a general discussion appears appropriate here.

Electric energy is industrially used as direct current and as alternating current, that is, as steady flow and as wave motion, usually of 25 or 60 cycles. Electric disturbances are of various character, and, where they are periodic or wave motions, are often of very high frequencies.

It can not well be doubted that electric disturbances in our systems are increasing in number. The reason therefore is found in the increasing size and energy of modern electric systems. Just as in a pail of water even a gale will not cause an appreciable disturbance, or, as a small pond is usually quiet while the ocean is never at rest, but continually traversed by undulations from small ripples to big waves, so in a small isolated plant high voltage disturbances are practically unknown; are rare in smaller central stations; while in the huge modern systems waves continuously traverse the circuits, from minute high frequency ripples of negligible energy to occasional high power surges of destructive energy.

The nature and form of disturbances met in electric systems are as variegated as those of any other form of energy. Single electric waves or impulses may appear as magnetic discharges, analogous to the snap of a whip in acoustics. Oscillations appear as waves which start suddenly and gradually die out, like the waves produced by throwing a stone in water; such are the disturbances caused by switching, synchronizing, etc. Then there are travelling waves, analogous to the ocean waves, of various size and wave length; such for instance as the disturbances caused by arcing grounds, by lightning, etc. Standing waves or stationary oscillations, like those of a tuning fork or violin string, may appear; and occasionally also, the most dangerous of all disturbances, cumulative oscillations, like the resonance of a tuning fork, namely, oscillations which gradually build up, increase in intensity until they finally limit themselves and become stationary, or die down again, or increase until something happens. Such for instance are the hunting of synchronous machines, certain internal transformer oscillations, etc.

Disturbances may affect the system by their quantity, or by their intensity. Electric power can be resolved into the product of two terms, quantity (or current) and intensity (or voltage), just as most other forms of energy are resolved into the product of two terms. Hydraulic energy is quantity of water times head or pressure; heat energy is entropy times temperature, etc. Instances of current disturbances are the momentary short circuit currents of alternators, the very high frequency currents of arcing grounds, etc. Voltage disturbances appear wherever an electric wave breaks at a barrier in a circuit, as at a reactance, or in the end turns of a transformer.

A wave in the water, as a big ocean wave, may cause damage by its bulk, by over-

*An address to the Association of Edison Illuminating Companies at their convention in Spring Lake Beach, N. J. Published in the General Electric Review by special permission.

turning a structure. So a current wave may cause damage by its volume: the momentary short circuit current of an alternator may tear the windings to pieces, twist off the engine shaft, etc. Again, waves in the water too small of themselves to do any harm, may still do harm by the continuous pounding—by undermining and washing away the shore. In such manner a continuous oscillation—a continuous surge—may destroy. Each individual electric impulse would not have sufficient energy to do damage, but when they follow each other successively, in thousands and millions, as coming from an arcing ground, then finally they cause destruction. Again, the damage may be done by the pressure or voltage. Just like an ocean wave, not high enough in itself to overtop the shore, when stopped at the beach, when breaking in the surf, throws the water up to heights that are much greater than the height of the wave, so in the same manner a voltage impulse in an electric distribution system, when it breaks at the entrance to another circuit, at a reactance, or the end connections of the transformer or generator, or the series coil of a potential regulator, may pile up high voltage and rise to values far beyond those which the wave has in its free path in the cable or the line; and there, at the point where it breaks, where the wave is abruptly stopped by reactance, the voltage may rise to destructive values.

Disturbances may enter the electric system from the outside, as by lightning; or they may originate in the system, as by switching, synchronizing, etc.; or again, they may originate in the circuit by outside interference, as by an arcing ground, a spark discharge to an isolated conductor, etc.

A characteristic of most of these disturbances (which usually are comprised by the name of transients) is that they easily pass from circuit to circuit across space by magnetic or static induction, but frequently do not travel along the circuit for any considerable distance. The cause thereof is found in their nature, particularly the frequency.

When an electric current passes through a circuit, there is in the space surrounding the conductor which carries the current an electric field: lines of magnetic force surround the conductor, and lines of electrostatic or dielectric force radiate from the conductor. In a direct current circuit, if the current is continuous, the field is constant; there is a condition of stress in the space surrounding the conductor, which represents stored enegy, magnetic energy and dielectric energy, just as a compressd spring or a moving mass represents stored energy. In an alternating current circuit, the electric field also alternates; that is, with every half wave of current and of voltage, the magnetic and the dielectric field start at the conductor, and run out from the conductor into space with the velocity of light, or 188,000 miles per second. Where this alternating field of the conductor, this electric wave, impinges on another conductor, a voltage and a current are induced therein. The induction is proportional to the intensity of the field (the current and voltage in the conductor which produce the field) and to the frequency. Thus, where the frequency is extremely high, intense induction occurs; that is, considerable energy is transferred from the conductor which produces the electric wave (the primary or sending conductor) to any conductor on which the wave impinges (the secondary or receiving conductor). The result is, that a large part of the energy of the primary conductor passes inductively across space into secondary conductors, and the energy decreases rapidly along the primary conductor. In other words, such a high frequency current does not pass for long distances along a conductor, but rapidly transfers its energy by induction to adjacent conductors. This higher induction, resulting from the higher frequency, is the explanation of the apparent difference in the propagation of high frequency disturbances from the propagation of the low frequency power of our alternating current systems: the higher the frequency, the more preponderant become the inductive effects, which transfer energy from circuit to circuit across space, and therefore the more rapidly the energy decreases and the current dies out along the circuit; that is, the more local is the phenomenon.

The flow of electric power thus comprises phenomena inside of the conductor, viz., the dissipation of electric energy by the resistance of the conductor through its conversion into heat; and phenomena in the space outside of the conductor—the electric field—which, in a continuous current circuit, is a condition of steady magnetic and dielectric stress, and in an alternating current circuit is alternating, that is, an electric wave issuing from the conductor and traveling through space with the velocity of light. In electric power transmission and distribution, the phenomena inside of the conductor are of main importance, and the electric field of the conductor is usually observed only incidentally, when it gives trouble by induction in telephone circuits, or when it reaches such high intensities as to puncture insulation, cause mechanical motion, etc. Inversely, in the use of electric power for wireless telegraphy and telephony, it is only the electric field of the conductor, the electric wave, which is of importance in transmitting the message; the phenomena in the conductor, the current in the sending antenna, are not used.

The electric waves of commercial alternating current circuits usually have the frequencies of 25 and 60 cycles. With a velocity of propagation of 188,000 miles per second, 25 waves per second give a wave length of $\frac{188,000}{25} = 7500$ miles. The distance to which the field of a transmission line extends is, therefore, only an insignificant part of the wave length, and the phase difference within the field of the transmission line thus is inappreciable. With the alternating fields of transmission lines, the effect of the velocity of propagation of the field is therefore negligible and is always neglected. Not so with the alternating field of a wireless telegraph station. Using frequencies from one hundred thousand to a million cycles, the wave length is from $\frac{188,000}{100,000} = 1.8$ miles to $\frac{188,000}{1,000,000} = 0.188$ miles, or about 1000 feet. With a wave length of from 1000 feet to 2 miles, the electric wave extends over hundreds of cycles within the operative radius of a wireless telegraph station, which may be hundreds or even thousands of miles. It is appreciable also in long distance telephone lines. The average frequency of the sound waves—500 cycles—gives a wave length of 376 miles, and a 1000 mile telephone line thus comprises over $2\frac{1}{2}$ waves. That is, at the moment when one half cycle of telephone current arrives in Chicago from New York, five succeeding half waves have already left the New York terminal and are on the way.

Abnormal electric waves in industrial electric power circuits vary from a few cycles per second (in the stationary oscillations of compound electric circuits) up to thousands, hundreds of thousands and millions of cycles per second. At frequencies of many thousand cycles per second, the ordinary measuring instruments, the oscillograph, etc., fail to record the wave; but such very high frequency waves can still be observed and measured through their inductive effects by bringing a conductor near them: the electric wave, impinging on this exploring conductor ("resonator" or "receiving antenna") then induces a current in it, and this is observed by a sufficiently delicate apparatus. In this manner, the telephone disturbances caused by alternating electric railway circuits have been studied by exploring antennae. A very intense wave, at short distance from its origin, may be observed by the spark across a small gap in the exploring antenna. Inversely, at hundreds of miles distance from the wireless sending station, the extremely weak wave is still observed in the receiving antenna by a change of the surface tension of a platinum hair wire dipped into an electrolyte, the change in resistance of which operates a relay. By exploring antenna, electric waves have been studied and observed up to frequencies of hundreds of millions of cycles per second—so-called "Hertzian waves,"—as they occur in industrial circuits between the end cylinders of high voltage multi-gap lightning arresters. There, they are the cause of the high sensitivity of the arrester for high frequency disturbances.*

We have to realize though, that light and radiant heat, the Hertzian waves, the waves of the wireless telegraphy station, the alternating fields of our transmission and distribution circuits, are one and the same phenomenon—electric waves traveling through space with the same velocity (188,000 miles per second) and exhibiting the same characteristics, but differing merely by their frequencies. This does not mean that electricity and light are the same, but that light is an extremely high frequency electric wave, an extremely rapid alternating electric field, while the electric field of the direct current is a steady stress in space.

From our knowledge of the identity of the alternating electric field and the wave of light radiation, we can derive a number of interesting relations between electric phenomena and the phenomena of light. To mention

* Dr. Steinmetz here went on to point out that for frequencies of hundreds of thousands of millions, or millions of millions of cycles per second, the above method of observing the electric waves fails; however, they may be detected by placing a conducting body in their path, when they manifest themselves as "radiant heat." Frequencies of several hundred millions of millions are apparent to the eye as light, while frequencies of ten thousand millions of millions probably constitute the X-rays. For the full discussion of this subject, see Dr. Steinmetz's paper on "Arc Lighting" in the December, 1911, issue of the REVIEW page 568—EDITOR

only one: the secondary current is repelled by the alternating magnetic field which induces it, that is, by the electric wave impinging upon it. This fact is made use of in the constant current transformer for constant current regulation. Applying the same phenomenon to the extremely high frequency light waves, means that the body which intercepts the light wave is repelled by the wave the radiation pressure. Thus at extremely high frequencies the radiation pressure is the analogous phenomenon to the repulsion between primary and secondary circuits in our industrial circuits.

So far we have made no hypothesis, but merely recorded the facts: we can measure the waves and their frequencies, their velocity of propagation and other characteristics, and show their identity. We may now speculate on the nature of the electric wave, on the mechanism of its propagation, etc.; but must then realize, that as soon as we leave the facts and indulge in speculation, we submit to uncertainty, which every hypothesis has, no matter how well founded.

The velocity of propagation of the electric wave is incredible, but it is a finite velocity, and after the electric wave has left the sending antenna, a finite time elapses before it is observed by the receiving antenna. The energy sent out by the oscillator, the electric circuit, the sending antenna, is thus received by the receiving antenna at a later time. The finite speed of propagation of the electric wave implies that the energy during its motion from the starting point to the point observed must reside for some time in intervening space. This means that there must be something in the space which carries the energy; a carrier of the energy of radiation, of light. That carrier we explain by the hypothesis of the luminiferous ether. We assume that the ether permeates all space, is of extreme tenuity and fineness, and is the carrier of the electric wave. The question arises: Is the ether a mere hypothesis, or is it real? Is it a form of matter or not? We may speculate on that, but may come to one conclusion or to the opposite conclusion, depending on our definition of what matter is. After all, it is really not a question of speculation, but a question of definition—of what you define as matter.

We always speak of the phenomena of nature within the conception of energy and of matter. Energy we can perceive by our senses. All we know of nature, all that our senses give us as information, is the effect of energy—energy which reaches our body through the eyes, through the ear, through the sense of touch; and if I were to make a definition of energy it would be "that thing which reacts on, and is perceived by, or can be perceived by, our senses." This is probably the most consistent definition of energy.

Now, what is matter? We cannot see or get any knowledge of matter. If we see a thing, we do not see the matter, but we see the radiating energy from it which comes to us. We feel the mechanical energy of its momentum, but the matter we cannot perceive. All the conception of matter is as the carrier of energy; but if you define matter as the carrier of energy, then the ether which carries radiating energy—carries the energy of the electric wave—is just as much matter as the bullet which carries the mechanical energy that was supplied to it in the gun.

The question then arises: What are the properties of this ether, which is the carrier of the electric wave? The velocity of propagation of a wave in a medium depends on its density and elasticity. The velocity of propagation of the electric wave through the ether is nearly 200,000 miles per second, while the velocity of sound waves through the air is about 1000 feet per second, or the electric wave moves a million times faster than the sound wave. This means that the ether must be of a density inconceivably lower than that of air, though we speak of the air as being of low density, and realize this when trying to navigate it. Furthermore, through the ether all cosmic motion takes place: our earth rushes through it at high velocity, and still there is no appreciable friction. That means that the density of the ether must be so enormously low that even at very high velocity the frictional resistance is inappreciable.

We might then consider the ether as a gas of inconceivably low density.

However, the light wave or electric wave is a transverse vibration; that is, the oscillating ether particles oscillate at right angles to the direction in which the ray of light travels, and therefore in their oscillation come neither nearer nor recede further from the ether particles in front or behind in the direction of the beam of radiation. The oscillation cannot be transferred from ether particle to ether particle in the direction of the beam, by approach or recession of the ether particles, and the transfer of oscillation in the direction of the beam thus can occur only by some thing, some force, which holds the ether particles together, so that a side motion of one causes a corresponding side motion of the particle ahead, without approach. That is, the ether particles can not be free as in a gas, but must be held together with some rigidity. In other words, the existence of transverse vibrations precludes that the ether is a gas, and requires it to be a rigid body, a solid: transverse oscillations can occur only in solids, but are inconceivable in fluids. From the nature of the wave motion of light, we thus would have to conclude that the ether, through which the earth and all bodies rush with high velocity, and without appreciable friction, is a solid. This is physically impossible, and here we find a very common physiological phenomenon: if we attempt to carry any speculation or theory to its final and ultimate conclusion, we reach contradictions. This probably is not the result of the nature of the phenomena, but is in the nature of our minds, which are finite and limited, and therefore fail when attempting to reason into the infinite.

A speculative hypothesis on the nature of electrical phenomena has in the last years been developed in the *ionic theory*. Its starting point is the study of the phenomena of conduction, more particularly the conduction of gases and vapors. In this, we must not merely consider typical cases, but cover the entire field of conductors. On first sight, it appears easy to divide all electric conductors in two classes: metallic conductors or conductors of the first class, in which the resistance slightly increases with increase of temperature, and electrolytic conductors or conductors of the second class, in which the resistance slightly decreases with the temperature. Further investigation shows, however, that there are numerous conductors which do not belong in either class, such as gases, vapors, etc., and that there are all transition stages between the different conductors represented, so that we can not speak of classes any more, but merely of types. Thus there are solid conductors, such as metallic oxides (for instance magnetite) and elements and their alloys, as silicon, etc., which, with a change of temperature, gradually change from metallic conductors of positive temperature coefficient to conductors of metallic character, but with negative temperature coefficient; and which at still other temperatures have such high negative temperature coefficients that the voltage decreases with increase of current, thereby having the same characteristics as are conductors; while at still higher temperatures they become electrolytic conductors. Such "pyroelectrolytic" conductors, to which the Nernst lamp glower belongs, are interesting because of the change of type of their conduction. Equally, if not more interesting, are gases and vapors as conductors, such as the arc, the Geissler tube, the static spark, etc. There seem to exist two classes of gas or vapor conduction: to the one belong the arcs, while to the other belong the Geissler tube and the electrostatic spark. Again, on first sight, it appears difficult to realize that the silent faintly luminous Geissler tube discharge, and the brilliant and noisy electrostatic spark, are one and the same phenomenon. However, the one changes gradually and without dividing line into the other by a change of gas pressure, and the differences, therefore, are due merely to the difference in the gas pressure. Furthermore, the usual noise and brilliancy of the static spark at atmospheric pressure is largely the result of the circuit condition under which it is produced: the passage of the spark closes the circuit and thereby starts a momentary more or less unlimited flow of electric energy. If however, this short circuiting effect of the spark is eliminated, as for instance by interposing between the spark terminals a glass plate which is not punctured, the electrostatic sparks appear as thin colored moderately luminous discharges which pass with moderate noise, the apparent difference from the Geissler discharge being then far less. With decreasing gas pressure, the electrostatic spark becomes less noisy, less brilliant, longer and thicker, and finally changes to the noiseless steady stream of the Geissler discharge, which traverses the space between positive and negative terminal with a glow, its color depending on the nature of the gas: for example, the glow is pink with air, orange-yellow with nitrogen, green with mercury vapor, etc. Going still to higher and higher vacua, the conductor which passes the current between the positive and negative terminal of the vacuum tube finally changes again and becomes a green discharge, which issues from the negative terminal in straight lines, like a beam of light, irrespective of where the positive terminal is located. It may not reach or come anywhere near the positive terminal, and if the positive terminal is located back of the negative terminal, the cathode ray, issuing from the latter, will really proceed away from the positive terminal.

Now this form of electric conduction (and to a considerable extent the conduction of the Geissler tube at lower vacuum) looks very much like electric convection: it looks as if the electric energy were carried across the terminals by luminous material particles, which are shot off, in straight lines, from the negative terminal with great energy, producing luminosity where they strike; and after losing their luminosity have to find their way to the positive terminal. The transfer of electric energy by the cathode ray would then have the same relation to the transfer of electric energy by a copper wire as the transfer of kerosene by a series of tank cars has to the transfer of kerosene by a pipe line.

Assuming then the hypothesis that the cathode ray is the transfer of electric energy by convection by material particles, we will see what conclusions we can derive therefrom.

A material particle containing electric energy is acted upon by an electrostatic field, in a direction depending on the polarity of the electric energy, whether positive or negative against surrounding space. The cathode ray, if consisting of material particles, thus would be deflected by an electrostatic field by an amount depending on the intensity of the field and on the energy, mass and velocity of the material particles. This is the case: the cathode ray is deflected, and measurements of the deflection of this ray by the electrostatic field thus give us a relation between electric energy, mass and velocity of the cathode ray particles. Moving electric energy, whether flowing through a metal conductor or carried by a moving particle, is acted upon by a magnetic field. The cathode ray thus should be deflected by a magnetic field by an amount depending on the electric energy, mass and velocity of the moving cathode particles. This is the case. From these two relations, given by the deflection of the cathode ray by the electrostatic and by the magnetic field respectively, we can calculate the mass and the velocity of the moving cathode ray particles. If the masses of the cathode ray particles, calculated by this assumption, were found to be of the same magnitude as masses of other particles, calculated by other means, such as the chemical atoms or molecules,—if their velocities were comparable with other known velocities,—this would be a strong confirmation of the hypothesis of electric convection by the cathode ray, that is, of the ionic theory. However, this is not the case, and the experiment therefore neither confirms nor contradicts the ionic theory. The calculation shows that, if the conduction of the vacuum tube is by convection of electric energy by moving particles, these particles, called electrons, must be very much smaller than the chemical atoms, or of a magnitude of one thousandth the size of the smallest chemical atom, the hydrogen atom. Their velocity of motion must be inconceivably high—comparable with, though smaller than the velocity of light. They carry electric energy at a negative potential against surrounding space, that is, the electron may be considered as the negative terminator of a line of dielectric force, while the positive end of this line of dielectric force terminates at the positive terminal of the vacuum tube, or at a positive electron, where such exists.

The question then arises: What is the electron? By the derivation of its hypothetical existence, it is a form of matter, since its mass has been calculated by the action of forces on its mechanical momentum. It thus would be a new form of matter, a new chemical atom, a thousand times smaller than the hydrogen atom. It has been called "an atom of electricity." As "electricity" is a vague term without physical meaning, which has loosely been used for "electric quantity" (and even "electric quantity" is a mere mathematical fiction, a component factor of electrical energy) no objection exists to giving the name "electricity" to this new hypothetical form of matter, represented by the electron. It naturally does not explain anything: The electron certainly is not electric quantity, nor is it electric energy, but it may be defined as that form of matter which is the carrier of electric energy. Then, however, the electron in its definition comes rather close to the hypothetical ether atom, which is the carrier of radiant energy, that is, the carrier of the energy of the electric wave in space.

The electron, however, can not be considered as electric energy, nor as representing or carrying a definite amount of electric energy, even when associated with a definite quantity of electricity, no more than the iron atom of a magnetic circuit can be considered as magnetic energy, or as carrier of a definite amount of magnetic energy. Energy comprises the product of quantity and intensity, and the electric energy carried by the electron is its electric quantity times the intensity of its electric field, that is, the potential gradient along the line of dielectric force, which starts at the electron, up to a reference point on this line of dielectric force—the potential of the positive terminal, of surrounding space, of the universe, or anything else. This disposes of the mistaken conception, occasionally expressed, that the electron represents a definite amount of electric energy, and leaves the amount of energy of the electron indefinite, that is, depending on an arbitrarily chosen reference potential, just as it is with any other form of energy: the amount of energy of any carrier of energy, such as a moving body, is always relative, depending on a reference point.

Obviously then, electric energy can not be measured by the number of electrons, and has no direct relation to it, but depends on the electric intensity, or potential difference.

In the last years, the ionic theory has been greatly strengthened by the discovery and investigation of phenomena similar to those of the cathode ray, though more general in nature, in the radiation of so-called "radio-active substances." A number of chemical elements, such as radium, thorium, uranium, etc., continuously send out rays of various kinds. Some of these, the β rays, are identical with the cathode rays of the vacuum tube, or, in other words, are deflected in the same manner by electrostatic and magnetic fields, and are therefore considered as electrons—terminators of the negative end of a line of dielectric force, of a mass about a thousandth that of the hydrogen atom, shot off by the radio-active substance with velocities approaching that of light. Other rays, the α rays, are deflected in an opposite direction by electrostatic and magnetic fields, and thus must be considered as carriers of electric energy of positive potential: positive electrons. Their mass, as calculated in the manner above described, is that of the helium atom (4 times the mass of the hydrogen atom), and they are therefore generally considered as helium atoms carrying electric energy of positive potential. They are shot off with velocities very much lower than the velocities of the negative electron, though still inconceivably high. When carrying electric energy, they contain the same quantity of electricity at positive potential that the negative electrons carry at negative potential, and if the latter are considered as terminators of the negative end of a line of dielectric force, the helium atoms as positive electrons are terminators of the positive end of a line of dielectric force.

A third class of rays, issuing from radio-active substances, are the γ rays. They have the same characteristics as the other rays, except that they are not deflected by electrostatic or magnetic fields. They are identical in their properties with the X-rays, discussed above as electric waves at the extreme end of high frequencies, and are usually considered as X-rays.

Here we come to one of those conclusions which do not appear rational: the α, β and γ rays are very similar in their nature, differing only by the direction and amount of their deflection, and it therefore does not appear reasonable to assume that the γ rays are ether waves, while the α and β rays are projectiles thrown off by the radio-active mass. The attempt of avoiding this dilemma by assuming the γ rays to be projectiles, which carry equal positive and negative electric quantity, and therefore are not deflected, appears forced and merely transfers the difficulty into the relation between X-rays and ultra-violet light. The latter is generally conceded—and corroborated by the phenomena of interference, etc.—to be ether waves. At the extreme ultra-violet, however, the properties begin to shade into those of the X-rays, and it again appears unreasonable to assume such an essential difference between ultra-violet and X-rays, as that the one are ether waves, the other projectiles.

In many instances, when we follow the reasoning of the ionic theory to its conclusion, we meet contradictions. For instance, the calculation of the mass of the electron shows that at very high velocities the mass is not constant, but increases with increasing velocity, becoming infinity; and therefore the kinetic energy of the electron becomes infinite, if its velocity equals the velocity of light. This is impossible, as it contradicts the law of conservation of energy: if we consider two electrons, moving in opposite directions at half the velocity of light, their kinetic energy against surrounding space would be finite. Their relative motion against each other, however, is at the velocity of light, and their kinetic energy against each other would be infinite. Since, however, they were set in motion by finite energy, their relative energy can not be infinite. To overcome this difficulty, a fictitious or apparent mass—the "electromagnetic mass"—has been attributed to the electrons, which is not the mass of mechanics. However, the calculation of mass and velocity of the electrons is based on the kinetic energy of the electron, that is, on its mechanical mass, and not a new kind of mass, which is not a mass in the mechanical sense.

These and other numerous contradictions to which the conception of the ionic theory leads, obviously do not mean that the ionic theory is fundamentally wrong in principle: we have also seen that the wave theory of radiation, in the properties of the luminiferous ether, lead to attributes that are contradictory and thereby impossible. We find the same thing in all theories—the chemical, the thermodynamic, etc. It simply means that our present formulation of the ionic theory, of the electromagnetic wave theory, and of all other theories are very far from final correctness, but are at best only very crude conceptions of the nature of things, which will have to be modified again and again with our increasing knowledge before we can expect to reach a moderately rational conception of nature's laws and phenomena, if we ever arrive there.

THE GROUND CONNECTION IN LIGHTNING PROTECTIVE SYSTEMS

Part I

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Terminology

There is some confusion in the use of the word "grounded." It is not unusual to hear some one speak of a conductor as grounded to a cable sheath when the sheath itself is fairly well insulated from the earth. Again one hears of a phase being grounded to the iron case of a transformer when the case is insulated from the ground by, say, a 30-foot length of dry wooden pole. This length of dry pole would give an insulation of not less than a megohm.

Another important case, and not unusual use of the word "grounded", occurs in relation to lightning arresters. There are many cases where "grounded" must mean a connection to a conductor which is connected to earth in the near vicinity of the arrester. An arrester grounded to a water pipe, however, may not have an electrical contact to the earth within a hundred feet from the arrester. This is usually an inefficient condition of protection. Although the measured ground resistance may be acceptably low, the inductance of such a long path to ground is, usually, objectionable. The important thing to know may be the distance to the actual connection to *terra firma*.

Again, an entirely contrary case may be cited where the point of grounding of an arrester on a semi-insulated conductor is far more important than its connection to earth. This condition exists in the protection of apparatus on electrical railways. It is far more important to ground a line arrester to a rail than it is to connect it to earth. (Using the same language, we have the apparently inconsistent expression "to ground the lightning arrester to earth.")

The general use of the word "ground" is a natural growth, since the lower terminal of an arrester is called the ground terminal irrespective of whether it is to be connected to the earth or not. The loose usage of "grounded" is too well established to allow even a hope of making it definite. The word is convenient but its indefiniteness is to be deplored. Its indefiniteness becomes no insignificant matter when some one, at a distance of several thousand miles, wants advice regarding a failure of protective apparatus, and the deciding feature is the value of resistance in the so-called ground to *terra firma*. This feature of resistance to earth is nearly always important, and the engineers who are called on in such cases must choose between giving "snap" judgment, or causing a long delay in the mails in ascertaining what was meant by "grounded."

In 1907, it was proposed to accept the term "grounded to" as a particular equivalent to "connected to", and retain the older term "earthed" as meaning the actual connections to *terra firma*. After four years no improvement on this suggestion has been noted. To make the language definite and mutually comprehensible we would have such statements as the following: The arrester was grounded on the rail but the rail was not earthed; or, A line wire was grounded on the iron case of a transformer, or metal cross-arm, but these iron parts were not earthed—or were earthed through the high resistance of a wooden pole; and so on. Whether the resistance of the wooden pole should be brought into consideration depends upon circumstances. Disturbances from surges with such a high resistance to ground are exceedingly rare. If the current to ground is sufficient to destroy the wood, it becomes important to take such a connection to earth into account. If the wood remains an insulator, as it will to limited values of electric potential, it makes little difference whether or not the statement is made that metal parts are earthed by the pole.

The obscureness of the term "grounded" comes not altogether from the looseness in its use, but also from the growth of the art. Factors which formerly were not important have been brought into prominence by new conditions to be fulfilled. Formerly, in the olden days of telegraphy, it was the factor of resistance only of an earth connection which was most important. Since then several new conditions have arisen which demand that other factors be given equal consideration. If the earth connection is for the neutral of a large constant potential generator, the conditions to be successfully fulfilled are quite different from those of an earth connection to an overhead grounded wire. Both of these installations have different requirements from those of an earth connection to a lightning arrester in a power house or substation. Still further, as has been mentioned previously, all lightning arrester practice does not require earthing.

Three Elemental Properties of the Earth Connection

This matter can be clarified only by an analysis of the requirements in each case. Before that is done, however, it is useful to note that the three main elements of interest in an earth connection are the resistance, inductance, and a condition which, for want of a better name, may be designated as the electrostatic *capacity factor* or equalizing connection.

In regard to the resistance, its constancy may be affected, either gradually, by droughts, freshets, freezing and such other changes as naturally attend the seasons; or suddenly, by the heat given out by an electric current passing to ground. Furthermore, in regard to the resistance of an earth connection, its laws differ from the ones we are accustomed to use. For example, we are accustomed to think that if the area of cross-section of the conductor is increased, the resistance will be correspondingly decreased. However, doubling the area of a pipe-earth by increasing the diameter does not reduce the resistance to earth by one-half; in fact, by such a change, the resistance to earth may be decreased by only a small percentage. If not in a reduction of resistance, what, then, is gained by an increase in area? This is a question that must be answered. Also how can the earth resistance be reduced? And why not by doubling the area of a single earth-plate?

In regard to the earth connection, there is still another factor of an unusual nature that must be taken into account, *viz.*, its permanency or life. When a conductor is installed overhead, its oxidation is of negligible value even after many years of use and the electro-chemical action is sensibly *nil.* In an earth-connection, however, conduction is naturally by electrolysis, which produces a dissociation of the materials; and, furthermore, the metal parts are subject to the chemical action of the soluble ingredients of the moist earth. Still further there is a great difference in wear on the earth-plate, depending on whether the current is alternating or direct.

In regard to the second main division, *viz.*, the inductance of earth-connections, the three main factors are length of the conductor, loops in the conductor, and multiple conductors.

There is still the third division which has been designated as the electrostatic capacity factor. This will be treated under two sub-heads.

In review, the factors involved are shown in the skeleton outline below:

- Grounds or earths
  - Resistance
    - constancy
      - gradual changes
      - sudden changes
    - permanency of life
      - chemical corrosion
      - electro-chemical corrosion
        - direct current
        - alternating current
  - Inductance
    - length of conductor
    - loops in conductor
    - multiple conductor
  - Electrostatic capacity factor
    - a single transformer case
    - a station
  - Accidental contacts with the earth

It is convenient not to follow the exact order given in the foregoing outline. It seems desirable to state, as briefly and definitely as may be done, the general laws concerning earthing, give instructions for making a pipe-earth, and then later give detailed data and curves on which the laws are based.

Principal Divisions

These laws may be considered under the following eleven divisions:

1. Variation in resistance due to depth of pipe.
2. Variation in resistance due to specific resistance of earth.
3. Variation in resistance due to multiple pipe earths.
4. Variation in resistance between pipe-earth at variable distances apart.
5. Potential distribution around a pipe-earth.
6. Ampere-hour capacity of a pipe-earth.
7. Variation in resistance due to change in diameter of pipe.
8. Minimum inductance of leads to pipe-earth.
9. Electro-static capacity factor, or how to minimize the effect of long leads and high resistance in the earth contacts.
10. Algebraic law of separating the resistance of several earths.
11. Methods of measuring resistances of earths.

Laws of Resistance of Earth Connections

1. Resistance versus depth of pipe. After a depth of several feet in the conducting stratum has been reached, each additional foot decreases the total resistance by 1 ÷ depth in feet. This is explained later.

2. Resistance versus specific resistance of the earth: Salting. Practically all the resistance is in the earth in the immediate vicinity of the pipe. This resistance depends on the specific resistance of the material. The specific resistance depends on the amount of moisture and the electrolyte in the moisture. To get the lowest possible resistance, pour strong salt water around the pipe.

3. Resistance versus multiple pipe-earths. When it is desired to lower the resistance to earth below that of a single pipe-earth, drive others at distances of not less than 6 feet. Then the total conductance is only slightly less than the sum of the individual conductances, and the total resistance is the reciprocal of the total conductance. For condition of uniform soil, the approximate rule may be stated: That two pipe-earths connected together give one-half the resistance of one, ten pipe-earths give one-tenth the resistance of one, and so on.

4. Resistance between pipe-earths at variable distances apart. For distances between pipe-earths up to one foot, the resistance increases rapidly. For every additional foot, the added resistance becomes less and less. At a distance apart of 6 feet, the resistance has reached nearly a constant value. Stated otherwise, the resistance between two pipe-earths at any distance apart greater than 6 feet is nearly equal to the sum of the isolated resistances of each.

5. Potential distribution around a pipe-earth. Since the resistance of a pipe-earth lies mostly in the immediate vicinity of the pipe, the greatest potential drop when the current flows, will also be concentrated there. Heating and drying out will tend to magnify this.

6. Ampere-hour capacity of a pipe-earth. The quantity of electricity that can be passed through a pipe-earth, without materially changing its resistance, increases directly with the wetness of the earth in contact with the iron, and the area of the iron surface exposed to the passage of the current; and decreases as the resistance of the earth in contact with the pipe increases. Certain critical values of current may be carried continuously by a pipe-earth without varying the resistance. The higher the current above this critical value, the more rapid the drying out. To increase the ampere-hour capacity, keep the pipe-earth wet with salt water.

7. Resistance of pipe-earth versus the diameter of the pipe. The resistance of a pipe-earth does not decrease in direct proportion to the increase in diameter of the pipe. Two pipes driven side by side and connected together will have only slightly less resistance to earth than one pipe; it is therefore not surprising that a pipe two inches in diameter has a resistance only about 6 per cent. to 12 per cent. less than a pipe one inch in diameter.

8. Minimum inductance of leads to a pipe-earth. Make the connecting wire as short as possible by taking as direct and straight a path as possible. The objection to sharp corners lies entirely in the fact that it is longer around two sides of a triangle than it is along the hypothenuse. A curved turn is shorter than a right-angled turn but it is not as short as the hypothenuse.

Loops in the lead introduce unnecessary impedance to high frequency impulses.

The inductance of a conductor to high frequency may be said to decrease with the increase of surface. A hollow metal tube conducts as well as a solid wire of the same circumference. A flat strip is an economical way of getting large surface with a small weight of metal. The minimum degree of inductance wtih the minimum weight of metal is obtained by using separated parallel wires. Copper is best on account of its conductivity and durability, but since only the surface layer of metal carries the current, galvanized iron is permissible in some cases.

General Instructions for Making a Single Earth Connection

An earth connection is necessarily made by electrolytic conduction. To obtain a low resistance, it is therefore necessary to have electrolytic moisture in contact with the earth-plate, or, lacking thus a fair degree of conductivity, it is necessary to have a very large area of cross-section for the current. One finds no dry earths that are conductors. If the earth contains no soluble substances which conduct electricity it is necessary to add an electrolyte. The one precaution in choosing an electrolyte is to avoid one which attacks chemically the metal conductor.

It is impossible, as many know, to make a rule or practice to cover all cases; but, the general practice of using pipe-earths can be justified in nearly every case of earth-connection. Coke, so often recommended for earth-connections, is not a good conductor in itself. It attracts and holds moisture, to be sure; but since that moisture usually does not contain an electrolyte in solution, it leaves the earth-connection with high resistance. From every point of view the iron pipe-earth is to be recommended,—on the basis of first cost, ease of inspection, resistance, care, measurements, etc. Iron is the cheapest available metal; its use in water-mains has thoroughly proved its serviceability even when embedded in salty marshes. Salt or washing soda is to be recommended as electrolyte. While washing soda has less chemical effect on iron than salt, the resistance is higher. In the majority of conditions, salt is preferable.

All the fanciful ideas in "grounds" may be classed with the platinum points for lightning rods. They are both miserly ways of burying money.

Just plain pieces of standard one to two-inch pipe, driven as much over six feet as is convenient, are best (see Fig. 1). Solid metal spear-heads on a pipe, and sleeve-joints which make holes larger than the diameter of the pipe, increase the contact resistance enormously. If for any reason they are used, special precaution should be taken to fill up the space between

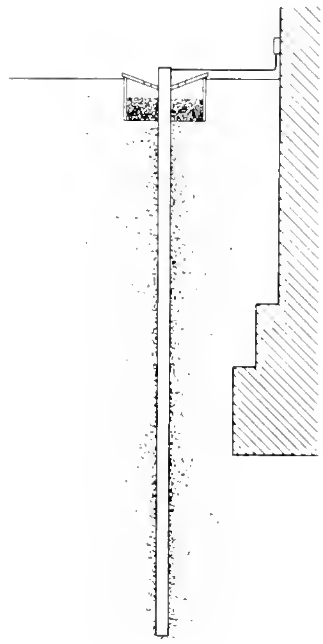

Fig 1. Illustration of a Single Pipe-Earth, containing all the essential features of a good earth connection. To avoid voltaic action the copper connecting wire at the top is not brought to the wall underground through the salt solution

the pipe and the earth by an abundance of salt water. If the pipe drives with too much difficulty a solid crow-bar will usually open up a hole. If there is no stand available for starting a pipe eight feet or more long, a shorter pipe, slightly larger in diameter, may be driven several feet and then withdrawn to make a start for the longer pipe.

A basin should be scooped out of the earth at the surface around the pipe, and salt brine poured in. The amount of salt water needed depends on the local conditions of the soil. Where the resistance of a pipe-earth is less than 100 ohms without salt, a bucket full of brine may suffice; where the pipe-earth does not reach moisture below, several bucketfuls may be necessary. Finally, a few handfuls of crystal salt should be placed around the top of the pipe in the basin. Whether the basin is to be filled with dirt, or made permanent by the use of a tile with a cover, depends upon the importance of the earth connection.

Specific Application of Earths

Earth connections for lightning arresters in electric stations (alternating current.) For the usual conditions. Drive two or three iron pipes into the earth at a point nearest the location of the arrester; then drive other pipes which encircle the station, and connect all of them to a common wire. The minimum distance between pipes should not be less than 6 feet. The resistance to earth decreases in proportion to the number of pipe-earths used. Eight pipe-earths might be considered the minimum number to use on a small station; more are desirable if the soil has a high resistivity. Ground all transformer cases and iron bases of rotary apparatus to the earth-pipes. Also connect the water-pipes to the earth-pipes.

Unusual Conditions. Electric stations on solid rock. If it is a hydraulic power house, make an earth connection by submersion of a metal plate in the water at a convenient point nearest the arrester, and connect this to all the metal grill-work in the fore-bay to get as large a surface exposed to the water as possible. Drive pipe-earths in the nearest soil and connect these to the other grounds.

Earth connections for neutrals of electric systems. The requisites are large plate area exposed to the passage of the current, and a large or continuous supply of salt solution around the earth connections. In cases of accidental grounds, the earth connection is seldom required to carry dynamic current for more than a few seconds. For the safety of the line, relays should be placed to open the circuit within a few seconds, even if the accidental ground is of high resistance. If a number of distributed pipe-earths are in a soil too dry to carry the current without the possibility of drying out, there may be added a group of pipe-earths specially salted and watered. If for any reason the earth connection is required to carry dynamic current continuously, it is essential to supply salty water continuously.

Earth connections for transformers on poles. (2300 volts and thereabouts.) To get a high degree of protection, a lightning arrester should be placed on the same pole with every transformer. The ground terminal of the arrester should be connected to the iron case of the transformer, in order to avoid the drop in potential of the ground wire down the length of the pole to the earth connection. This ground wire should contain an easily disconnected joint. As a matter of safety the lineman in climbing the pole opens this joint and bends back the ends to insulate the upper parts from the ground while he is at work. The ground terminal of the arrester should be connected to the secondary of the transformer either directly or through a small gap, according to the practice followed on the secondary circuit. By following the foregoing outlined practice, any cheap iron wire down the pole may be used, and also a single pipe-earth. In cities, it is desirable to cover the ground wire with a wooden cleat or other insulation to a distance above ground of about eight feet. An accidental cross between a phase and the ground wire might dry out the earth, and if the ground wire could be touched by any one standing near on moist ground, a severe shock might be received. If the soil is especially dry, two salted pipe-earths are desirable.

Grounds for arresters on trolley lines. This is an unusual condition where earth connections are not necessary, and in some places on account of electrolysis in neighboring water-pipes and gas-pipes, are undesirable. The arrester should be grounded on the rail. The object is to keep the potential normal between the trolley and the rail, but not necessarily to the ground in the neighborhood. On account of the unavoidably long connection of the arrester circuit from the trolley, down the pole and back to the rails, the line arrester cannot, in itself, give good protection to a car. It can, however, greatly relieve the strain on car arresters. Incidentally, it protects the insulators in the neighborhood to some extent.

Grounds for signal circuits. It has been the practice to use a buried coil of copper wire for a local ground near the relays. A number of signal engineers have recognized the value of using a rail for an earth connection and have used an extra gap between a rail and the local ground or earth. Measurements of the relative resistance of the local earth and a rail show that a rail, in spite of its position on wooden ties and rock ballast, has only a small fraction of the resistance of a local earth-plate. Furthermore, the rails, on account of their length, gather in the radiating earth-currents of a lightning stroke. It seems reasonable to presume that an induced potential from electrostatic charges will exist principally between the overhead wires and the rails. Protection should therefore be provided between these two circuits. So far as the writer knows, no reason is evident why the ground terminal of a lightning arrester should not be connected directly to one rail without the use of a local earth-plate. So long as the lightning arrester is shunted across the coils and contacts to be protected, the inductance of the length of rail is a factor that does not enter the problem of protection. At any rate, even when a local ground is used, there should be a lightning arrester connection to a rail.

Earth connections for telephone arresters. A pipe-earth or rod-earth is usually sufficient. The earth-connection should be capable of carrying the current of a series arc circuit without drying out. In case of such an accidental cross, the fuses protecting the instrument will not, and should not, melt and open the circuit. It is necessary for the earth connection to maintain a fair degree of conductivity in order that the potential at the telephone receiver may be kept down to a safe value. Where possible, the telephone arrester is grounded to a water main.

Earth connections for towers on electric transmissions. Two distinct conditions arise. *First*, earthing of overhead grounded wires on wooden pole lines; and *second*, protection of the legs of metal towers from electrolysis.

First, an earth connection to an overhead grounded wire is desirable at every pole. One pipe-earth may be considered sufficient, in general; at most, two pipe-earths would seem sufficient.

Second, metal towers are usually connected metallically to their overhead grounded wires. When such a line parallels a direct current trolley, the return currents from the rails pass to the tower legs and through the overhead grounded wire. The electrolytic corrosion on the legs of the towers may be minimized by grounding the towers through salted pipe-earths. The entire leakage current from the rails through the tower can be prevented by the use of a slight amount of insulation between the tower and overhead wire. This small gap from the overhead wire to ground will not materially affect its protective value.

In the next part of this paper some of the different subjects given in previous outlines will be treated in detail in their designated order.

(To be Continued)

INDUSTRIAL MOTOR DRIVE

By G. E. Sanford

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A comparison is made between the group drive and the individual drive in motor applications; figures as to relative costs are given, based on the requirements of a small machine shop; while some notes are added on the selection of a motor of suitable size for various classes of drive, and its installation with the driven machine. This paper has been specially re-written for the Review, from the notes of a lecture which the author gave before the student engineers of the Harrison Lamp Works.—Editor.

Advantages of Individual Drive

One of the advantages of individual drive over shaft drive is the saving in power. With individual drive the power is consumed only when actually needed, and none goes to waste when a machine is stopped; while with a shaft drive a large amount of power is continuously being wasted by friction in bearings and belting. As an example of this, I recently made a test to determine the power lost in a certain group drive, as a result of a complaint to the effect that the motor was not large enough to do the work satisfactorily. The motor was a 10 h.p. machine and was belted directly to a main shaft, 30 ft. long, running at 300 r.p.m. From this were driven loose pulleys about 10 in. by 4 in. on six countershafts, as well as loose pulleys about 12 in. by 3 in. on seven drills and miscellaneous machines. A reading taken with only the main shaft and the loose pulleys running, showed about half-load on the motor, this being calculated on half-load efficiency of the motor. The saving in power otherwise lost by friction of shafting is more noticeable when a plant is running a few men overtime, and long lines of shafting are running with only one or two tools in use.

With the individual drive there is a saving in labor of shifting belts from one step of a cone to another, or from a main shaft to a countershaft. A department usually possesses only one or two belt poles, and it often requires some time to find one or to wait until some other user has finished with it and then if in getting the belt back on a main shaft pulley, it is knocked off the countershaft pulley, further delay ensues while a ladder is obtained. The labor involved in re-aligning the shafting, replacing worn out bearings, etc., is also saved. This job has to be done of course when the shop is shut down, and is paid for on an overtime basis. There is also considerable time lost in looking for ladders and planking for a temporary staging, to say nothing of danger to the millwrights through working on an insecure footing. This last point may include too the loss of time and labor due

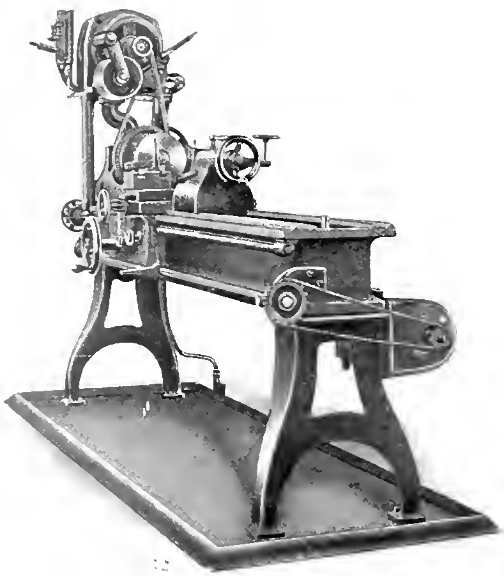


Fig. 1. Individual Drive of Lathe with 2 H P. Induction Motor

to a burn-out in a motor driving a group of machines, as most of these motors are located on the ceilings so as to be out of the way. With a burn-out in one of these motors or trouble with a main shaft during working hours, a number of operatives will be idle an hour or more; whereas if the trouble occurs on an individually-driven machine, the operator can usually be temporarily transferred to another machine without loss in production.

With individual drive the machines can be located to better advantage as regards floor-space and light. As an instance of economy of floor space I may cite a case at Lynn, where we formerly had all punch-presses running from shafting, and all the flywheel shafts had to be parallel with the main shaft. With this arrangement, space had to be provided for the troughs which held the un-cut stock for each press. We put a motor on each of 50 or 60 punch-presses of one style, and re-arranged them with the flywheel shafts at about 45 deg. angle from the aisles, so as to let the stock trough of each extend out behind the adjacent press, also putting two of these rows back to back. By doing this we succeeded in placing nine presses in a space formerly occupied by five.

A point in favor of individual drive is the facility with which the work can be taken to and from the machine by a crane. In this case the machines are wired from underneath the floor. Motors are especially well adapted to the drive of portable drilling machines and other tools used in machining pieces which are too large to be easily taken to the stationary tools.

In connection with locating with respect to light, probably everyone is familiar with the ordinary method of arranging engine lathes, end to end, and two lines back to back, the whole line being parallel to a side of the building. With this scheme, half of the men are at a disadvantage in being between their work and the light, while the other half are worse off on account of facing the light. On the other hand if the center lines of the lathes are arranged at right angles to the side of the building, with the tail stock toward the window, the men then get the light over their right shoulders. The amount of light in a room equipped entirely with individual drives is far better than that with shaft drive, as the shafting, pulleys and belts throw considerable dirt on ceilings and walls; and this, together with the black hangers, shafting, pulleys and belts, makes a very dark combination, which gets worse with age instead of improving. I know of one building with a floor space of approximately 90 ft. by 190 ft., which has on the third floor a large number of screw machines, these having from two to four belts each, from the countershaft to the machine, depending on make and style. The height of this building relatively to that of the surrounding buildings is such that no shadows are cast on the windows of the room from 8 a.m. until nearly sunset; but in spite of this it is necessary to keep incandescent lamps burning all day at the machines in the middle of the room.

In a modern shop, if the management is at all progressive, it is necessary to provide for additions and re-locations of machinery from time to time. With motor-driven tools it is a simple matter to remove the wires between the mains and the machine; whereas with the shaft outfit it means that, to remove the pulley belonging to that particular countershaft, it may be necessary to uncouple and take down part of the main shafting (if the pulley is solid, as most of the old ones are); and it is then a lengthy business to strip off anywhere from one to a dozen other pulleys in order to get the one which is required, put back the others, set up the shafting and re-align each pulley moved. The whole performance has to be gone through again when putting the pulley up in the new location.

With individual drive on a machine, the efficiency is greater than with the shaft drive, on account of the motor being nearer the work. This difference in efficiency is most noticeable in a comparison of adjustable speed machines, with direct current motor having a number of points with slight variation in speed between points, and in other cases where there are 4 or 5 steps on the machine cone. With the individual drive the operator is able to keep the speed at the maximum by a touch of the controller, for both tool and material, when working on stock of varying diameters, as, for instance, in facing a disk.

On punch presses, power shears, etc., the number of accidents to operators is noticeably less with individual drive, as the general arrangement with shafting drives consists of a belt from a pulley on the main shaft to the machine flywheel; a touch of the treadle will cause a complete cycle on the machine, with possibly disastrous results to a man engaged in setting a die or adjusting a shear

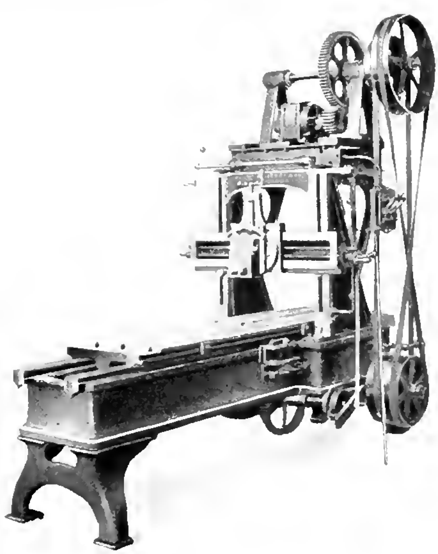


Fig. 2. Individual Drive. Induction Motor driving Pratt and Whitney 24 inch Planer

blade. Instances have been known of men being seriously injured by accidentally hitting the treadle. With individual drive the motor may readily be shut down before any adjustments are made.

Relative Costs of Group and Individual Drive

If a manufacturer is considering a new building, new tools, etc., the methods of driving the tools will be a very important question. Some will go into the subject as far as to find that the initial cost of the individual drive is much in excess of that of the group drive, and decide immediately in favor of the latter without making a proper study of the question of maintenance and other points. The following figures are based on the requirements of a small machine shop.

Original cost of group drive:

4—18 in. by 8 ft. lathes at $550.00	$2200.00
3—34 in. upright drills at $300.00	900.00
3—24 in. shapers at $600.00	1800.00
1—15 h.p. constant speed motor	300.00
1—motor starting panel and wiring	50.00
Stringers, hangers, boards, etc.	60.00
Belting	140.00
60 ft. $2\frac{3}{16}$ in. line shafting	15.00
Couplings, pulleys and shaft hangers	100.00
Erection of line shafting	75.00
Increased power plant required on account of frictional losses (est.)	200.00
Total	$5840.00

Original cost of individual drive:

4—18 in. by 8 in. lathes arranged for motor drive at $650.00	$2600.00
3—34 in. upright drills arranged for motor drive at $320.00	960.00
3—24 in. shapers arranged for motor drive at $675.00	2025.00
3—3 h.p. c.s. motors at $100.00	300.00
7—3 h.p. v.s. motors at $140.00	980.00
Starting and control panels and wiring	300.00
Total	$7165.00
	5840.00
Excess cost of individual drive	$1325.00

There are certain losses incidental to the group drive which do not occur in the individual drive. These losses as estimated for the above group drive per annum would be as follows:

(1) Friction loss in shafting varies from 20 to 60 per cent. of the total power supplied and can safely be estimated at 25 per cent.; which based on an average load of 15 h.p. at ten hours per day for 300 working days or 15 x 0.25 x 300 x 10 x 0.02c. =	$225.00
(Cost of power estimated at $0.02 per h.p.-hr.)	
(2) Time lost by ten machine operators in hunting up belt poles, shifting belts, replacing lacings, etc., 20 min. each per day for 300 days or 10 x 20 x 300 = 60,000 mins. or 1000 hours, which at $0.30 per hour =	300.00
(3) Interest, depreciation and repairs, equal to 15 per cent. of excess cost of power plant, viz., $200.00	30.00
	$555.00

From this it is evident that in about 2½ years the increased cost of the individual drive would be wiped out. The friction loss would probably be increased, however, if power was purchased from a public service corporation, the increase being dependent on local conditions as regards rates, etc. Furthermore, if there were no heavy shafting to suspend from the roof trusses, there would be a saving of possibly 5 per cent. in the cost of the building.

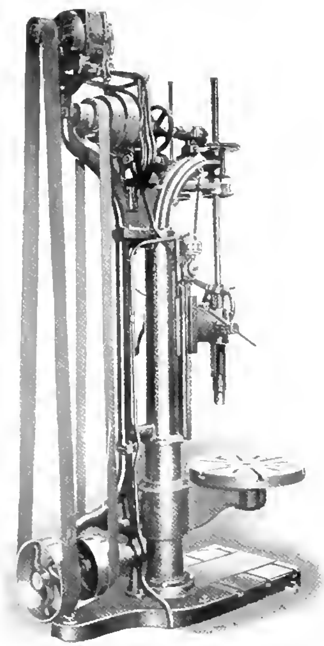


Fig. 3. Induction Motor driving Prentice 24 inch Drill

Selection of Motor Size for Required Service

In connection with the selection of motors to drive tools where the power required is not known, it is customary to set up a temporary motor large enough to carry the maximum load on the machine, and make careful tests to determine the average and maximum loads. It is usual then to select a motor based on the average conditions, provided that the maximum is not so great as to stop the motor or slow it down to such an extent that it cannot regain normal speed before the maximum is on again. This is based on an overload rating of six hours at 25 per cent., and momentary at 50 per cent. overload. In cases where the load varies rapidly, as for instance the reverse of a planer, it is usual to add a fly-wheel to the main driven shaft to help out over the peak load.

It appears from tests whch have been made that machine tool makers in many cases use motors which are altogether too large. The following data were obtained on a 48 in. planer fitted with a 20 h.p. motor: Cutting stroke, 4 tools each ⅛ in. feed by ⅛ in. deep, 2 in scale and 2 in second cut, cast steel at 37 ft. per min., 9.8 h.p.; reversing bed to run back 25 h.p., approximately; running back 10 h.p.; reversing to cut 25 h.p., approximately. This machine was fitted up by the maker, but if a 15 h.p. motor had been used I do not think it would have given any trouble.

A test on a 24 in. planer showed the following: Cutting stroke 3 h.p.; reversing bed 8 h.p.; running back 6 h.p. We fitted this planer and three or four others like it with 3 h.p. induction motors about two years ago. All but one have given no trouble; that one, however, is set for a very short stroke, only two or three inches; and after we melted the solder out of several rotors, we changed

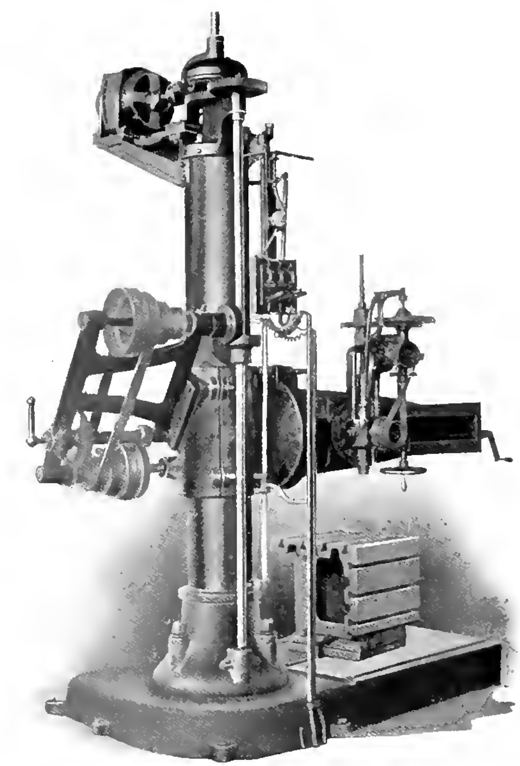


Fig. 4. Induction Motor driving 4 1-2 ft. Universal Radial Drill

to a 5 h.p. We are having a 3 h.p. rotor made with conductors and end rings cast in one solid piece, and intend to put a 3 h.p. motor back when we get this. Other cases of over-rating on the part of machine tool makers are as shown in table below. The figures in the second column are the sizes specified by certain machine makers, while those in the third are sizes which we have in use on the same make of machine operating satisfactorily.

Machine	Maker's Equipment	Our Equipment
48 in. planer	25	10
Grinder 24 in. wheel	5	2
Grinder 18 in. wheel	2	1
6 ft. radial drill	5	3
36 in. upright drill	5	3
26 in. engine lathe	10	4
60 in. gear cutter	5	3
Circular milling mach. for R.R. gears	15	10
Gear hub milling mach.	10	5
chine	10	5
12 in. slotter	5	1
4 in. tapping machine	$7\frac{1}{2}$(shunt)	3(comp'd)

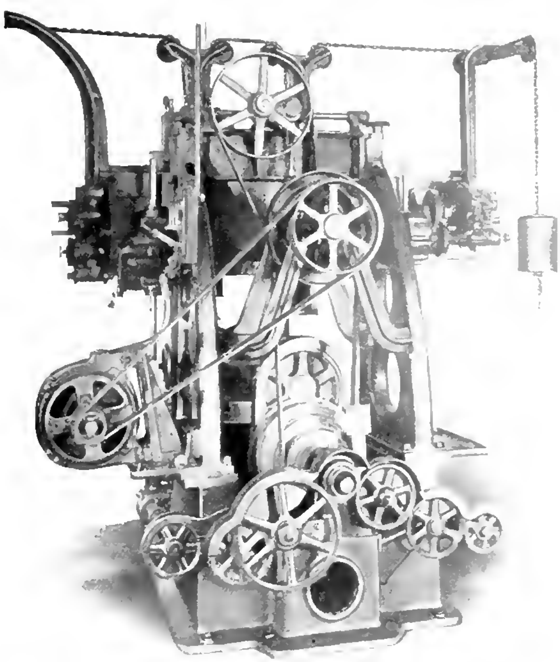


Fig. 5. Induction Motor driving Bullard 42 inch Boring Mill

Another palpable case, where an unnecessarily large motor is installed, recently came under my notice. In this instance a 26 in. disk grinder was driven by a 20 h.p. motor with the shaft extended on each end, carrying two steel disks about $\frac{3}{4}$ in.

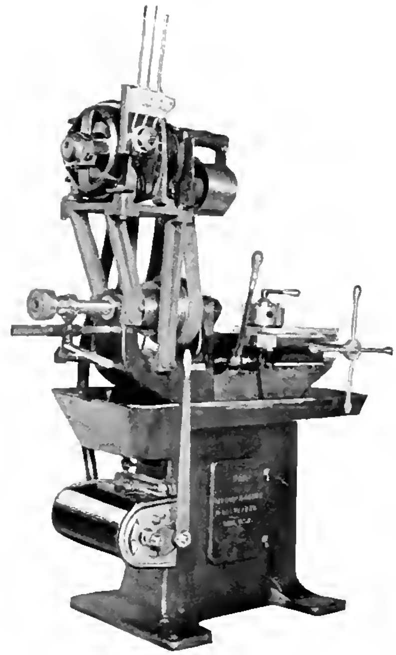


Fig. 6. 1 H.P. 4-Speed Induction Motor operating Bardons and Oliver Screw Machine

thick with emery sheets pasted on them. A test was made with two men, each holding a piece of cast iron with a bearing surface of about 24 sq. in. Both men were above the average in strength and had pieces of stock on which they could get a good grip. They were instructed to stop the motor if they could. The maximum horse power noted was 6.3.

Another interesting grinder test was made on a machine with wheel 24 in. by $3\frac{1}{2}$ in. This was equipped by the maker with a 5 h.p. shunt motor, and connected to the wheel with a silent chain. Under these conditions it was apparently considered necessary to have a fairly large motor in order to overcome the inertia in starting the wheel, since, of course, there was no momentary belt slip to aid the motor in getting up to speed. A test with large planer tool under ordinary conditions took 2.4 h.p. A test with a man holding the end of a $\frac{3}{4}$ in. by 2 in. machine-steel bar against the stone with all the pressure he could exert, took 4 h.p. This motor was removed and replaced with a 2 h.p. induction motor with ordinary belt, and this has been running for nearly four years. We find that most small engine lathes are

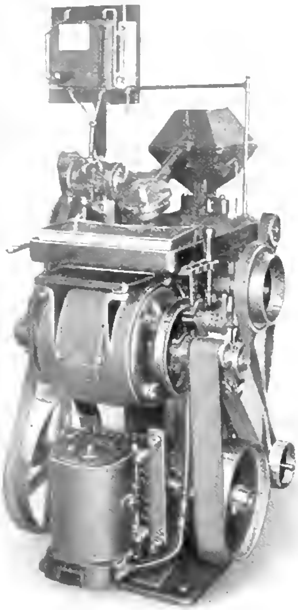


Fig. 7. Direct Current Motor Driving Manville Automatic Screw-slotting Machine

fitted about right, the only ones under-motored, which I recall, being the 12 in. and 14 in. of one certain make. These two sizes have given us considerable maintenance trouble due to armature burn-outs from overload.

A certain tool company could easily use smaller motors on any of their lathes under 24 in. For example, they use a 3 h.p. motor on a 16 in. machine. We had a case some time ago where a lathe of this size was speeded too high for the class of work required of it, so we replaced the 3 h.p. motor with a 2 h.p. slow speed motor. The department foreman was somewhat afraid of this reduction in power, as he did not want to be responsible for burning out the motor; so we arranged a maximum load test, where I was to watch the instruments and he would operate the lathe, each of us to take the responsibility for our own part of the outfit. The first cut in cast steel $\frac{3}{32}$ in. chip, 0.01 in. feed, 47 ft. per min. took 1 h.p. This shook some tools off the lathe bed. With the second cut the depth was doubled, and this took 1.6 h.p. The test was stopped while some of the screws in the machine, which were loosened due to jarring, were fixed up. The stock was changed and the test continued, using machine steel. The machine then jarred excessively on the following tests:

¼ in. chip 0.022 in. feed 72 ft. per min. . 3.1 h.p.
¼ in. chip 0.044 in. feed 40 ft. per min. . 3.8 h.p.

We then tried doubling the feed again, and after two or three revolutions of the stock broke the lathe. These tests showed that a 2 h.p. motor would do any work that the lathe could carry. We have since changed over more of these, putting on 1½ h.p. motors.

Location of Motor Relative to Machine

With regard to attaching the motors to machines, many tool manufacturers are building their machines with the motor drive included as a part of the machine. With old machines, however, it is an entirely different proposition. The motors should be located so that as far as possible they will not add to the floor space occupied by the machines, while they should also be so arranged that the shop attendant can easily

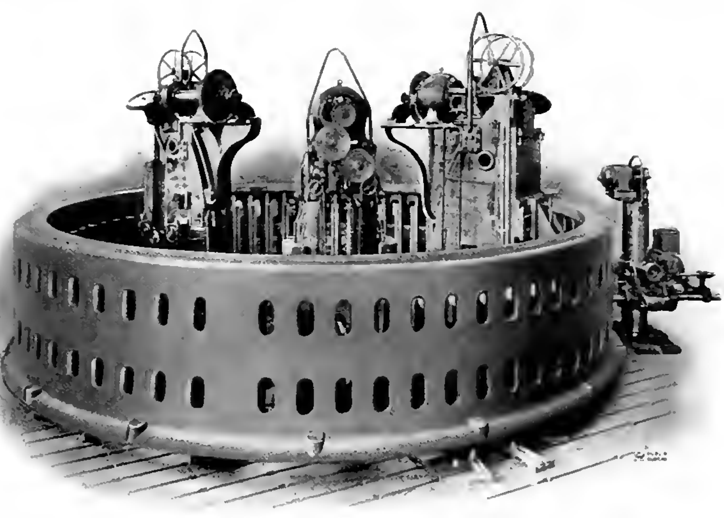


Fig. 8 The Application of Machine Tools in Floor-plate Work

get at them to clean or make repairs. They should be out of the way of the operators but the controller or switch should be within easy reach. In some cases, e.g., a band-saw, it is practically impossible for a man to reach the main switch from the operating position, so we have located emergency switches under a corner of the saw table which can be used to stop the motor. Large machines may be equipped with circuit-breakers having a no-voltage release, and small switches connected to this coil may be located at operating points.

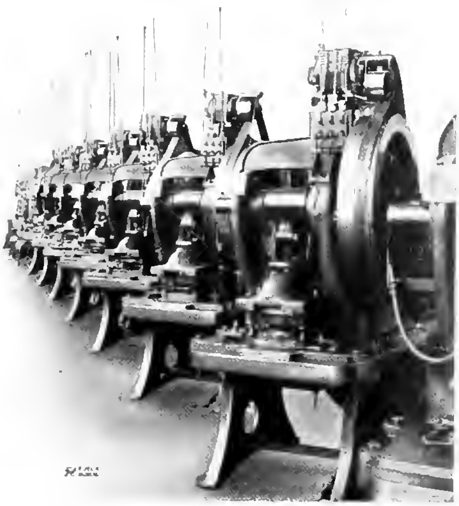


Fig. 9. Ferracute Punch Presses Individually Driven by Induction Motors

The cost of installation should be kept down to a minimum, but should not be done so cheaply as to prejudice a visitor against changing his machines. Cast brackets should be used in preference to forgings, as a few well-designed patterns can often be used on several different machines by trimming fitting strips and filling the crevices with soft metal. Attention should be given to the appearance of the drive, as a set of brackets with square edges and corners looks decidedly out of place when attached to a machine the general lines of which are well-rounded. It is surprising how much improvement can be made in the looks of a casting if the patternmaker spends a little extra time in rounding the corners and edges of the pattern.

In laying out a drive for an old machine, it is necessary to make very careful measurements of the machine, and to make an outline sketch to scale of that part of the machine to which the motor will be attached, leaving out all parts not actually required. With an outline sketch of the motor it is then an easy matter to select the relative location. We have a number of cardboard motor outlines which are tacked over outline drawing of the machine, and which often save time in determining the exact location for the motor. Most of these layouts are made on a scale of 3 in. to 1 ft., but we also use $1\frac{1}{2}$ in. to 1 ft. on some of the simpler jobs, and half scale on some of the complicated ones. We have on rare occasions made a full-scale layout on the floor in order to get certain measurements or locate just where a belt will go.

Fig. 10. Various Machine Tools with Individual Motor Drive

TRANSPORTATION AND ERECTION WORK IN CHINA

E. F. Colyer

A recount of the difficulties experienced in transporting and erecting the machinery and in constructing the power house for the Mukden electric light plant, occasioned by the primitive methods and ignorant labor that still have to be contended with in most parts of the Chinese Empire. This article is of timely interest in view of the present uprising in China, the avowed object of which is the overthrow of the present Manchu government.—Editor.

In the rapid development of a New China modern methods of transportation will inevitably exert a powerful influence. So long as communication between distant sections of the empire is restricted to the conveyances which have served for centuries any radical change in ways of living or any wide acceptance of Western standards is practically impossible. As the country's highways are improved and its railways extended many of the difficulties attending the introduction of up-to-date machinery and methods will be removed. The cost and trouble of transporting goods and passengers in wheelbarrows, jinrickshas, or in native carts is a very serious handicap, which, with the present conditions of the mechanical arts in China, makes the lot of the erecting engineer anything but an easy one. The installation of the electric lighting plant at Mukden, Manchuria, illustrates in a most interesting way some of the troubles which have to be overcome in localities where primitive methods prevail. In the General Electric Review for September, 1910, will be found a description of this installation. The photographs reproduced herewith were furnished by Mr. J. E. Popper, the erecting engineer.

Fig. 1. The Imperial Palace at Mukden Birthplace of the present Manchu Dynasty

Mukden, the seat of the Chinese Provincial Government in Manchuria, is a city of some 300,000 inhabitants, situated on the main line of the South Manchurian railway between Port Arthur and Harbin, at the junction of this road with the Trans-Siberian Railway.

Fig. 2. A Chinese Wheelbarrow Used for Passengers and Freight. Typical Chinese Street

It is also connected by rail with Pekin and with Seoul, Korea, so that in a way its position may be said to possess special advantages. It is in about the same latitude as New York and has an agreeable climate. As is very common in China the city is surrounded by a massive wall, the gates of which are closed at ten o'clock each night, remaining closed until six o'clock next morning. During the night no one is permitted to enter or leave the city unless provided with a pass.

Fig. 3. The Jinricksha, Popular Throughout the East

From the railroad station the apparatus for the plant had to be hauled about five miles through the western gate, and entirely across the city from one side to the other. The roads and streets are not in very good condition, and as the wagons or carts are of the crudest sort sixteen mules were required to haul a case containing a turbine weighing about six and a half tons. (Fig. 5.) The wheels of these carts are keyed to enormous wooden axles, which makes the turning of corners a very difficult job. The smaller packages were carried on what is known as Pekin carts, and Fig. 4 shows supply material arriving at the storeroom loaded on one of these carts. It may be said that the marks shown on the cases are not the shipping marks, but were added en route. For the construction of the power house lime in baskets (Fig. 8) was delivered by wheelbarrow—and the Chinese wheelbarrow is an institution. Not only is it used for the transportation of merchandise, but for the carrying of passengers as well. Where towns are connected by roads which are not much more than footpaths this single wheeled cart, provided with a man to push and another in front pulling on a rope, is almost invaluable, as substantial loads can be carried at good rates of speed.

The Mukden plant was at first intended principally for the lighting of the streets and the Government buildings, and it was planned to install the machinery in the building of the local mint. It being later decided that the lighting plant should be kept separate from the mint, the erecting engineer was called upon to turn architect, and to design a power house and boiler room. These buildings, the first 41 ft. 2 in. wide by 63 ft. 6 in. long and the other the same width but 54 ft. 8 in. long, were built of native brick, by Chinese masons, and while presenting a very creditable appearance in the photographs, the work of the masons did not greatly commend itself to the engineer, who states that after the walls were finished "one could see on them all kinds of sine waves."

Fig. 5 Loading 500 Kw. Turbine on a Manchurian Cart

To support the roof of the boiler room five trusses were made locally from designs of the erecting engineer, using some 2 in. by 2 in. by 1/2 in. angle iron which had been originally purchased for cross arms, poles, etc. For the power house a different form of truss, having rods for tension members, was used. These were also made locally, all to the great

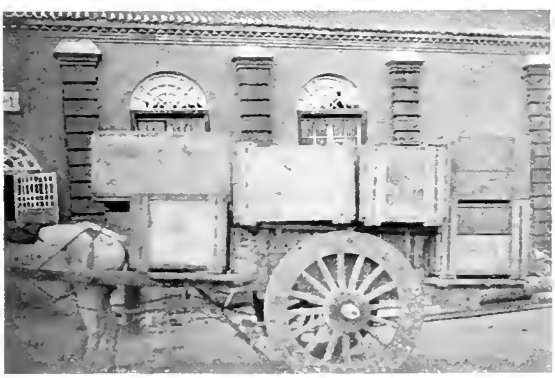


Fig. 4. Delivering Supply Material to Storehouse on a Pekin Cart

Fig 6. Exciter for Turbine Loaded on Manchurian Cart

surprise and admiration of the Chinese Government architect, who was later shown over the building and who at first could not credit the statement that the work was done in Mukden. In view of the crude

Fig. 7. Unloading Turbine Base—Showing Construction of Cartwheels and Axles

equipment of the local machine shops (as shown in Fig. 10), his surprise may be considered only natural. A good test of the strength of these trusses was had when installing the four-ton superheater. Having no

Fig. 8. Delivering Lime to Power House

crane this superheater was raised on one truss, together with the eight coolies lifting it. Fig. 11 shows one of the completed trusses being carried to site of power house.

Throughout the installation of the plant it was necessary for the engineer to first train the workmen to do whatever had to be done. Regarding this the engineer writes:—

"The boiler came all knocked down. Had to expand all the water tubes there, also the superheater. There was no one that knew anything about the erection. I had to hold a regular instructing school for a while—in fact with everything—until I succeeded in getting what I wanted. Not only this part made me worry, but afterwards the so-called masons (in my opinion some of them never saw a brick before). The most particular work was the fire arches above the stoker. Two arches are almost straight and if not properly made are apt to give out the first time the fire is put under them, for they are exposed to an intense heat. Fortunately, but with great difficulty, I got the brick work to some satisfaction finished. With great effort I instructed a Chinese to line up the boiler. After three days he said he had everything lined up. To make sure I went over the whole thing, and sure enough I found it the opposite way. The consequence was I had to do it myself and it took me three days to get it right, or I never would have been able to get the piping in place without any trouble."

At the Chinese New Year work was suspended as it was impossible to get the workmen to do anything for at least two weeks. Mukden was also visited by the plague, and an international conference to devise means of fighting it was held in the city soon after the installation of the plant,

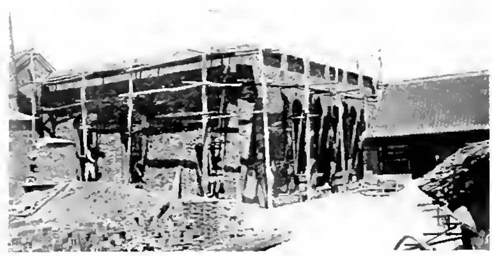


Fig. 9. Building the Power House

an appropriation of 150,000 taels having been made by the Government for the purpose. This plague is of the pneumonic type, is highly contagious, and to a large degree fatal. In Mukden the outbreak was kept under fairly close control, a rigid quarantine of suspects and the isolation of patients being enforced by the Chinese authorities.

In a recent magazine article emphasis was laid on the relative inefficiency of such unskilled labor as is available for construction and other work in China. Notwithstanding the very low rates of pay the total cost for any particular operation is usually much greater than in the United States. In Mukden mechanics get from 25 to 50 cents per day. A first class man may get 60 cents. Coolies receive from $3.35 to $6.70 per month. With the increasing readiness of the Chinese to avail themselves of up-to-date machinery it is probable that this condition will in time disappear, but it seems likely that it will be a long while before present primitive methods are wholly discarded and steam and electricity displace animal and man power to the extent that they have done elsewhere.

Fig. 10. A Chinese Machine Shop—Two Boys Driving an Engine Lathe

Fig. 11. Carrying One of the Completed Roof Trusses to Site of Station

By the establishment of the Imperial Polytechnic College at Shanghai, the Chinese Government has shown that it realizes the value of scientific training. This college, which is under the control of the Department of Communications, gives all instruction in English along lines similar to a first class American University. All students have studied English for ten years, and the candidates for entrance are obliged to pass a very rigid examination. Of 1200 who came up for examination for the freshman class of 1910 only 180 were passed. From the college ten students will be graduated in electrical engineering this year, while there are twenty in the junior class. For the use of the electrical laboratory of the college a considerable quantity of apparatus and instruments, both alternating and direct current, was recently shipped from this country.

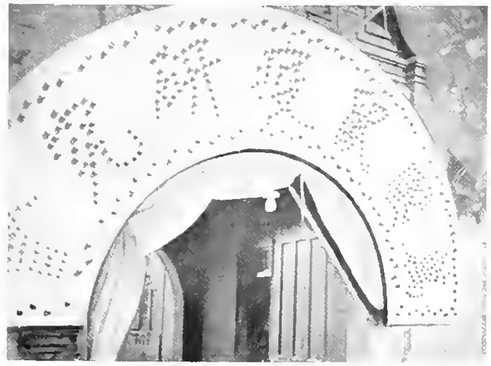


Fig. 12. Sign at International Plague Conference Using 5 Watt Tungsten Sign Lamps

Fig. 13. A Primitive Form of Bevel Gear Driven Waterwheel for Irrigation Purposes

THE SCHENECTADY WORKS

The electrical manufacturing business has grown with such phenomenal rapidity that some twenty-five or thirty years may be said to have witnessed its evolution from practical obscurity to the front rank of the world's most important industries.

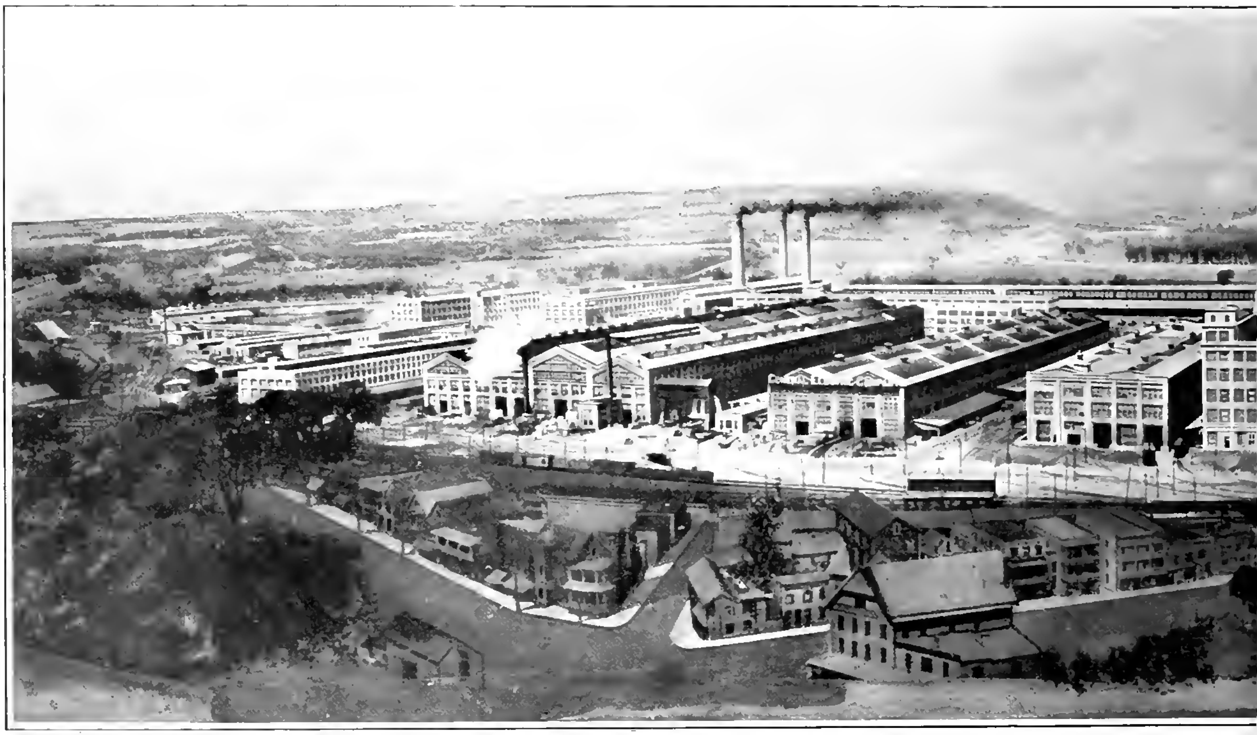
No better conception of this wonderful growth can be had than is furnished by a comparison of the Schenectady Works of today with what they were twenty-five years ago, at the time of their occupancy by the Edison Machine Works, of New York City. For instance, we read in an old Schenectady paper dated December 10, 1886, the following:

"Six carloads of machinery were received at the Edison Works this week. The Edison electric light which was recently put in the machine shop is now in running order. Wires are now being put in the other buildings, and will probably be ready in a short time. A pattern room has been constructed over the business office, and work will be commenced there in a few days. Ten men were taken on yesterday morning. In all, there are now about twenty-five hands at work."

In the issue of December 22nd, twelve days later, we find:

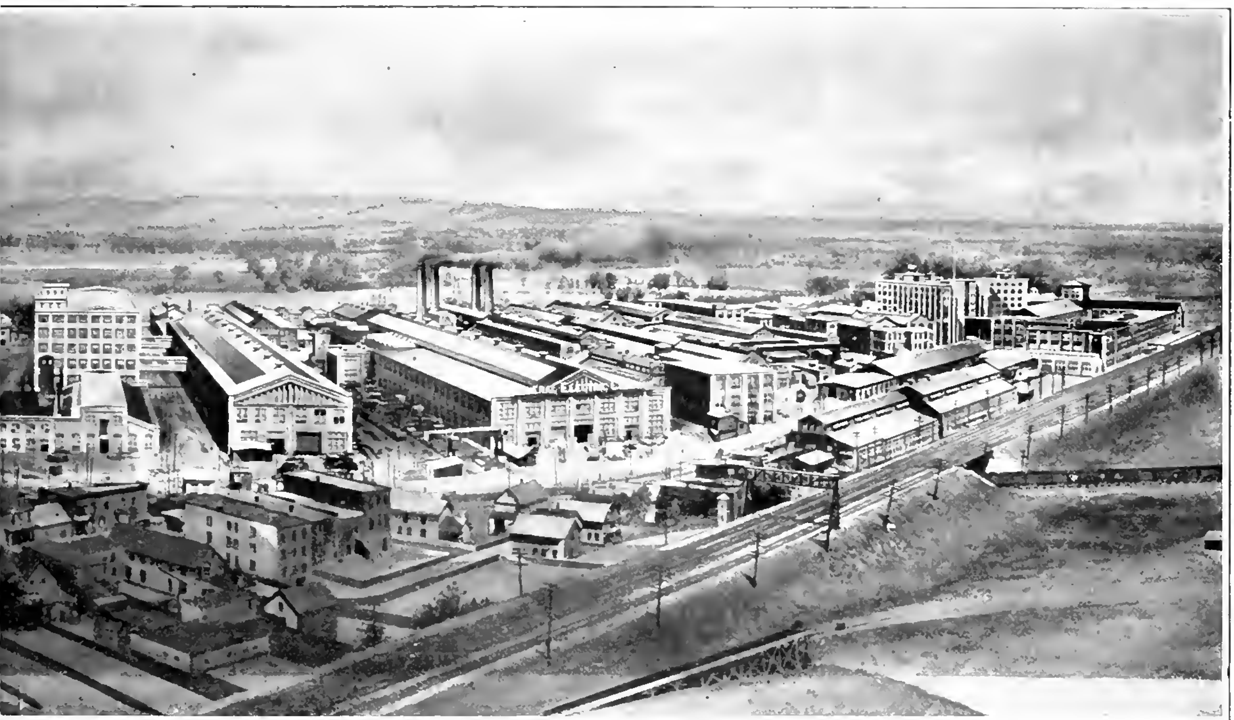
"Six carloads of machinery and castings for the Edison Works arrived from New York yesterday, also three horses and two wagons. There are now seventy-five machines in running order in shop No. 2, or the machine shop. In shop No. 1, the pipes for the steam heater are now being constructed and the wires for the Edison electric light, which is now being used in the works, are being placed in position. Five more men arrived this afternoon from New York, and it is expected that two hundred and fifty others, who have been in the Electrical Tube Works at New York, will come out next week, and the present force of two hundred and fifty men at work here will be thus increased to over five hundred before the advent of the new year. The building to be used as a blacksmith shop and, perhaps, foundry, now being constructed, will probably be ready for use by January 15th, and will afford employment to about two hundred additional men. An office 16 ft. by 16 ft., for the time-keepers and gate tender, has been erected near the gate leading to the plank road."

"The headquarters of the Edison Manufacturing Company will hereafter be located at this city, the New York shops having been entirely closed."



Shops Nos. 1 and 2 referred to are present buildings Nos. 10 and 12. These buildings were erected by the McQueen Locomotive Works in 1883–84, but had never been occupied up to the time of their purchase by the Edison Machine Works. The building referred to as in course of construction is present building No. 8. All of these buildings have been changed more or less by additions, with the exception of building No. 10, which, so far as the exterior is concerned, has practically its original appearance.

The present magnitude of the Schenectady Works is best shown by a recent photograph, here reproduced. These Works constitute the largest plant in existence engaged in the manufacture of electrical apparatus. They cover 335 acres of ground and comprise more than one hundred large buildings (many of them with a ground area in excess of 100,000 square feet) and half as many small ones. The total floor space of these buildings is 4,595,000 square feet. The number of persons employed, when the plant is operating at its normal rate of production, is approximately 16,000; this figure being exclusive of an office force of about 1800.



With a few exceptions all the principal buildings are arranged on either side of a main thoroughfare, which extends in a straight line from end to end of the yard—a distance of about three-quarters of a mile. The principal offices of the General Electric Company, both engineering and commercial, are located in a modern eight story building, directly opposite the main gate and along one side of this thoroughfare. Other engineering offices are located in the various factory buildings, so that the designing engineers may easily keep in touch with the work in the shops.

Two power houses, with a normal rating of 21,000 kw. in prime movers, are kept in continuous operation to supply electric energy for the machine tools, cranes, lighting, testing, and for the industrial railway that serves all buildings. The more recent of the two power houses is exclusively a Curtis steam turbine station, 4 turbo-generator sets with a rating of 14,000 kw., being installed therein.

The Works maintains its own fire department, which is supplied with apparatus of the most approved type, including two high pressure pumping stations; a special police and detective force; an emergency hospital; two restaurants; a water pumping station for general factory purposes, auxiliary to the city service; and a telephone exchange, to which are connected one thousand instruments serving all departments.

When it is stated that several days at least would be required to visit all departments, it is at once apparent that any detailed description of the Works in the space at hand is impossible.

ELECTRICALLY OPERATED COKE PLANT OF THE INDIANA STEEL COMPANY, GARY, IND.

By J. M. Matthews

Advertising Department, Schenectady,

Besides containing an interesting description in detail of the construction and operation of the Kopper regenerative by-product coke oven, this article details the various steps in handling and crushing the coal in this particular installation preparatory to charging the ovens. The by-product recovery is also described. This is the first coke oven plant in this country installed with the "direct process" ammonia recovery system, and is electrically operated throughout.—Editor.

The largest and best equipped coal-handling and by-product coke making plant in the world is at Gary, Indiana. It is of special interest because it is operated throughout by electric motors, receiving their current from the gas power plant of the largest steel plant on earth. Another claim to distinction lies in the use of 560 Koppers' regenerative by-product coke ovens, with a total coke capacity of 8000 tons per 24 hours, and Koppers' modern direct-process for recovering ammonia from the gas in the form of ammonium sulphate. This is the first coke oven plant in this country installed with the direct-process for ammonia recovery.

Fig. 1. Conveyors Between Breakers and Hammer Mills

Coal Handling

Let us follow the coal from its arrival at the storage yard, thence to the breaking and crushing building, on to the mixer building, and finally to the coke ovens. We will follow the coke from the ovens until it is quenched and ready for the blast furnaces; and trace the course of the coke oven gases through the by-product house until, freed of tar and ammonia, they are ready for use in the coke ovens and in the soaking pits of the steel plant nearby.

Coal for coke making is dumped from railroad cars into a concrete storage yard which has a capacity of 350,000 tons. The walls of this yard are inclined under the railroad tracks to deflect the coal away from the sides of the yard, so that the grab buckets of two large Wellman-Seaver-Morgan coal bridges can reach it with greater ease. The bridges are each equipped with 7-ton buckets and can load twenty fifty-ton larry cars per hour. Their closing and opening lines and trolley travel are each operated by a 150 h.p. mill type slip ring induction motor and the two bridge trucks are operated by eight 30 h.p. motors of the same type.

Coal, after being loaded into a transfer car, is dumped into one of twelve hoppers at the unloading house. These hoppers are each equipped with a shaker distributer driven by a 15 h.p., squirrel-cage induction motor. Each of the shakers can evenly distribute 40 tons of coal per hour on the belt conveyors. A continuous supply of coal is assured by keeping one hopper full at all times. The coal is carried from the unloading house by four belt conveyors, each of which has a capacity of 500 tons per hour. They are driven by four 30 h.p. squirrel-cage motors, which, together with those used to operate the Bradford breakers, hammer mill crushers and intermediate conveyors, are controlled by a special electrical interlocking system. The stopping of any conveyor or machine automatically holds up all operations prior to its own, thereby preventing waste or jamming. The unloading house conveyors carry the coal to Bradford breakers, each of which has a capacity of 500 tons per hour. It is here broken to one-inch mesh and separated from what little slate, stone, wood, iron, etc., it may contain. Power for this operation is furnished by four 75 h.p. squirrel-cage motors.

Between the breakers and the next operation, *viz.*, crushing the coal in hammer mill crushers so that 85 per cent. of it will pass through a No. 64 wire mesh screen, are four conveyors each with a capacity of 500 tons per hour, which are driven by four 30 h.p. squirrel-cage motors. These conveyors are shown in Fig. 1. The eight hammer mill crushers, with a capacity of 350 tons per hour, are driven by 250 h.p., squirrel-cage motors. As the coal crushing house is thick with coal dust floating around in the air, all motors used in it are in a separate room built on the side of the house (see Fig. 2). In many other cases, however, conveyor motors, located near conveyors in other buildings, are showered with coal dust. Crushed coal is carried from the crusher house to the mixer building by two conveyors, each of which has a capacity of 500 tons per hour. They are 120 feet long, travel 580 ft. per minute, and are housed over to insure protection against the elements. In the mixer house are two 500-ton mixers run by two 15 h.p. squirrel-cage motors with automatic control. The unloading, breaking and crushing machinery, and the mixer are connected by an electric signal system, which, by electrically-operated air whistles, indicates any change in character or mixture of coal being sent through.

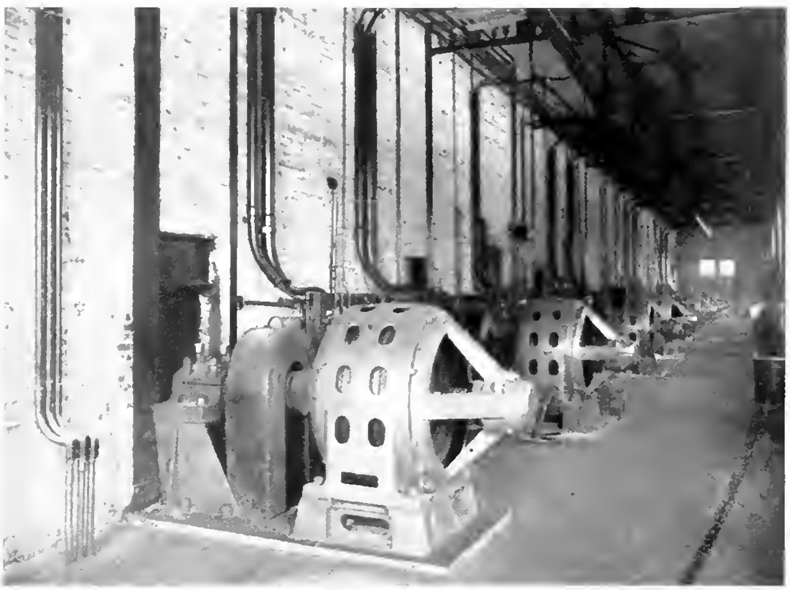


Fig. 2. 250 H.P. Squirrel-Cage Motors Driving Hammer Mills

The mixer building has a storage capacity of 2000 tons of pulverized coal. In it 80 per cent. Pocohontas and 20 per cent. Ronco coal are mixed, which gives a coke yield of 84 per cent. of coal charged. From the mixer house six 500-ton conveyors carry the crushed coal to four cylindrical storage bins over the coke oven batteries. These four bins have a capacity of 2100 tons each, and the six conveyors will completely fill them every ten hours; these conveyors are driven by two 100 h.p., two 75 h.p. and two 30 h.p., 3-phase squirrel-cage motors. It is unnecessary to run the coal-handling plant at night due to its capacity and that of the storage bins.

Coke Making

Larry cars (shown in Fig. 3) run under the storage bins and over the tops of the coke ovens, into each of which they charge 12¾ tons of coal through the charging holes on top. The coal is then levelled by a travelling leveller which is operated by four 30 h.p. mill type slip ring motors. The charging of the individual ovens of the battery is done in a certain sequence which leaves some ovens always ready for pushing, thus assuring continuous operation of men and equipment. Coking requires 18 hours (9520 tons of coal will be coked in 24 hours when entire plant is complete) giving 8000 tons of coke per day.

The advantages of the type of oven selected for the Gary plant are interesting. The ovens are heated with gas evolved from the coal carbonized. The coal yields from 50 to 60 per cent. more gas than the quantity necessary for its carbonization, and in the old bee-hive process of coking this surplus gas was wasted. A further advantage is that

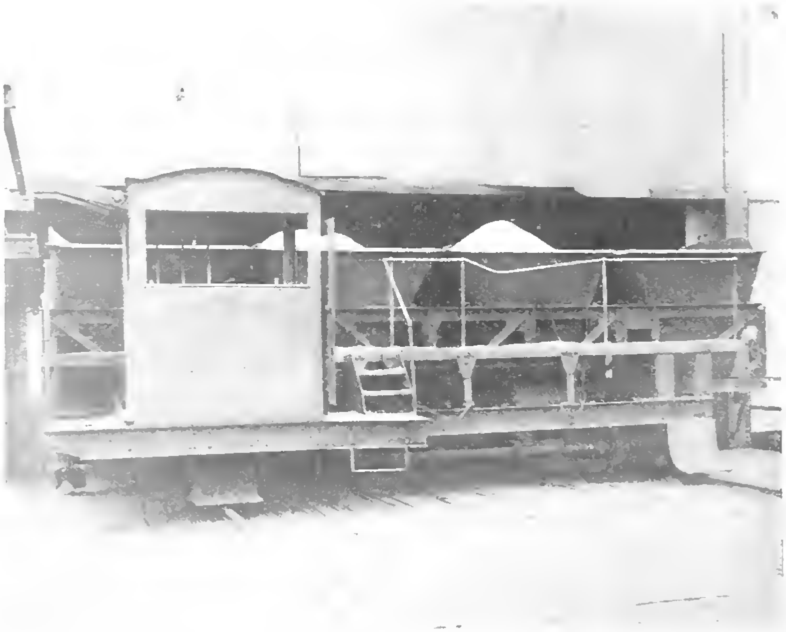


Fig. 3. Larry Car Receiving Crushed Coal Overhead from Storage Bins, and Delivering Into Coke Ovens Through Charging Holes in Roof of Latter

it is not necessary that the gas be consumed on the spot directly it is produced; but it can be conveyed any distance without material deterioration, while it can be stored during the time it is not required and consumed during the working hours of the day. Regenerators serve as a store for heat, by means of which a whole battery of ovens can be shut down entirely for a week or so, and started again without any heating up being necessary. This is not possible where regenerators are not used. The regenerators also enable the ovens to be worked at less than one-quarter of their capacity without going cold, whereas most other systems cannot be worked much below their normal capacity without cooling down.

The oven chambers are approximately 39 ft. long, 9 ft. 10$^3/_8$ in. high, and from 17 to 21 in. wide. They have doors at either end operated by a travelling door machine on the coke discharge side, and a door machine attached to the coke pusher at the ramming side. The top of the oven is provided with openings for charging the coal and an opening through which the gases of

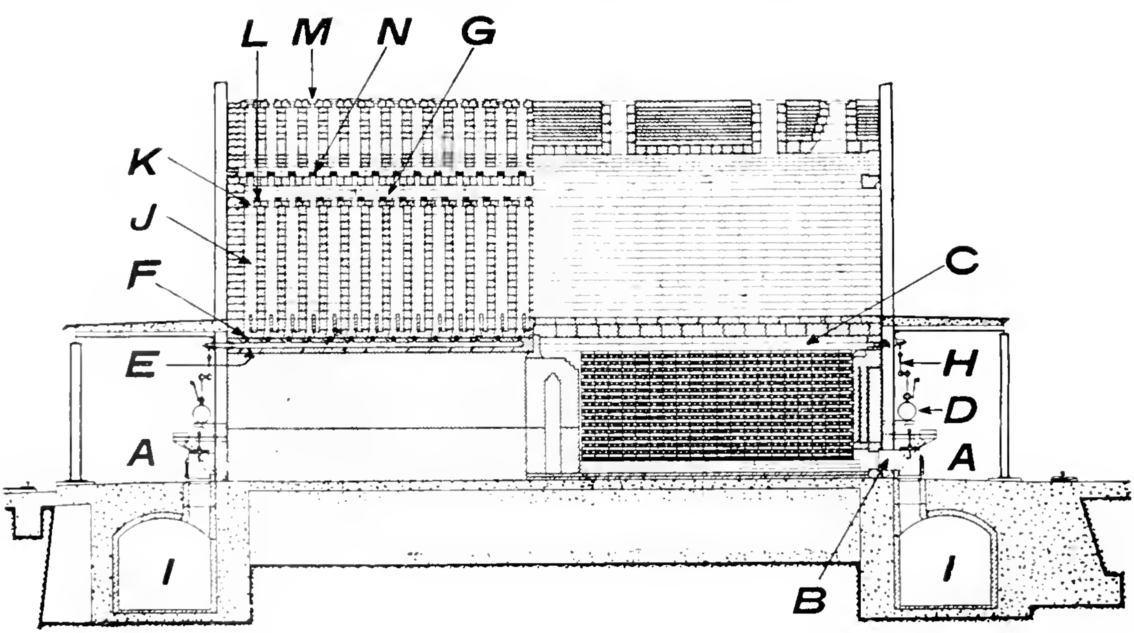


Fig. 4. Longitudinal Section Through Coke Oven and Heating Flues

distillation are drawn off to the condensing plant.

Referring to Fig. 4, the air for combustion flows along the passage ways, A, at the front and back of the ovens, and thence it passes into the regenerators through inlets B. In the regenerators, the temperature of the air rises to 1200 deg. Cent. (2190 deg. Fahr.) The highly heated air passes out of the regenerators into the vertical heating flues through the openings, C. The gas from the by-product plant, freed from tar and ammonia, is returned to the ovens by the mains D, running along the whole length of the ovens on each side. Branch supply pipes, H, conduct the gas into the gas-distributing channels, E, which are situated directly beneath the oven walls; thence it passes through the gas nozzles, F, into each vertical flue, where it ignites with the hot air entering through the passage, C, previously referred to. A jet is, therefore, formed on a level with the oven floor in each of the heating flues in the oven walls.

The employment of regenerators renders it necessary to reverse the heating process after a certain period, usually about 30 minutes. This is done automatically by a motor-operated dial-switch system which controls the gas and air valves. The system of heating flues is divided into two sections, so that combustion can take place alternately in each half of the oven wall. When the gas is burning in the flue in one half of the length of the wall, the products of combustion pass up the flues and enter the top horizontal flue, G, whence they make their way down the flues in the other half of the oven wall, and enter the regenerator through the same passages, C, by which the air is admitted to the flues when the direction or combustion is reversed. On issuing from the regenerator, the waste gases pass into the flue leading to the chimney, after having given up their heat to the checker-work of fire brick. The products of combustion of the gas and air pass up the heating flues, J, and through the openings, K, at the top of each flue. These openings are furnished with dampers, L, which can be easily regulated, together

Fig. 5. Motor-Driven Door Extractor on Discharge Side of Coke Ovens

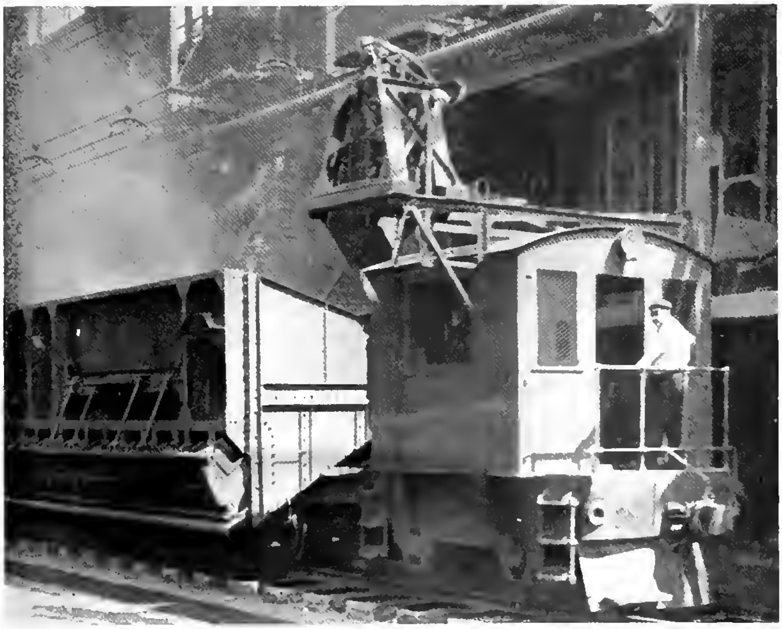


Fig. 6. Locomotive and Car on Discharge Side of Ovens. Partial Quenching Takes Place Here

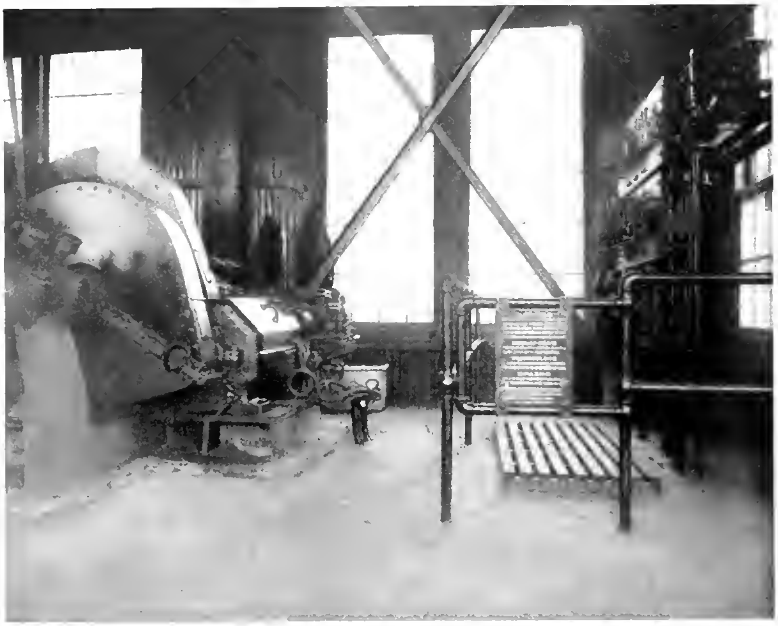


Fig. 7. 30 H.P. Motors and Automatic Control Equipment Operating Hoists for Quenched Coke

with dampers in the regenerating passages so as to enable the exact amount of air to enter the flue necessary for perfect combustion. The sliding bricks are accessible from the top of the ovens through the openings, *M* and *N*, which are fitted with easily removable plugs.

At this point, particular attention should be directed to the sliding bricks and to the openings at the top of of the ovens which give access to them, as these are two of the principal features of this type of oven, distinguishing it from all other constructions. The openings at the top of the ovens serve not only to provide means for regulating the dampers, but serve more particularly to give access to the gas nozzles, *F*, while they further permit of the flues being inspected at any time. The gas nozzles are furnished with oval orifices, to enable them to be taken out by a rod having a T-end. The orifices in the nozzles vary in size, according to their position in the flues. The removal and replacing of a nozzle can be easily effected in a few minutes.

It happens from time to time in all ovens that dark places appear in the oven walls indicating that the combustion is defective; and in the absence of means of access to the flues, it would be necessary to cool down the oven and break into the walls in order to remedy the defect. By means of the openings over each flue in these ovens, the cause of any irregularity in the heating can be immediately detected, and in the great majority of cases, such defect can be rectified in a few moments. The effect of any adjustment in the regulation of the gas and air can, moreover, be seen immediately.

It will have been seen that each oven wall is formed of about 30 vertical flues, and that each of these flues is provided with a heating jet, and also with means for regulating the

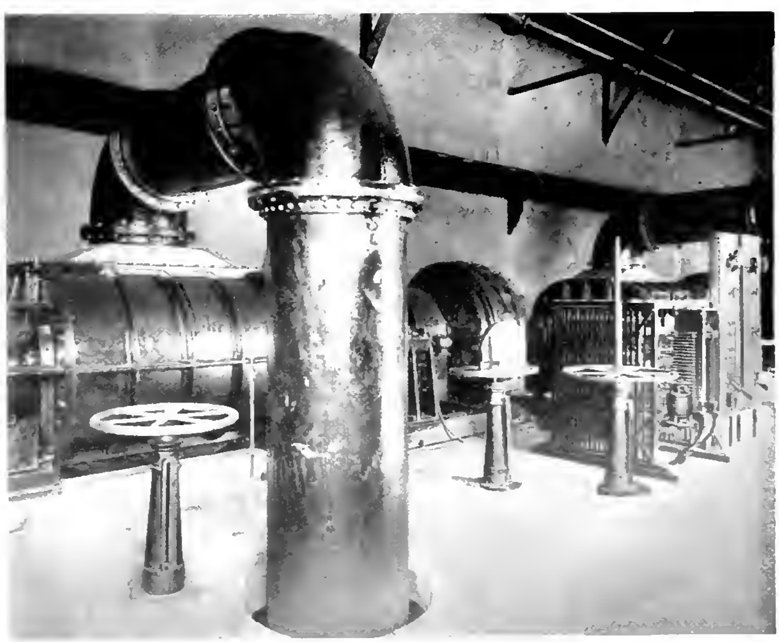


Fig. 8. Gas Exhausters Operated by 250 H.P. Motors

admission of the gas and air, namely, by substituting the gas nozzles, and by adjusting the sliding bricks over each flue respectively. It is, therefore, easily possible to control the heating so that the oven walls will be subjected to exactly the same temperature from end to end. Unless this uniform heating be attained, it is impossible to produce a coke which will be homogeneous throughout the charge.

When coking is completed, and the gas fully given off, the doors are removed and the charge is pushed out by the travelling ram (see page 2) operated by two 50 h.p. motors and one 7 h.p. motor (on door opener), all being mill-type slip ring machines. While being pushed, the coke is partly quenched by water sprinklers as it falls into a steel and cast iron car. To this car is attached a three-phase locomotive equipped with two 50 h.p. mill type motors; and as soon as the charge is entirely in the car, it is rushed to the shower hood where quenching is completed (see cover and also Fig. 6). The coke is then elevated to storage bins by two automatically controlled 30 h.p. squirrel-cage motors (Fig. 7); and finally is run through screens operated by two 30 h.p. motors of the same type.

Each of the two batteries of coke ovens is equipped with grinding pans and clay elevators for preparing luting material for the oven doors, operated by 15 h.p. squirrel-cage motors.

The gases from the ovens go through divided water-sealed mains, thence to coolers of the multi-tubular water-tube type, and after passing around the tubes, leave at a temperature of about 30 deg. C. The gas is then drawn by exhausters (Fig. 8) driven by 250 h.p. motors controlled to give constant gas suction, and is then delivered to the tar extractors. The tar and ammoniacal liquor which condense here are run off along with the condensation from the coolers, and separated by gravity in the tar separating tank. From the tar extractors, the gas passes to reheaters, where its temperature is raised to about 70 deg. C. by the use of steam. The heated gas is then conducted to the lead-lined acid saturators, containing a solution of about 5 per cent. of free sulphuric acid, and leaves them

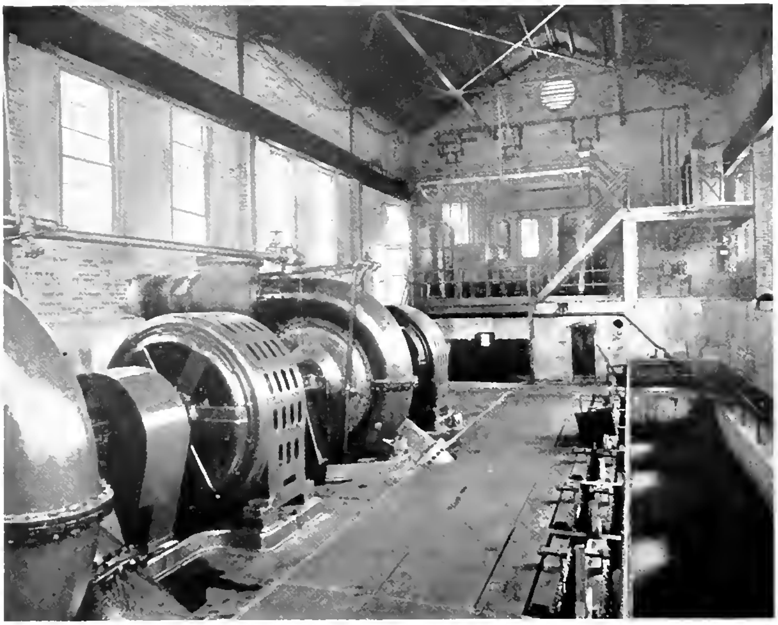


Fig. 9. Interior of Pump House

at about 30 deg. C. At this low temperature the chemical affinity between the acid and the ammonia is so great that a neutral salt (ammonium sulphate) is easily obtained. The salt is continuously removed from this enclosed saturator by an ejector and delivered into a draining table, from which it is run off, with the mother liquor, into a centrifugal dryer in the usual way. When desired, concentrated ammonia liquor is produced instead of ammonium sulphate. The ammoniacal liquor is treated with lime to decompose fixed ammonia compounds, and then heated to vaporize the ammonia which is conducted to the gas main and is absorbed in the saturators. About 1 per cent. ammonium sulphate and 2 per cent. of tar is obtained.

The coke yield is approximately 84 per cent. of the weight of the coal coked. Roughly 50 per cent. of the total daily yield of about 100,000,000 cubic feet of gas is used at the steel plant, and about 50 per cent. is used to heat the coke ovens. The coke plant is supplied with 60,000,000 gallons of water a day by two centrifugal pumps, operated by 1300 h.p. slip ring motors. (Fig. 9).

THE DIARY OF A TEST MAN

No. XV. MEASURING WATER VELOCITY FCR A 13,500 H.P. WATERWHEEL

The installation of the 7500 kw. waterwheel-driven generator sets at the Holtwood, Pa. power station of the Pennsylvania Water

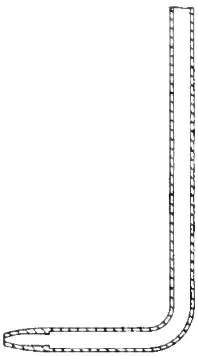


Fig. 1

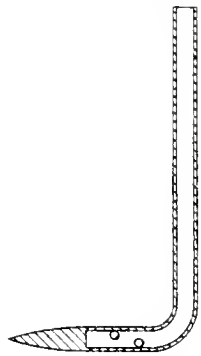


Fig. 2

and Power Company, has been followed by a number of interesting tests, which, owing to the size of the plant and the nature of its installation, are of unique interest. The following brief description relates to some special tests which were carried out to determine the efficiency of the hydraulic turbines at that station.

To determine the efficiency of a hydraulic motor, it is necessary to measure the quantity of water supplied to, or discharged by, the wheel. The methods available for this measurement are, first, by means of a weir placed above the wheel or in the tail race below the wheel; and second, by means of one or other of the standard devices for measuring the velocity of the water, whence the quantity may be calculated by knowing the cross-section of the supply or discharge pipe. From the nature of the hydraulic development at Holtwood, weir measurements were impracticable; and consequently a suitable scheme had to be devised for measuring the velocity of the water supplied to the wheel. The pitot tube method in this case was decided upon. The efficiency of the electric generators had been previously determined by actual test at site, so that it was possible to arrive at an accurate estimate of the actual effective horse power delivered by the hydraulic motor under the various conditions of the test, and hence its efficiency. It should be noted that the efficiency thus measured was the hydraulic efficiency of the plant, as it was impossible to separate the efficiency of the approaches, in order to obtain the efficiency of the wheel itself.

Each wheel-pit receives its water through four rectangular gateways approximately 6 ft. wide by 16 ft. high. The amount of water discharged through these openings can, under any set conditions, be determined by measuring the velocity of flow at various points in the cross-section, and so obtaining the true mean velocity.

For the information of those who may not be familiar with hydraulic measurements by means of pitot tubes, it may be stated here that if a bent tube, as in Fig. 1, be placed in a stream so as directly to face the current, the water column in the upright portion of the tube will rise to a height h, which theoretically $= \frac{v^2}{2g}$ As the velocity of water in the approaches to the wheel pit is small, h is consequently small, and would be in-

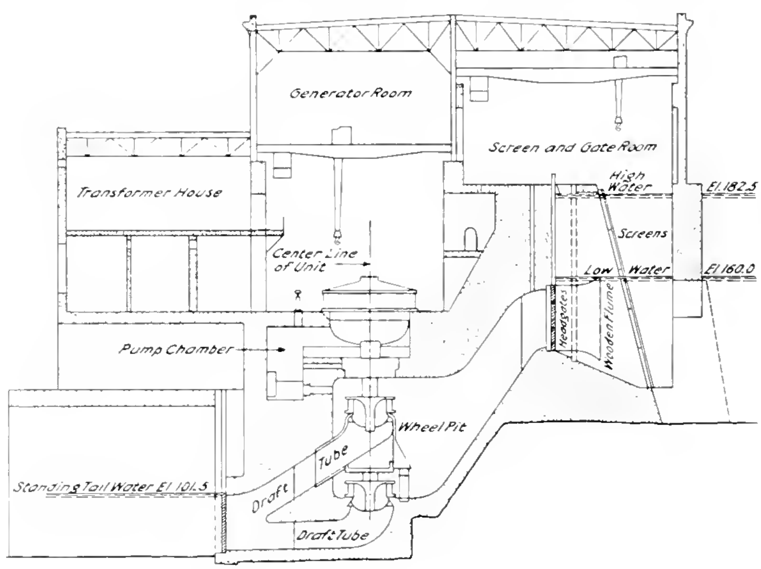


Fig. 3. Cross-section Through Turbine Room and Gate Room

capable of accurate measurement with the actual level of the head water as zero line, particularly as the surface of the latter is agitated. A second tube is therefore employed (shown in Fig. 2). This is closed at the end, which is of a conical shape to allow of the water flowing by, parallel to its sides, smoothly and without eddies. There are small holes in the sides of this tube, and as there is no component of velocity normal to these holes, the water level in this tube simply rises to the same level as the water in the stream. If now a vacuum of equal degree be created in both of these tubes, the water column in each may be raised up an equal amount to some convenient height, where the difference of level can be satisfactorily read. It is with this difference of level alone (representing the velocity head) that we are concerned. The foregoing is a statement of the bare principle underlying these tests. To obtain a sufficient number of readings under conditions which will not prejudice the accuracy of the results, and will admit of the measurements being read in some convenient and accessible place, a carefully planned testing system is required.

Readings were taken simultaneously before each of the four gates opening into the wheelpit. For this purpose there was constructed for each gate a movable framework, to which the pitot tubes were attached, and this framework was lowered into the water in front of the gate. Each frame consisted of a rectangular skeleton about 6 ft. by 30 ft. made of channel iron securely braced at intervals. Seven pairs of tubes were fixed to the bottom horizontal, in order to measure the velocity at seven points across the width of the opening. Each tube was connected to a $^3/_8$ in. iron pipe, and these pipes were carried up the framework and terminated in glass tubes to which connection was made by flexible rubber hose. The glass tubes were held rigidly against a wooden board, fixed to the frame, and graduated by horizontal lines to enable the heights of the water columns in the glass tubes to be easily and quickly read. The tops of the glass tubes were connected by rubber hose to a common header, which in turn was

Fig. 4. Showing Construction Work on the Wooden Testing Flumes

connected by another rubber hose to a vacuum line. By adjusting the vacuum, the water columns could be maintained at a level convenient for reading. At the top and bottom of each glass tube, there were cocks for the purpose of isolating the water column in the tube when a reading was being taken. Difficulty would otherwise have been experienced in taking readings, as the height of the water columns was continually varying up and down. The entire framework was suspended by steel ropes running over a pulley which was fixed to the roof principals.

In order to obtain a steady stream of water without eddies, a special wooden flume was constructed for each gate and fixed to the sides of the submerged concrete arches. In Fig. 4, these wooden flumes can be clearly seen, though it should be pointed out that this photograph was taken during construction work, and that actually, when making the test, these flumes were dropped right down until they came opposite the gate, and were then fixed in that position. The relation of Fig. 4 to Fig. 3 can be more

Fig. 5. Upper Portion of Moveable Framework, with Glass Reading Tubes Backed by Graduated Board

easily seen by noticing the relative positions of the screens in each picture. It should, of course, be remembered that the wheel-pit for each waterwheel receives its supply of water through four headgates. The four archways shown in Fig. 4 therefore represent the entrance to only one turbo-unit.

Fig. 5 shows clearly what the top part of the frame looks like. The man is standing on the gateroom floor, and the lower part of the skeleton framework is probably some 30 ft. lower down and is, of course, directly opposite the headgate. In Fig. 6 can be seen three of the reading stands, two of these being raised some 8 ft. above the gateroom floor, and at the extreme left a fourth reading stand for the fourth headgate is faintly discernible. The platform upon which the tester is seated is rigidly fixed to the framework, so that the whole thing may be moved bodily up and down through the hole in the gateroom floor.

For the purpose of the actual test, readings were taken at each gate at seven different levels in the incoming water. For the purpose of obtaining a true mean velocity, three complete sets of readings were obtained on all the tubes at each of these seven levels; and it will therefore be seen that for any given load on the machine, practically 300 readings were necessary, which means close upon 1200 for the four gates.

The principle of the pitot tube for measuring the velocity of a stream is, of course, no novelty; it is, indeed one of the oldest methods for securing accurate results. But it is certainly not often that it is applied on such a scale as this, or that the engineering work in securing the readings requires such an ingeniously planned system. The advantage in this particular instance lies in the rapidity with which these 1200 readings for any one load may be taken.

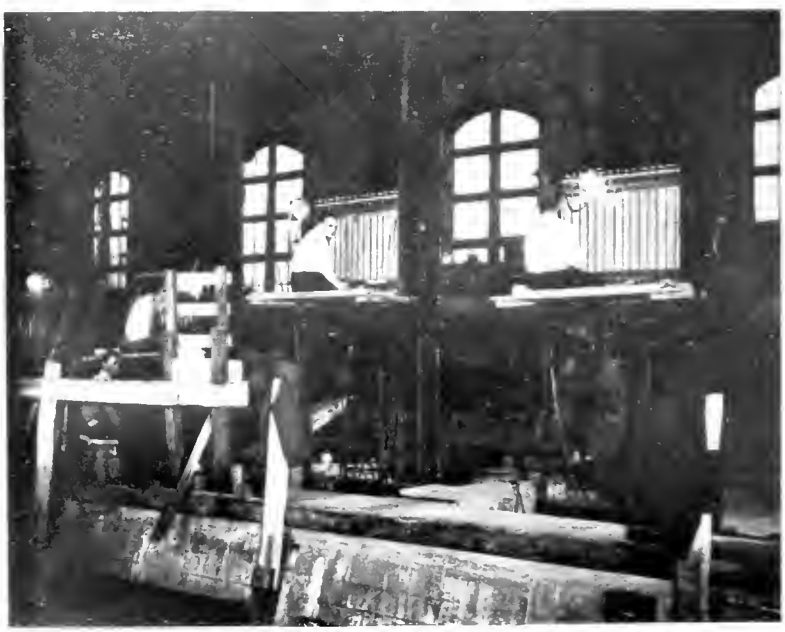


Fig. 6. Testers Mounted on Benches Secured to Tube Framework

THE ECONOMIC ADMINISTRATION OF INDUSTRIAL ESTABLISHMENTS

By John Calder

Manager, Remington Typewriter Works, Ilion, N. Y.

The major portion of this paper was originally delivered as an address before the Engineering Club and the Altoona Railway Club on October 25, 1911. The author has written a special introduction for publication in the Review, in which he makes a plea for some revision in the present college methods of training young engineers, by means of which they may become versed to some extent in modern business methods, and may learn to what degree knowledge of the human factor bulks in executive success.—Editor.

It was the engineer-in-chief of a great modern undertaking requiring the combined efforts of civil, mechanical and electrical engineers, and of a big labor army with many officers graduated only in the school of experience, who expressed his desire for and belief in the ultimate supremacy of the college man as an executive.

At the same time he frankly stated that, where one college graduate had failed him for lack of technical attainments, nine had disappointed his expectations for other reasons. Some failed owing to inability to discipline themselves, and many others did not properly supervise, use and co-operate with those under their control. Some did not realize that the engineer is no longer any man who can merely subdue or adapt natural forces and materials to the needs of civilization. Not a few can now solve satisfactorily the purely mechanical side of problems; but the successful engineer is the man who, in addition to this, can make the dollar go farthest and draw out the best efforts of his workmen.

Apart from the fact that young men still seek the engineering career who have no vocation for it, there are, the writer believes, several educational causes for failure and discouragement which might be removed. The first of these is neglect of general culture prior to the college course. This is a marked defect in our present high school system, and also in all the "get wise quick" schemes of a semi-scholastic nature for "framing-up" an engineer. This neglect is followed too often—and even encouraged at some colleges—by options and by too early specializations, which frequently remove the last chance the young engineer has of laying the foundation of an all-round mentality. No young graduate should now be allowed to leave college in total ignorance of the large extent to which knowledge and study of the human factor bulk in executive success.

It is not too much to ask of college authorities that the correct "point of view" here should be the possession of *all*, and that the elements of economic administration of money, men and things, should be emphasized and illustrated during student days. If they are, many early shop and field experiences will be trebled in value to the young graduate, and he will be enabled to make much more capital out of his inevitable day of small things. The following remarks upon engineering for profit, the art of shop management, and the field for the organizer, may possibly present a fresh point of view to younger brethren in the craft.

The Importance of the Organization

Taking the desire for more economical business administration for granted, consider for a little, in the order of their importance, the various factors which will influence the result. At the outset we must reckon with the fact that *the organization, and not the system, is the primary consideration.* This is not the order of precedence prescribed by some professional systematizers, but any other is a mistake.

Every business worthy of the name must be provided with an organization; and no matter what particular system may be followed it cannot attain economic distinction if it is not effectively organized. The primary object of organization is to bring brainy men together for work and action. A wise organization seeks and encourages men of ambition. It believes that the ambitious man is not necessarily dangerous. It knows that success demands an aggregation of strong individualities, free to contribute their quota of wisdom, but loyally subordinating their individual preferences to the general policy once declared. In order that its work may be well done, and its action strong and forcible, the organization must move forward as a harmonious unit. No amount of clever scheming alone will secure this. Herein lies the task of the organizer of men, as distinguished from the mere systematizer of things. His work is much easier to talk about than to carry out, but it needs brief mention here.

When any business or industrial work becomes larger than its proprietors can take care of, they seek for assistance; and from that moment they and their delegate, the general manager, become organizers. The organizer's success will depend not merely, or even chiefly, upon extended technical experience and close knowledge of the business; but upon his ability to select his assistants, to transfer his own work to them, and to inspire those assistants with his own ideas, his own energy, and his own ability. Emerson says "Every great business is but the lengthened shadow of one man," and he is right. The modern administrator of industrial establishments is a manager of men rather than of things, and the human factor touches his business on all sides. The writer lays stress upon it at this stage, so that it may not get out of focus in a paper which is chiefly devoted to an analysis of things.

An organization, therefore, cannot go into commission. It must have a strong, resourceful leader, and a carefully selected, well trained, loyal and enthusiastic staff. This will only come through intimate contact with a man, not a mere machine or inanimate system. Having chosen men, frequently young men, for their record and potentialities, particularly for signs of executive ability—a not too plentiful quality—they should be expected to win solely upon their merits, and to make the most of the business by making the most of themselves. Unless the leader sees and plans for an opportunity for a useful career, not only for himself but also for his staff, he cannot reach the highest success. The cold-bloodedness of some of the modern schemes for exploiting the higher human energies is not only repelling—it is a fatal defect.

The Systematizer

Organization, though the greatest factor in business, implies co-ordination, or system, and not much can be accomplished without the aid of the latter. Business methods and apparatus, particularly those of mechanical and transportation concerns, are being closely scrutinized and many proposals made for securing greater internal economy. At such a time it is well to bear constantly in mind that any system, however attractive and justifiable in some of its features is, like the plant itself, worth no more than it can earn.

No manufacturer is in business as a subject for experimentation, which may not point the way but merely warn others from following. All money and worry expended on system beyond the earning point is wasted. An admitted experiment of measured duration and conclusive nature is one thing; but a shop revolution covering years of transition experiences is irretrievable and usually unsupportable. Dead uniformity and absence of scope in a system for individual initiative and incentive are not necessarily factors in securing what are the sole justifications for special outlays on system, viz: absolute certainty of increased economy, accuracy and dispatch. In concerns in which system is an expensive hobby and not an economical tool, all kinds of extravagances will creep in and will be justified by some philosophy which ignores common sense.

One of the claims brought before proprietors by some of the external practitioners of system is that it will not only render the efficiency of their business self-perpetuating—a most desirable end if attainable—but that it will also enable them to become, to a large extent, independent of their managers and higher executives. This is a somewhat mischievous doctrine. No army of clerks, mechanically following set instructions however perfect, can take the place of the full use and recognition of able engineering administrators and shop assistants, under any conceivable works system. The human element in system, as well as in organization, is half of the problem; and there is a tendency to a too great rigidity in most of the shop systems offered for general application. It is not a recommendation for any business system, imported from the outside, but rather the reverse, that it should insist upon absolute conformity to type in details, without regard to the problem in hand and the great amount of experience already acquired from it. Some of the most practical modifiers of shop management are fully alive to this, but there is a tendency amongst the less wise to vigorously wield the new broom. It is the belief of the writer that the best type of shop system is evolved, not from the outside, but in the shop itself, through careful analysis of its special conditions and requirements by the responsible administrator, thoroughly in sympathy with, and experienced in, advanced practice.

A busy and prosperous administration can sometimes be helped by system advice from the outside. It should never be controlled by it. The most natural tendency of the outside adviser without responsibility for current product and profit is to stereotype the detail of his previous limited practice, and to dry up the springs of initiative and suggestion within the plant. The best system for any particular shop is that which will co-ordinate all the efforts of a good organization, and which will draw out and suitably reward the best effort of every one concerned—not forgetting the employer. The most suitable management for so doing will never be exactly alike in any two cases, though the principles followed may be identical.

The System of "Scientific Management"

It was to an already progressing and intensively developing shop practice that there was presented ten years ago *Scientific Management*, a phrase to conjure with, and which is much in the air at present.

It appeared at first with a more modest title, and made its appeal through the ordinary professional channels to the engineer. It was a worthy appeal based upon a quite unusual amount of self-denying investigation, but it did not receive the immediate consideration it deserved. This was partly because the straw man which it set up, and repeatedly and vigorously knocked down, was merely a lay figure, and not really representative, as alleged, of the best existing shop practice. In the case of the more open-minded and thoughtful engineers, ready to learn from any source, the "science" of the movement was accepted with considerable reservation; and, from the humanitarian point of view, the illustrations used by the gifted author of the system laid it open to not unjustifiable attack, and to the complaint that, though a deeply interesting experiment had been made, it did not justify the far-reaching generalizations based upon it. In the ten years which have elapsed professional efficiency engineers, with no such experience as the able author of "Scientific Management," have multiplied somewhat more rapidly than the demand for this service would warrant; and quite recently "scientific management" itself has caught the fancy of the press and of the man in the street, and has been let loose through a popular propaganda upon an indiscriminating public. It will come back to its moorings after a while. Actually the particular system described and advocated by Mr. Fred W. Taylor has made relatively little progress; and, while economic administration of industrial establishments has been quickened not a little by its advent and discussion, the most of the general advance has been the result of causes operating before that event, and much of it has not been along the specific lines of such proposals in "Scientific Management" as are original with its author.

The fact of the matter is that Mr. Taylor's "Scientific Management" is a very big and difficult task, requiring professional ability of the highest order. Stripped of the data, apparatus and phraseology which have led careless readers to think of it as a new way of running machinery, of paying men, of avoiding labor trouble, of insuring dividends, etc., it is neither more nor less, in its essence, than a proposal to revolutionize our industrial life. Viewed in that light it is a most interesting and suggestive speculation, which well repays close study by engineers. It presents itself to the shops in complete technical detail, a most expensive detail; and many businesses cannot contemplate the years of outlay involved before the returns promised should accrue. The author of the system is entirely frank on this aspect of the case; and system practitioners whose promises have a "get-rich-quick" flavor are certainly not installing the genuine "Scientific Management." The writer believes thoroughly in the principles enunciated by Mr. Taylor, but is of the opinion that they are offered for application in a detailed system too complicated, too rigid and too unyielding for immediate application to every-day needs.

Shop management is an art rather than a science. It has to deal with too many unknown quantities and variables either to aspire to scientific rank or to adopt a fixed creed. Few individual businesses can afford the interference and expense involved in carrying out effectively the extensive scientific program of the proposal under discussion. By professional societies or national agencies many shop problems still unsolved might possibly be greatly assisted, without the risk of interfering with business; but the installation of the whole machinery of scientific management has been very seldom attempted. Nevertheless, though committal of a shop to one rigid program of outside origin in all its implications—and the control of the business, it must be remembered, is an invariable stipulation—is not, in the writer's opinion, desirable; there is yet plenty of scope for more systematic analysis and regulation of shop processes and expenditures. The business world, and engineers in particular, owe much at present, and will owe more, to the ability and devotion with which the author of "Scientific Management" has elaborated and advocated his particular combination of things old and new.

The Proper Use of System

There are several rules in regard to office and shop routine which the writer would recommend all managements to observe, irrespective of the class of work done.

(1) Have a well considered system of doing things, definite and business-like in all departments; not an imitation of something else, but one designed for your own case.

(2) See that a broad view of the subject is taken, and provision made for properly dovetailing the various department systems.

(3) Make the connection clear to all employees by the use of a self-interpreting organization chart.* Such a table saves much explanation.

(4) Have as little system and as few forms as possible. Make them a means, not an end. There are many daily items of shop practice being perpetuated in expensive card systems today, of which no use whatever is being made or is ever likely to be made.

(5) Do not treat the system as a fetich. It is a good servant but a bad master. So much of it as is justifiable is merely organized common sense. Prune and pare your system until it gives the utmost economy and dispatch.

(6) Do not fail to note closely what your system costs and if it is really paying its way. Very few experts can answer that question. With many it is purely a matter of faith.

(7) Be always on the outlook for improvements and suggestions from any responsible quarter, and be discriminating in adopting them.

The writer has spoken of useless records, with reference to data which need not be recorded at all in permanent form. Some other records are useless because their form renders them so for the purpose of frequent and rapid reference. Still other records are useless because they are inaccurate and unreliable. The writer has heard it urged, in all seriousness, that detailed shop and cost data cannot be trusted; but this is simply a plea for slovenliness, which the users would not tolerate in their own technical spheres. It is just as easy and cheap to collect—almost automatically in a good system—correct figures, as it is to record inaccurate ones; and the man who knows exactly what he is accomplishing will always come out ahead of his competitor who only thinks he knows.

The college boy more and more realizes nowadays that mathematical propositions are few and far between, and stiff commercial and shop problems many in the practical engineering field; but a good deal of dearly-bought experience could be purchased more cheaply, the writer believes, if more of the money expended in our universities was devoted to lectures by practical men on the real needs and practice of every day manufacturing life. It is a hopeful portent that the manager and his assistants are no longer too busy to interest themselves in the details of factory accounts. These become, when properly presented, exceedingly interesting and suggestive documents; and the amount of modern system which we need bids fair to amply justify itself, particularly in lean years, by its results. The rest is dead-weight and should go promptly overboard.

The Variety of Management Problems

Systems of management are necessarily as various in their details as the business conditions which have to be met. The simplest condition is that of a concern manufacturing a thoroughly standardized product, which, under no circumstances, will they adopt or modify for special use. As a business policy this may be carried too far, and the product may be out of date before the fact is realized. In such a business, however, at one sweep many of the difficulties experienced by general engineering concerns are disposed of; and attention can be concentrated on a limited number of definite problems, the satisfactory solution of which may be attained by gradual and experimental stages.

In plants in which standardization, a manufacturing basis of business, and reason-

*In his original address the author illustrated this point by presenting an actual chart which showed graphically the subdivision of the manager's control over the executive and manufacturing departments, and their various sub-departments.

able frequency of improved product, are carried out to their fullest extent, the shops and executive staff have practically no necessary relation with the customer. They deliver the finished product to the warehouse of the sales organization, and the problems which their system should solve are purely internal. The lighter machinery manufacturers of standardized contrivances are embraced in this class.

At the other end of the scale we have the business in which a complication of agencies, some within and many outside the plant, must be skillfully tied up to each other by red tape. As little as possible of red tape is required, however, if they are to produce the desired results by a given time. These problems of successful management include such industries as shipbuilding, or mechanical operations dependent upon the simultaneous progress of civil engineering work at a distance, as well as work involving combinations of contracts.

In a class by themselves are problems like ship-docking and repairing, and locomotive overhauling, where *the time during which a large investment is earning nothing is a governing consideration.* Between these extremes, i.e., where cost is the determining factor on one hand, and speed of completion on the other, there are all possible variations, no half-dozen of which could be efficiently managed on precisely the same system.

The Engineer and Shop Management

The writer's own philosophy and practice in the economic administration of industrial establishments are the development of a quarter of a century's experience in the shops, ranging from the designing and engineering involved in the building of ships, locomotives, stationary engines and mill machinery, to the manufacture of coal-handling plants, typewriters and adding machines. These twenty-five years have been marked by a steady extension of the engineer's art which now underlies a large part of our modern civilization. The development, however, has been intensive as well as extensive. Within the shop the managing engineer and his staff have advanced, from a position of more or less subordination to clerical controllers under the general system, to a position involving no mean understanding of the once mysterious departments of accounting and costing. In many cases through the domination of the engineer in management, empirical rating and arbitrary labor in shop practice have become things of the past.

The minute sub-division of processes in manufactures was predicted and its advantages set forth in 1776 by Adam Smith, the Scotch philosopher at the University of Glasgow and the eminent author of "The Wealth of Nations." Sixty years later the principle was firmly established; and Charles Babbage, the noted English mathematician and mechanician, described in 1834 in his "Economy of Machines and Manufactures" the minute division of labor in repetition work obtaining in his day, in various industries which he cited. He also furnished a complete philosophy of the subject, with examples of calculations as to the limits of reasonable investment in labor saving machinery. Industries, such as textiles, in which machinery reigned supreme at a very early stage, were most affected by the new principle, which evolved quite naturally with the dawn of modern industrialism.

In our own day practical political economy has been somewhat neglected by engineers; and three-quarters of a century after Babbage we find the division of labor by machines carried much farther than the divisions of handicrafts which he also advocated and described. In many cases with us the "trade" is still the economic unit instead of the "task," and this is particularly so in the metal-manufacturing and the building industries. Not only so, but labor has shown no disposition to improve the "trades," many of which are notoriously wasteful of time and effort. There can be little doubt in these days, when the high cost of living is a live topic, that economic necessity, if not inclination, will finally drive us to take up, in all seriousness, the conservation and intensive application of human energies in every department of activity, distributive as well as productive; and that new avenues of usefulness will open up for the production engineer.

Proceeding from the foregoing general principles, the author of the paper sets out to show how they may be applied to the solution of a concrete problem, citing the case of the Remington Typewriter Works, at Ilion, N. Y. In dealing with this administrative problem, there are involved the economic handling of 2500 work people, of whom 500 are females, and the production of about 100,000 typewriting machines a year. In solving the problem, the aim has been to evolve an organization scheme of executive and manufacturing departments, reporting to one manager, which will be capable of producing daily the full quantity of machines in all their required varieties, by the most efficient shop and labor arrangements, and with a minimum of fixed and cash capital locked up in the process.—Editor.

AUTOMATIC REGULATION OF DIRECT CURRENT MACHINES

By H. A. Laycock

Power and Mining Engineering Department, Schenectady

This article describes the operation of several recent types of automatic regulators; voltage regulators for single direct current generators compensating for armature drop, falling speed, and line drop, by field control; a regulator for motor-generator sets, maintaining the motor speed with varying impressed voltage as well as controlling the generator field; a regulator for Edison 3-wire systems; and a speed regulator for constant speed direct current motors. Previous articles on automatic regulators by the same author have appeared in the Review as follows: "Regulators for Alternators" (June, 1909); "Constant Current Regulators" (Dec., 1909); and "Power-Factor Regulators" (Jan., 1910).—Editor.

The voltage regulation of direct current generators is a difficult task to accomplish with the present isolated installations. A number of difficulties arise in controlling

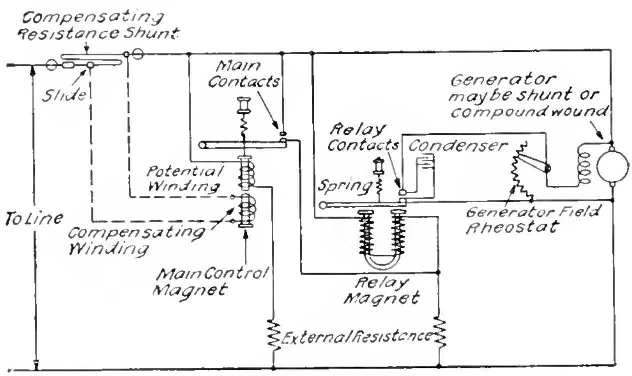


Fig. 1. Connections of Voltage Regulator for Small Direct Current Generators

the voltage of the direct current generators when these generators are subjected to heavy motor loads. In the first place, the standard installation for office buildings, apartment houses, hotels, etc. is to use a slow speed engine-driven generator. In designing a slow speed generator the drop in the armature is considerable. The average load usually is about 25 per cent. lighting and about 75 per cent. elevators; and when the elevators start up, not only is there a momentary rush of current through the armature of the direct current machine such as to produce an internal drop of about 8 per cent., but further the speed of the engine will fall off about 2 per cent., thus making 10 per cent. This together with about 1 per cent. line drop gives a total of 11 per cent. internal drop, without considering the shunt field of the generator at all.

The problem, therefore, of regulating these plants has been a very difficult one, since the automatic regulator, to be of use, must necessarily be applied to the fields of the generator. The generator should be designed with a short magnetic circuit so that it shall be quick to respond to changes in field strength, in order to overcome the momentary losses in the generator as well as the dropping off in speed of the engine. There are several quick acting automatic regulators which operate directly upon the fields of the direct current generators, and in which the time element in the regulating equipment is practically eliminated.

Fig. 1 shows a voltage regulator for small direct current generators. This regulator is designed with a shunt magnet connected across the busbars of the generator and so adjusted that the special metal contacts float at a given voltage. The composition of these special contacts is such that any possibility of arcing or freezing is entirely eliminated. These contacts open and close a very sensitive relay which is also equipped with a pair of secondary contacts using a condenser across same to absorb the arc, the secondary contacts being connected directly across the shunt field rheostat of the generator. The latter is adjusted to such a position that, without the regulator, it will reduce the voltage to about 35 per cent. below normal, after which the regulator switch is closed and the rheostat is short-circuited. The voltage would then build up instantly to full field if it were not for the fact that the spring, counter-balancing the main contacts against the pull of the shunt magnet, is such that the main contacts open at normal voltage, thus tending to insert suddenly 35 per cent. of the field rheostat. The voltage instantly tries to fall, at which time the main contacts close.

With this cycle of operation the regulator is operating from 200 to 600 times a minute, depending upon the time element in the fields of the generator. For a high speed generator designed on fairly low saturation the time element is very much less, and will regulate very much closer than a machine running at low speed designed on higher saturation. The internal drop of the armature in a high speed machine is materially less than a slow speed machine and the regulation therefore is much better.

In addition to the shunt coil of the main control magnet there is a series coil which is connected to a shunt in the main line circuit, or feeder, which will automatically compensate for the drop in the line up to 15 per cent. The action of the current coil is such as to oppose the potential coil, thus allowing the spring to close the main contacts and build up the voltage in proportion to the drop in the line. In this connection the voltage is held constant at some distant point, the busbar voltage being raised and lowered to overcome this drop. This regulator is particularly adapted to generators which are driven from shunt wound motors upon which the impressed voltage varies over a wide range, thus causing variations in speed and in generator voltage.

Fig. 2 shows the connections of a voltage regulator connected to a motor-generator set of which the impressed voltage on the motor varies to such an extent that it is impossible by controlling the field of the generator alone, to hold up the voltage, due to the drop in speed on the motor. In cases of this kind the same type of regulator is used having a second relay, which operates in the reverse direction to the first relay. One set of relay contacts short-circuits the generator field rheostat; while the second set of relay contacts, being reversed, cuts in resistance in the motor field rheostat, thus increasing the speed so that it is possible to hold constant voltage on the generator. When the speed tends to increase the reverse action takes place, i.e., the first set of contacts cuts in resistance on the generator and cuts out resistance on the motor. By this connection, a motor-generator set which is subjected to a broad range of impressed voltage, such as occurs when it is connected to a trolley circuit, can be regulated with perfect satisfaction.

Fig. 3 shows the connections of a voltage regulator, for use with slow speed generators for larger

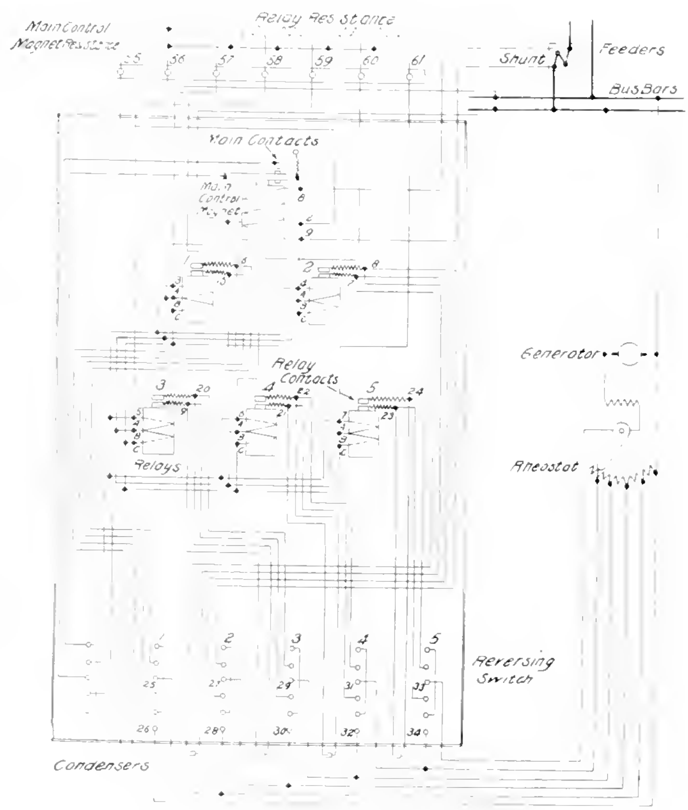


Fig. 3. Connections for Large Slow Speed Generators

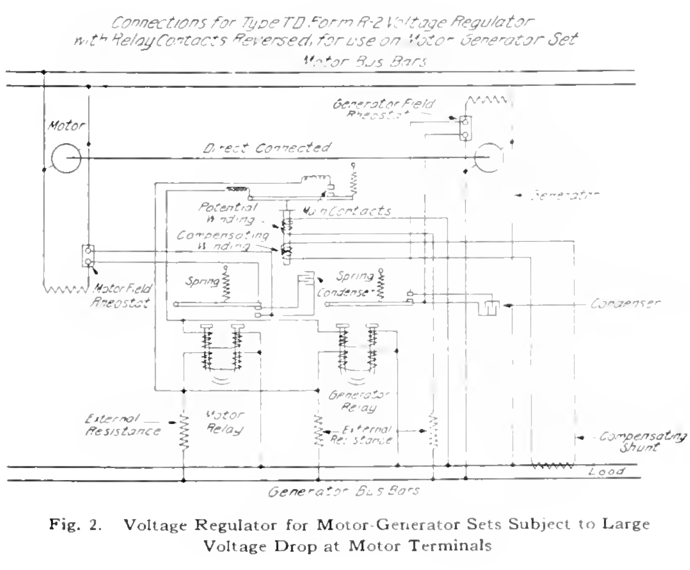


Fig. 2. Voltage Regulator for Motor-Generator Sets Subject to Large Voltage Drop at Motor Terminals

work. Theoretically the operation of this regulator is the same as the smaller regulator previously described (Fig. 1) with the exception that it is designed with from two to twelve relays. The diagram showing

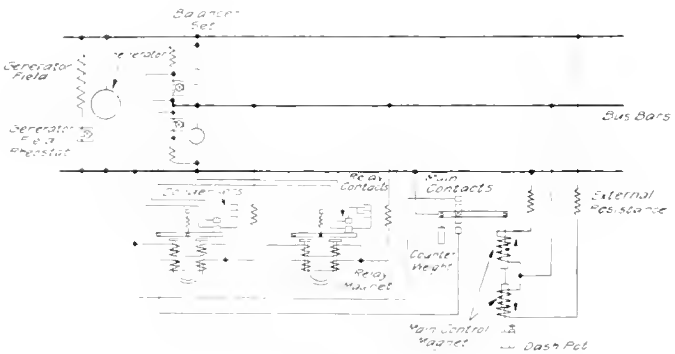


Fig. 4. Regulator for Edison Three-Wire System Employing Two Generators

the connections is for a 5-relay regulator connected to one large generator, the main contacts of the regulator controlling all 5 relays. The generator field rheostat is divided into 5 equal ohmic sections, having a set of contacts across each section so as to handle the discharge from the large machine. This type of regulator can also be used for compensating for line drop by the addition of a shunt, in the same manner as the regulator previously described.

For Edison three-wire systems, where two generators are employed to obtain the neutral, and where the load is unbalanced to an extent that varies the voltage between the neutral and the outside, the regulator shown in Fig. 4 is used. This regulator is designed with two shunt coils, each connected to one side of the three-wire system, and is equipped with a double set of main contacts. The action consists in either opening or closing a pair of relays operating in opposite directions, so as to open or close the shunt circuit across the field rheostats of the balancers. Thus, if the voltage were high on one side of the system the relay corresponding to that side would have its contacts open, while the relay on the other side would have its contacts closed, and *vice versa*. This regulator will keep the neutral on a three-wire system in perfect balance from practically no load to full load.

There are any number of special applications for voltage regulators for direct current work which would come under a special heading. Probably the most useful of these automatic regulators is the one shown in Fig. 5, which is an automatic speed regulator for shunt wound motors.

Frequently on motors driving printing presses, looms, etc., where constant speed is required irrespective of load or voltage, it is necessary to have an automatic device which will hold this speed constant. The regulator in question is designed with a centrifugal governor, arranged with a pair of contacts known as the main contacts, the governor being mounted on the end of the shaft by one bolt. As the governor is set at a given speed the contacts will just open; before cutting in the governor the rheostat of the motor is first cut in, so that the machine runs at a slightly higher speed than is wanted with the maximum load or voltage drop. A relay is used which closes the shunt circuit across the motor field rheostat, and to this relay the contacts are connected in such a manner that when they close the motor immediately begins to slow down; but as soon as this takes place the adjustment is so close that the governor will open the contacts and the resistance be immediately cut in. In this manner they will operate at a high rate of speed, in a similar way to the ordinary voltage regulator. The speed can be kept at a constant value with a

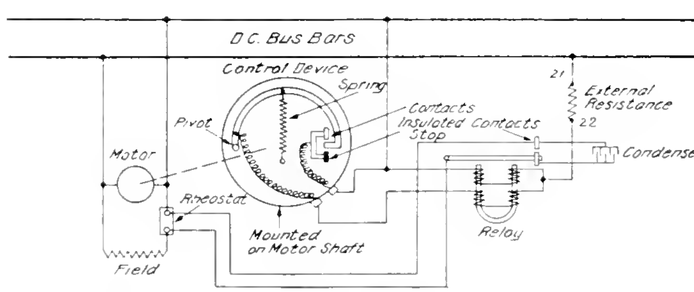


Fig. 5. Regulator for Controlling Speed of Shunt Wound Motors

broad range of impressed voltage, or throwing on or off of heavy load on the motor. This device is made in larger sizes, depending on the requirements. There is a secondary contact arranged on the governor so that, in case anything should happen to the regulating mechanism, the contacts will be closed across the motor field rheostat, thus reducing the speed instead of increasing it.

It can be noted from the description of the automatic regulators given in this article that the time element is practically negligible. The other forms of voltage regulators which have been tried in connection with direct current generators have been either motor-driven or solenoid-operated rheostats or carbon plate resistances, in which the voltage had to change materially before the operation of these devices attempted to regulate at all. Naturally they were entirely too slow to catch a sudden load, and thus a perceptible flicker in the incandescent lights was noticeable.

DELTA-DELTA TRANSFORMER BANKS IN MULTIPLE

By W. W. Lewis

Transformer Engineering Department, Pittsfield

In the November, 1911, General Electric Review, Mr. L. F. Blume gave the solution of the problem of the division of current in legs of a delta-delta bank of transformers, one leg having impedance different from that of the other two.*

A particular application of this problem occurs when one transformer of two or more delta-delta banks of transformers operating in multiple becomes disabled, necessitating the operation of the two remaining transformers of that bank in open delta, in multiple with the complete deltas of the other banks. Or, if it is desired to operate in delta three transformers, one having impedance different from that of the other two, the solution given by Mr. Blume may be used to determine what load can be carried on the combination, and how the current will divide in the individual transformers.

In the discussion that follows these assumptions are made:

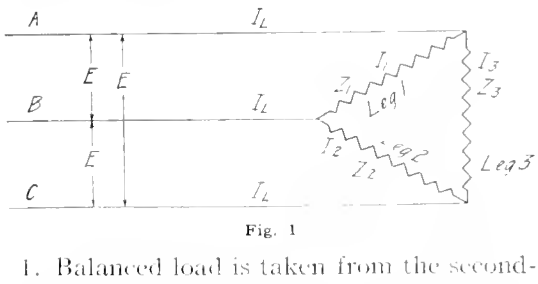


Fig. 1

1. Balanced load is taken from the secondary.

2. The impedance angles of the three legs are equal, i.e., in each leg the proportion of resistance to reactance is the same.

3. The ratio of all the transformers is the same.

* Three-Phase Vector Representation, by L. F. Blume, General Electric Review, November, 1911. The present article is based upon a contribution to a discussion before the Pittsfield section of the A.I.E.E., to whom Mr Blume's original paper was presented

One side (the load side, for instance), of a delta bank of transformers may be represented as in Fig. 1. It is assumed that the impedances of all the transformers are

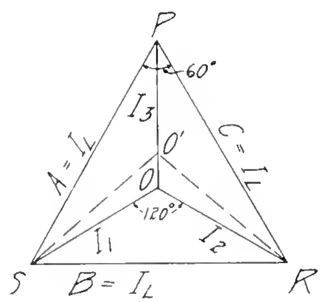


Fig. 2

alike. Fig. 2 is the current diagram, $I_1 = I_2 = I_3 = I_L/1.73$, 120 deg. apart, representing the currents in the three legs; $A = B = C = I_L$, 60 deg. apart, representing the line currents; $Z_1 = Z_2 = Z_3$ representing the impedance. If the impedance of leg 3 is increased (the ratio of reactance to resistance remaining the same), point O (Fig. 2) will shift to O'; and when Z_3 = infinity, i.e., when all transformers of leg 3 are removed, point O will coincide with point P; and, assuming the line currents to be unaffected by the change in impedance, the following relations will hold:

$Z_1 = Z_2$
Z_3 = infinity
Current $I_3 = 0$
Current $I_1 = A = I_L$
Current $I_2 = C = I_L$
Current $B = I_L$
Angle SOR = angle SPR = 60 deg.

At any intermediate value of Z_3 between Z_1 and infinity, the point O will occupy an intermediate position O' between O and P, and $O'P$, $O'R$ and $O'S$ will represent the currents in the three legs with the proper phase relation. Angle $SO'R$ will have a value between 60 deg. and 120 deg.

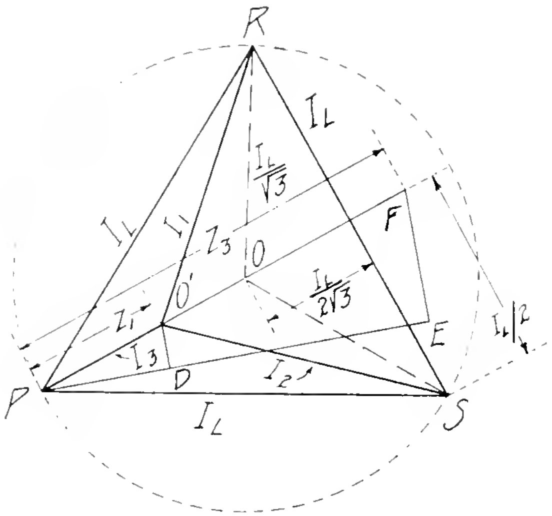


Fig. 3

First Solution, Impedance of Two Legs Equal

In Fig. 1 let

$Z_1 = Z_2$

$\frac{Z_3}{Z_1} = \frac{Z_3}{Z_2} = r$

$I_1 = I_2 =$ total current in legs 1 and 2

$I_3 =$ total current in leg 3

$I_L =$ line current.

In Fig. 3 triangle $PO'D$ represents the impedance triangle for legs 1 and 2, and triangle PFE the impedance triangle for leg 3. $O'O =$ one-third $O'F$. With O as a center and with OP as radius, a circle is described, and the inscribed triangle PRS constructed. Then PR, RS and PS represent the currents in lines A, B and C, and $O'R$, $O'S$ and $O'P$ represent the currents in legs 1, 2 and 3.

It may be found by a consideration of Fig. 3 that

$$I_1 = I_2 = \frac{I_L}{r+2}\sqrt{r^2+r+1} \qquad (1)$$

$$I_3 = \frac{\sqrt{3}\, I_L}{r+2} \qquad (2)$$

It is usual to express impedance in terms of the corresponding per cent. voltage drop and transformer rating. As

$$Z = \frac{(\text{per cent. } IZ)\, E^2}{(\text{kv-a.})\, 10^5}$$

the above expression for the ratio r may be modified as follows:

$$r = \frac{Z_3}{Z_1} = \frac{Z_3}{Z_2} = \frac{(\text{per cent. } IZ)_3\, (\text{kv-a.})_1}{(\text{per cent. } IZ)_1\, (\text{kv-a.})_3}$$

$$= \frac{(\text{per cent. } IZ)_3\, (\text{kv-a.})_2}{(\text{per cent. } IZ)_2\, (\text{kv-a.})_3}$$

in which

$(\text{per cent. } IZ)_1 = (\text{per cent. } IZ)_2 =$ per cent. impedance drop of legs 1 and 2,

$(\text{per cent. } IZ)_3 =$ per cent. impedance drop of leg 3,

$(\text{kv-a.})_1 = (\text{kv-a.})_2 =$ rated output of legs 1 and 2,

$(\text{kv-a.})_3 =$ rated output of leg 3.

(1) and (2) are the equations of current in the legs of the delta for different values of the ratio r.

These equations may be expressed thus:

$$\frac{I_1}{I_L} = \frac{I_2}{I_L} = \frac{\sqrt{r^2+r+1}}{r+2} \qquad (3)$$

$$\frac{I_3}{I_L} = \frac{\sqrt{3}}{r+2} \qquad (4)$$

In Fig. 4 are plotted equations (3) and (4) for values of r from 0 to 10. It will be noted that curve (3) is asymptotic to 1.0, and that curve (4) is asymptotic to zero, i.e., when $r =$ infinity, $I_1 = I_2 = I_L$ and $I_3 = 0$.

When r approaches indefinitely close to zero, the curves must be used with caution. At the limit when $r = 0$, Z_1 and Z_2 are infinitely great with respect to Z_3; which means that,

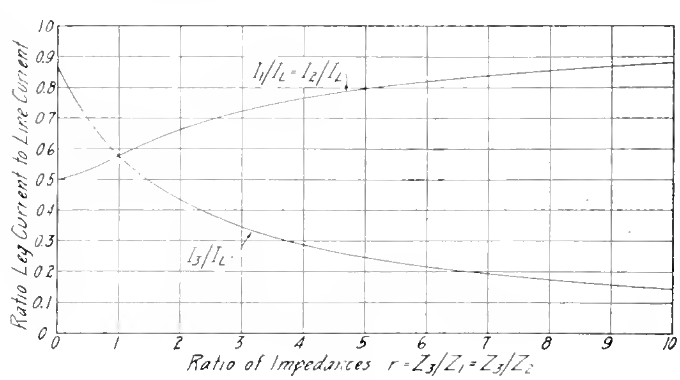


Fig. 4

in order to maintain balanced line currents, the impedance drops across legs 1 and 2 must be infinitely great compared with the impedance drop across leg 3. This leads to impractical conditions. The curves are reasonable, however, within a very wide range.

Example 1:

Assume one transformer missing in two delta-delta banks of like transformers operating in multiple (Fig. 1, two transformers each in legs 1 and 2, and one transformer missing from leg 3). It is apparent that

$$Z_3 = 2\ Z_1 = 2\ Z_2,$$

or

$$r = \frac{Z_3}{Z_1} = 2.$$

Substituting $r = 2$ in equations (1) and (2):

$$I_1 = I_2 = \frac{1.146\ I_L}{\sqrt{3}} = 0.662\ I_L$$

$$I_3 = \frac{0.75\ I_L}{\sqrt{3}} = 0.433\ I_L$$

The phase angles of the currents, found by the solution of triangles of which the three sides are known, are as follows

Angle $PO'S$ (Fig. 3) = angle $PO'R$ = 131 deg.

Angle $SO'R$ = 98 deg.

As each transformer has been designed for a current of

$$\frac{0.5\ I_L}{\sqrt{3}} = 0.289\ I_L$$

it is apparent that leg 3 is now carrying 150 per cent., and that each transformer in legs 1 and 2 is carrying 115 per cent. current. To reduce the current to normal in leg 3, it is necessary to reduce the load to two-thirds normal. Then leg 3 will carry normal current and each transformer in legs 1 and 2 will carry 76.4 per cent. normal current. The power-factor of leg 3 is 100 per cent., and of legs 1 and 2, 98.2 per cent.

That is, a reduction of $16\frac{2}{3}$ per cent. in transformer capacity has caused a reduction of $33\frac{1}{3}$ per cent. in output to maintain normal heating. The transformer in the weakened leg (3) will carry normal load, while the transformers in the full legs (1 and 2) will carry three-fourths normal load.

Example 2:

In Fig. 1 let

Rating of transformer 1 = 200 kv-a.
Rating of transformer 2 = 200 kv-a.
Rating of transformer 3 = 300 kv-a.
E = 1000 volts
Normal load = 900 kv-a.
Normal line current = 520 amperes
(per cent. $IZ)_1$ = (per cent. $IZ)_2$ = 3.0
(per cent. $IZ)_3$ = 2.5

Then

$$r = \frac{5}{9}$$

$I_1 = I_2 = 0.534 \times 520 = 278$ amperes
= 139 per cent. rated current.
$I_3 = 0.678 \times 520 = 352$ amperes
= 117 per cent. rated current.

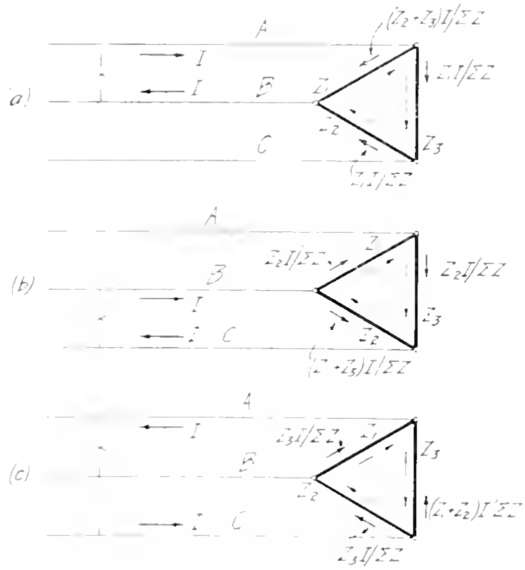


Fig. 5

Therefore, in order not to exceed rated current in any transformer, all currents must be reduced to

$$\frac{200}{278} = 0.72$$

of above, or

$I_1 = 0.72 \times 278 = 200$ amperes
$I_3 = 0.72 \times 352 = 253$ amperes
$I_L = 0.72 \times 520 = 374$ amperes
Output = 0.72 × 900 = 648 kv-a.

The phase angles of the currents may be found by the solution of triangles of which the three sides are known.

Second Solution, Impedance of all Legs Different

The examples above considered relate only to the case of two legs with like impedance, the third leg having different impedance. If, however, the impedances of all three legs are unequal, the problem is more complicated, and is best handled by a second method.

Let Fig. 5 represent the condition when the three impedances are different. Each circuit is loaded independently with a fictitious current I, which equals the normal three-phase line current divided by 1.73, the currents in the three circuits being 120 deg. apart. The arrows pointing toward the delta show the assumed positive direction.

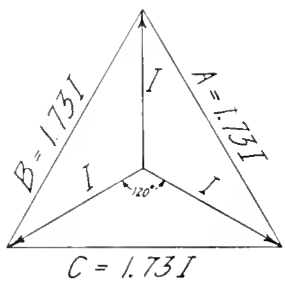


Fig. 6

The long arrows inside the delta indicate the assumed positive direction of the currents in the delta. Fig. 6 shows how the currents I unite to form the line currents, and the arrows indicate their assumed positive directions.

The single-phase currents I divide in the two paths offered in inverse ratio to the impedances, as indicated by the outside arrows in Fig. 5. $\Sigma Z = Z_1 + Z_2 + Z_3$. In Fig. 7 these values of current are plotted to scale in the proper direction. The resultant lines $O'R$, $O'S$ and $O'P$ represent the currents in legs 1, 2 and 3 respectively, and the lines PR, RS and PS, the currents in lines A, B, and C respectively, when three-phase balanced load is placed on the system.

A consideration of this figure leads to the following equations of currents in the three legs:*

$$I_1 = \frac{I_L \sqrt{Z_2^2 + Z_3^2 + Z_2 Z_3}}{Z_1 + Z_2 + Z_3} \qquad (5)$$

$$I_2 = \frac{I_L \sqrt{Z_1^2 + Z_3^2 + Z_1 Z_3}}{Z_1 + Z_2 + Z_3} \qquad (6)$$

$$I_3 = \frac{I_L \sqrt{Z_1^2 + Z_2^2 + Z_1 Z_2}}{Z_1 + Z_2 + Z_3} \qquad (7)$$

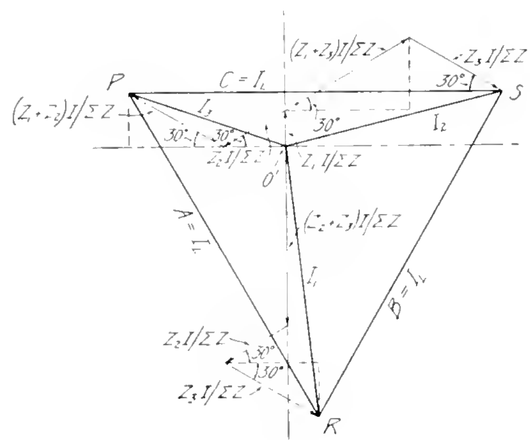


Fig. 7

Substituting in (5), (6) and (7)

$$Z = \frac{(\text{per cent. } IZ)\ E^2}{(\text{Kv-a.})\ 10^5}$$

gives

$$I_1 = \frac{I_L (\text{Kv-a.})_1 \sqrt{e^2 + f^2 + ef}}{M} \qquad (8)$$

$$I_2 = \frac{I_L (\text{Kv-a.})_2 \sqrt{c^2 + d^2 + cd}}{M} \qquad (9)$$

$$I_3 = \frac{I_L (\text{Kv-a.})_3 \sqrt{a^2 + b^2 + ab}}{M} \qquad (10)$$

in which

a = (per cent. $IZ)_1$ (Kv-a.$)_2$
b = (per cent. $IZ)_2$ (Kv-a.$)_1$
c = (per cent. $IZ)_1$ (Kv-a.$)_3$
d = (per cent. $IZ)_3$ (Kv-a.$)_1$
e = (per cent. $IZ)_2$ (Kv-a.$)_3$
f = (per cent. $IZ)_3$ (Kv-a.$)_2$
M = (per cent. $IZ)_1$ (Kv-a.$)_2$ (Kv-a.$)_3$ + (per cent. $IZ)_2$ (Kv-a.$)_1$ (Kv-a.$)_3$ + (per cent. $IZ)_3$ (Kv-a.$)_1$ (Kv-a.$)_2$

* In Fig. 5 (a) the admittances of the two parallel paths from A to B are

$$g_1 = \frac{1}{Z_1}$$

$$g_2 = \frac{1}{Z_2 + Z_3}$$

and the total admittance

$$G = \frac{1}{Z_1} + \frac{1}{Z_2 + Z_3}$$

Current I divides into two parts such that the current in each path is to the total current I as the admittance of each path is to the total admittance G.

$$\text{Current leg 1} = \frac{1/Z_1}{1/Z_1 + 1/(Z_2 + Z_3)} I$$

$$\text{Current legs 2 and 3} = \frac{1/(Z_2 + Z_3)}{1/Z_1 + 1/(Z_2 + Z_3)} I$$

which equations simplify to

$$\text{Current leg 1} = \frac{(Z_2 + Z_3)\ I}{Z_1 + Z_2 + Z_3} = \frac{(Z_2 + Z_3)\ I}{\Sigma Z}$$

$$\text{Current legs 2 and 3} = \frac{Z_1\ I}{Z_1 + Z_2 + Z_3} = \frac{Z_1\ I}{\Sigma Z}$$

In like manner the division of the current I indicated in Figs. 5 (b) and 5 (c) takes place. The final current in each leg (I_1, I_2 and I_3) is the resultant of the three components thus found, 120 deg. apart. These components are plotted in Fig. 7, and from this figure we find:

$$I_1 = \sqrt{\left(\frac{(Z_2 + Z_3)\ I}{\Sigma Z} + \frac{Z_2\ I}{\Sigma Z} \sin 30^\circ + \frac{Z_3\ I}{\Sigma Z} \sin 30^\circ\right)^2 + \left(\frac{Z_3\ I}{\Sigma Z} \cos 30^\circ - \frac{Z_2\ I}{\Sigma Z} \cos 30^\circ\right)^2}$$

which may be simplified to equation (5).

In like manner the expressions for I_2 and I_3, equations (6) and (7), are derived.

Example 3:

Let rating of transformer 1 = 100 kv-a.
Let rating of transformer 2 = 150 kv-a.
Let rating of transformer 3 = 200 kv-a.

$(\text{per cent. } IZ)_1 = 3.5$
$(\text{per cent. } IZ)_2 = 3.0$
$(\text{per cent. } IZ)_3 = 2.5$
$E = 1000$ volts,
Normal load = 600 kv-a.
Normal line current = 346 amperes.

Then by equations (8), (9) and (10):

$I_1 = 0.42 \times 346 = 145$ amperes
= 145 per cent. rated current,
$I_2 = 0.64 \times 346 = 222$ amperes
= 148 per cent. rated current,
$I_3 = 0.71 \times 346 = 246$ amperes
= 123 per cent. rated current.

Therefore, it is necessary to reduce all the currents to

$$\frac{150}{222} = 0.676$$

of the above, in order not to overload any leg. Then

$I_1 = 0.676 \times 145 = 98$ amperes,
$I_2 = 0.676 \times 222 = 150$ amperes,
$I_3 = 0.676 \times 246 = 166$ amperes,
$I_L = 0.676 \times 346 = 234$ amperes,
Output $= 0.676 \times 600 = 406$ kv-a.

The phase angles of the above currents may be found by the solution of triangles of which the three sides are known.

Third Solution

A third solution of this problem was given in the *Electrical World* of May 26, 1910,* and leads to results identical with the above. This solution depends on the number of similar units in each leg, and is applicable whether the numbers of units (p, q and r) in the three legs are equal or unequal.

Impedance Angles Not Equal

In the foregoing solutions it has been assumed that the impedance angles ($O'PD$ and FPE, Fig. 3) are equal, which is the case when the resistance and reactance bear the same relation to each other in the different legs. The more general case of one transformer having impedance different from the other two and also a different impedance angle, is treated graphically by Mr. Blume. When the impedances and impedance angles of all three legs are different, the solution becomes quite complicated. No attempt will be made to solve the general case here, as the assumption that the impedance angles are equal permits equations that are simple and accurate enough for most practical purposes.

* "Transformer Currents in Weakened Deltas," by Nicholas Stahl, *Electrical World*, May 26, 1910.

ELECTRIC ADVERTISING SIGNS

By G. H. S. Young

of the N. Y. and Q. Electric Light and Power Company

This article gives the reasons why, in the author's judgment, there should be a better co-operation between the sign manufacturer, the lamp manufacturer, and the central station, in order to develop the advertising sign business to its fullest extent. The lines along which attention should be directed are indicated; and point is given to these contentions by examples from the author's wide personal experience.—Editor.

The object of this paper is to urge the desirability of better co-operation between the three important parties, the electric sign manufacturer, the central station, and the lamp manufacturer. The reasons for these three parties getting together, working along similar lines, and talking one and the same kind of talk, are:—

1st. The central station cannot sell its product without the current-consuming appliances, which, in this discussion, are embodied in the electric advertising sign.

2nd. The electric sign manufacturer cannot conduct a successful business without the central station supply of current, and the assistance of the central station in installing and maintaining the signs.

3rd. The lamp manufacturer has no outlet for his product for this class of work without the sign manufacturer and the central station.

Many central stations have done as much as is at the present time practicable along these lines—for maximum sale of current, which naturally also means signs and lamps; many more central stations *think* they have done and are doing everything possible and practicable and getting the best results obtainable, as to peak load conditions and income, in their respective sections; and still many more are making a bad failure of their efforts and opportunities. This criticism is the result of visiting and working with many central stations in the east, studying reports and conditions of others, and discussing the matter with central station men and supply men from many sections of the country.

I have seen central station companies obtain what might be termed "wonderful maximum development of electric sign lighting" by getting merchants, both large and small, to put up electric signs, thus obtaining a large connected load; and yet fail in obtaining the maximum *income* and *steady* load. Signs connected on a meter basis will not be operated long hours or in bad weather. I have seen other central station companies obtain maximum development of both the *steady* connected load, and *income*, by getting as many sign manufacturers as possible to work on every prospect, and fail in maintaining the maximum load income after the first or second year. This condition is due to the cheaply constructed class of signs put up by manufacturers to meet competition; lack of harmony in colors and effects; and blowing or falling down of badly installed signs. In this last mentioned case, usually there are failures of sign manufacturers who were over-anxious to get the business. Prohibitive ordinances are afterwards passed by the City, in consequence of accidents due to signs falling; or due to the action of some merchants in trying to get their signs far out over sidewalks so that they might the better be seen; or putting up "freak signs" and so infringing on the rights of others and the public at large, and compelling demands for reform from city improvement societies.

In other cities, where prohibitive ordinances have been in force for a year or more, after the removal and destruction of many thousands of dollars' worth of freak and badly constructed signs, central stations have been afraid to ask for "a safe and sane" ordinance, and usually have done nothing towards obtaining a sign load and income until the old managers have retired and more progressive men have been put in charge. Men who have had the combined central station, sign engineering, designing and sale-promoting experience—necessary in order to successfully electrify a city—are seldom consulted or employed, and mistakes of the past twenty years are repeatedly being made. These conditions affect all the three factors first mentioned. A definite illustration of an average city of say 150,000 population may lead to a better understanding of the subject; and I will assume the following load-income condition which I have found obtainable, and which should be maintained from year to year.

Number of signs	300
Average number of lamps per sign	100
Number of connected lamps	30,000—5 watt
Kilowatts connected	150
Flat rate average per month	100 hours
Kilowatt-hours per month	15,000
Income per year at 7 cts. net	$12,600.00

This load should not be difficult to obtain and maintain in any city of 150,000 population, and I would not consider it "maximum development."

To electrify a city successfully the central station should see that the building fronts on commercial streets are "cleaned up," that is, that all projecting wood and cloth signs are removed, by ordinance or otherwise; and that a new ordinance permits only *metal signs* with at least one lamp per square foot of sign surface. This rule will give the city some street illumination, which they would not obtain from wooden painted signs or glass transparencies, in return for the privileges granted of projecting the electric signs over the public sidewalks.

The ordinance should specify electric signs constructed entirely of metal, hung with galvanized iron chains and irons, and should permit these signs to project from the building line at least six feet over the sidewalks; the bottom of such signs to be ten feet above the sidewalk, perpendicular signs ten feet or more long to be fitted with a re-lamping ladder.

Considering the legal conditions previously stated, it must be borne in mind that each electric letter must have a space on the sign of at least one foot square, and that such letters require an average of at least six lamps each; these are minimum requirements. For signs on building fronts the central station can obtain *horizontal signs*, projecting at right angles to the building, which are usually double-faced; *single-faced signs*, placed across the front of building; *V-shape signs*, consisting of two single-faced signs joined at the apex, the two ends fastened to the building; or *vertical signs* wich are usually double-faced.

The rights of tenants of adjoining buildings must be considered and not infringed. The sign man is often asked to furnish a sign reading "restaurant," double-faced, to project at right angles to the building; it is quite apparent that this is impossible with a 6 foot ordinance, and that at least 10 feet would be necessary. Such a sign can, however, be placed V-shape, but requires a space at least 16 feet wide across the front as each section would be 10 feet long. It must be remembered that space between letters is essential. A sign such as this with letters 12 inches high could not be read at a greater distance than about 400 feet.

Some time ago a central station man wrote to a firm of sign manufacturers, with which the writer used to be connected, inquiring for a design and price on a sign to read "drugs." He stated that his prospect wanted a sign exactly like "Jungman's," New York City. A design and price was at once sent him, and it was then found that the city ordinance would not allow a sign to project over three feet; Jungman's sign required seven feet. Nothing further was heard from this prospect. This central station had employed a sign man at a salary of $125.00 per month, and he had been working about three months. He reported that he had ten to fifteen good prospects which he believed could be closed if the manufacturers' representative would spend a few days with him. The trip was made and three days spent in calling on the prospects, getting up new sketches, and making prices; but not a single order could be closed, largely because the merchants had had larger and better signs first presented to them which they found could not be installed.

If we consider the total cost of this mis-spent effort, the necessity for a careful consideration of the simple facts contained in this paper will at once be apparent to all concerned.

The solicitor's salary amounted to about	$375.00
His expenses, at 50 cents per day	39.00
Central station overhead expenses estimated at	20.00
Manufacturer's representative expenses	25.00
Designs and postage	10.00
Newspaper and circular advertising about	100.00
Total	$569.00

These facts were at once placed before the general manager and a positive plan of operation decided on. As a result of well-directed effort, a new ordinance was obtained which permitted electric signs to project ten feet from the building; arrangements were made with the central station construction department to properly instal and connect signs, and a schedule of prices was made up to cover such work, which was included in the contract of sale of the sign; a flat rate contract was drawn up covering all lamps, turning on and off of signs, cleaning lamps and signs, and in fact, keeping them in operation from dark to 11 P.M. every night, based on a seven cent per kw-hr. rate worked out, with a contract form covering service for not less than one year. This resulted in perfecting a sign department having all departments working with and assisting it. Designs are so ordered that they fit the prospect, and in many cases are closed on submittal. Merchants have been led up to purchasing signs costing from $300.00 up, using a correspondingly larger number of lamps; whereas it was previously difficult to get them to spend more than about $100.00—and the commercial part of the city is being gradually beautified and "electrified."

Merchants must be educated up to consider an electric sign as the most important fixture of their business. It is out in front, seen every day and night, and a better impression is made on the public with an electric sign which costs $500.00 than with a gold-plated cash register, costing about the same amount.

Architects generally do not approve of electric signs on new buildings. Recently a fine hotel building was erected in New York City; it was a handsome monument to the architect's skill, and he would not approve of any kind of a sign on the exterior. The proprietor agreed with him, saying that he was so well known that the public would find him without an electric sign. Several months passed and the business did not prosper and his creditors became worried. One day a drayman who had goods to deliver there, asked one of the hotel employees where the particular hotel was located, stating that he had driven around the block several times and could not find the place. This employee told the proprietor and an electric sign was finally placed. They tell me that their receipts at once increased several hundred dollars per week.

A carefully planned and properly executed scheme to "electrify a city" often starts a local boom, and results in better business conditions, improvements in building fronts and increase in values. In this connection I wish to cite the case of the city of Rochester, where I believe the efforts to electrify the city constituted a considerable factor in the improved "convention city" as we see it today, as compared with only about four years ago. This work should be carried out to some extent with the co-operation of the local board of trade, but the central station should assume full responsibility for securely placing and taking care of electric signs, and should see that they do not become dirty and unsightly. The cost of such attention can easily be merged with the flat rate contract.

MEETING OF TRANSFORMER SPECIALISTS

The first annual meeting of the General Electric Transformer and Regulator Specialists was held in Pittsfield, October 17th, 18th and 19th, with headquarters at the Maplewood Hotel, where all sessions convened.

The specialists were given an opportunity to discuss with the designing engineers and the general office representatives situations existing in the field. Special market requirements were given careful consideration, and suggestions received for the further standardization of transformers for the higher voltages now coming into common use for distribution purposes; in fact, every phase of the business was thoroughly discussed.

The morning sessions and short afternoon sessions were followed by trips through the shops under the direction of the designing engineers, so that material covered by the various papers could be thoroughly inspected. Each specialist received a book containing all of the papers read at the meetings, which papers were very completely illustrated with the most recent photographs of the apparatus under discussion.

BOOK REVIEW

CENTRIFUGAL PUMPS

By Louis C. Loewenstein, E.E., Ph.D.

and

Clarence P. Crissey, M.E.

D. Van Nostrand Co. 435 Pages Price $4.50 Net

This book contains 320 illustrations and 8 folding plates, and fills a long felt want in the literature on the subject. It gives a large amount of useful information concerning the theoretical design of centrifugal pumps, which could only be obtained previously in German publications; and in addition contains chapters on the Design of Impellers, Diaphragms, Casings and Heads, Critical Speeds of Shafts, and a large amount of information concerning the types of pumps made by the best known manufacturers of Europe and America. A number of curves are given showing the performance of various types of pumps.

The scope of the book is well shown by the following quotation from the preface:

"The object of this book is to present to those interested in centrifugal pump manufacture and design, and to technical students, a clear presentation of the fundamental principles involved, a full explanation of the calculations necessary in securing the best efficiencies and performance, a proper understanding of the constructive details of the various types, the best methods of manufacture and a correct knowledge of the proper proportions of pump parts in order to secure safe and smooth operation. The authors have made use of material furnished from many sources. Much of the theoretical presentation was obtained from *Die Zentrifugalpumpen*, with the kind permission of the author, Mr. Fritz Neumann. Dr. H. Lorenz's recent publication *Neue Theorie und Berechnung der Kreiselrader* has also been quite helpful. The theory presented by Dr. Lorenz is based upon the calculation of the flow of fluids by means of three dimensional equations as compared to the prevalent practice of using two dimensional equations. A new and welcome point of view is secured by this theory, but as yet it has not been sufficiently developed to supplant the older and more generally accepted methods of calculation. The constructive details of the various types and makes of pumps were obtained in most part from manufacturers and the technical magazines. The methods of calculating the strength of impellers, casings and diaphragms, and the critical speeds of high-speed pumps have been used by the authors for a number of years and are partly their own work and partly based upon the results obtained and published by other investigators."

Maxwell W. Day.

GENERAL ELECTRIC REVIEW

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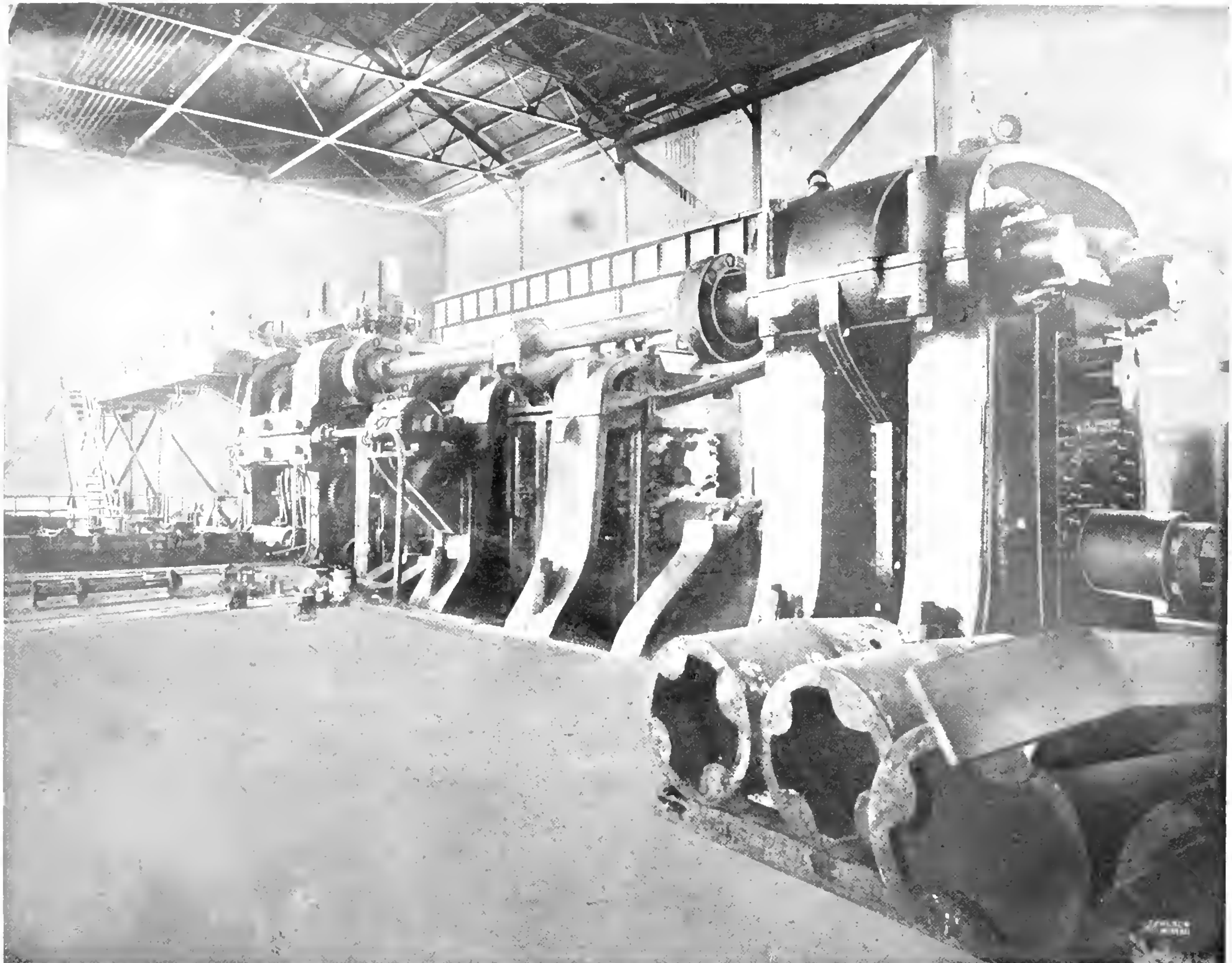

Main Rolls of Universal Plate Mill, driven by 6500 H.P. Induction Motor, Indiana Steel Company, Gary, Indiana

(See Page 81)

GENERAL ELECTRIC REVIEW

TRANSIENT ELECTRICAL PHENOMENA

In this issue we are commencing a reprint of the paper on "The Nature of Transients in Electrical Engineering," which was prepared by Dr. C. P. Steinmetz for the International Congress on Applied Electricity, held at Turin, September, 1911. This subject Dr. Steinmetz has made peculiarly his own, and the paper in question represents the most noteworthy contribution to its literature which has been made during the last twelve months.

An electrical transient is defined as the phenomenon by which at a change of circuit conditions the stored magnetic and dielectric energy of an electric system readjust themselves to the changed circuit conditions. In the earlier days of the industry investigations on transients of a relatively simple character were carried out to determine such questions as the ability of a generator to build up from its residual magnetism, the rapidity with which a compound generator would respond to changes of load, and other matters. Nowadays a study of the subject of transients is necessarily concerned with more complicated problems which have arisen with the growth of the modern supply systems, such as, for instance, the discharge of generator fields, the starting currents of transformers, the short-circuit of turbo-alternators, and so on. The question of high frequency and high voltage line disturbances also provides a fruitful field for the study of the nature of transients, on account of the great destructive power which such disturbances possess in a modern network of lines of high and medium voltage and power, overhead and underground, interconnected at various points.

The paper commencing this month gives a complete mathematical analysis of transient phenomena in transmission circuits. Such transients may be divided into two classes. First, there are single-energy transients which exist in circuits storing energy in only one form, usually magnetic, and in which the transients can only consist in a change in the amount of energy stored. Transients in low voltage circuits, and even in primary distribution circuits of 2300 volts, may be considered as single-energy transients, since the stored dielectric energy is negligible and the only appreciable quantity is the stored magnetic energy. Secondly, there are double-energy transients which exist in circuits storing energy in the form of both magnetic and dielectric energy, and in which there is a change of energy from one form to the other in addition to a change in the amount of stored energy. In considering transients of this second class, Dr. Steinmetz calls attention to a quantity which may be defined as the natural impedance of the circuit, and which is given by the square root of the ratio of self-induction and capacity. One can calculate the voltage of an oscillation or surge from its current, and *vice versa*, by means of the known value of the natural impedance of the circuit; and in dealing with disturbances in mixed transmission and distribution circuits, a study of the values of this constant for various sections of the system is of the greatest importance in determining the action of these sections one upon the other, as well as the nature of such action, whether beneficial or baneful.

This paper will probably be completed in the March Review; and we may take this opportunity of announcing that in that issue we hope to commence a series of papers by Prof. E. J. Berg on this same subject. These papers will represent the substance of the lectures which Prof. Berg is delivering to his students of the graduate year at the University of Illinois. To quote from the author's preface: "In a general way the scope of the course is that of Dr. Steinmetz' *Transient Phenomena and Oscillations;* but the mathematical treatment is essentially modified so that students with only a fair knowledge of fundamental mathematics can readily follow it, and thus later be in a position to enjoy the concise and rapid elegance of Steinmetz' work."

THE INTERPRETATION OF OSCILLOGRAPH RECORDS

It has many times been said that the oscillograph is to the electrical system what the indicator is to the steam engine. This is certainly epigrammatic; but in our opinion the analogy would seem somewhat to confine the limits of the former instrument, and give no suggestion of the wide range of uses to which the oscillograph is now put. The extent of these applications is becoming broadened as a knowledge of its possibilities becomes more general; while, even were its use to be confined to the laboratories and stations which are now using it, the individual operators would soon discover, as they have always discovered in the past few years, that the more familiar they become with its use, the more they can detect and interpret from its records.

Details in the structure and operation of the instrument itself have already been fully dealt with in the REVIEW (November, 1910, and April, 1911.) With regard to some of its uses, a glance through any of the papers on high tension subjects (to name only one section) presented before recent meetings of the Engineering Societies, will indicate the extent to which the oscillograph is now used in furnishing the data upon which these reports are based. Many such papers, in fact, become little more than a collection of oscillograph records, showing normal and abnormal voltage and current waves on transmission lines in service, as well as simply the results of laboratory tests. The paramount question in a central station system of any kind will always be the avoidance of interruptions; and though the oscillograph is not connected in circuit when breakdown occurs and until damage is done, nevertheless the details may be reconstructed afterwards, and readings obtained to determine what happens during, say, a sudden short-circuit, under test conditions which faithfully reproduce working conditions. After this the necessary precautionary measures may be taken to avoid a repetition; and the manufacturer may design the right apparatus, whether it be lightning arresters, power limiting reactances, or what not, to take care of the abnormal conditions should they arise. The short-circuit tests taken on a 12,000 kw. turbo-alternator by the Commonwealth Edison Company in the spring of last year (to cite no other instance), afford a fine example of what the oscillograph may accomplish under severe test conditions.

It must not be imagined that the instrument is a heavy, cumbersome affair which cannot be easily moved from place to place. If the appropriate potential and current transformers are not on hand, additional bulk and weight in transportation are certainly added to the outfit; but where these are obtainable on site, the entire apparatus may be transported with comparative ease. Neither can the oscillograph be described as a delicate instrument and one requiring very expert handling. An oscillograph used for obtaining valuable results, which later formed the basis of an Institute paper, "was not by any means a new one, but had seen some pretty severe service under factory conditions. It was taken to quite a number of remote points . . . . where appliances were very meagre. It was shipped about a number of times (half-a-dozen or more) from one point to another. It was used under all sorts of crude conditions, and the films were developed only under such circumstances and with such appliances as could be got together at the various points of observation. Further, in some of the observations it was necessary to relay the signals for the switch operation to two or three persons at the observing end, through more than a hundred miles of private telephone line, and through two or three persons at the switch end; and yet the observations were obtained with an exposure of film of only a very few seconds."*

The article by Mr. Taylor Reed on the interpretation of oscillograph records which we are publishing in this issue may serve to bring out more clearly to many of our readers the serviceability of the oscillograph for practically every kind of electrical observation. This article has been written with the special purpose of showing the nature of the deductions which may be drawn from a record; and, with this end in view, a number of cuts are shown representative of several applications to which the instrument is now being put. It will be noted that these are not in any way confined to the study of abnormal conditions, but may be used to record everyday behavior of various electrical apparatus. These illustrations are explained in the text of the article, and attention directed to the physical meaning of the various periods in the photographed curves.

*See Proceedings, A.I.E.E., August, 1911, p. 1789.

THE NATURE OF TRANSIENTS IN ELECTRICAL ENGINEERING*

Part I

By Charles P. Steinmetz

1.—Accompanying the flow of electric power through a circuit, there occurs a dissipation of power in the circuit, by its resistance. There also exists a condition of stress in the medium surrounding the conductor, which we call a *magnetic field*, and represent by lines of magnetic force, as shown in drawn

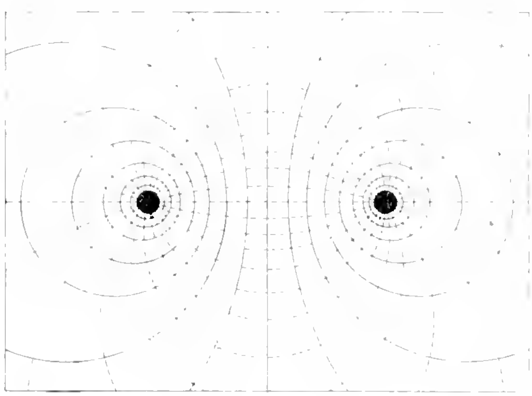

Fig. 1

circles in Fig. 1. There further exists a condition of stress in the space surrounding the conductor, which is called the electrostatic or *dielectric field*, and is represented by lines of dielectric force, shown dotted in Fig. 1. This figure is the cross section of the two fields, the magnetic field and the dielectric field, of conductor and return conductor.

Neither the strength of the magnetic field, nor that of the dielectric field is proportional to the power which flows along the conductor, but the product of both fields is proportional to the power. We therefore resolve electric power into two component factors, of which the one is proportional to the magnetic, the other proportional to the dielectric field. The factor, which is proportional to the magnetic field, is called the current i; the factor which is proportional to the dielectric field, is called the "*voltage*" e. Thus:

$$p = ei$$

represents the resolution of electric power into two factors, which are proportional respectively to the two components of the electric field, the dielectric and the magnetic.

i is the quantity component of electric power: the larger it is, the greater is the loss in transmission, and the larger transmission conductors are required. Inversely, the greater e is, the further the electric power can be sent, the smaller a conductor is required and the less is the loss, but at the same time the greater is the tendency of the electric power to leave the conductor, that is, the greater is the difficulty of insulating the conductor so as to keep the power flowing in its proper channel. e thus is of the nature of an intensity component, and is frequently spoken of as electric pressure or tension.

The resolution of power or energy into the product of a quantity factor and an intensity factor is not characteristic of electric energy alone. For instance, hydraulic power is the product of the flow or quantity of water and of the head or pressure of it. Gravitational energy is expressed by weight times elevation: heat energy as the product of temperature and entropy, etc.

There exist in the magnetic and in the dielectric field some conductor forces, which act on, and produce motion of bodies brought in the field, that is, are capable of doing work, and these fields thus must contain energy. Thus in the space surrounding the conductor which transmits electric power, there is a storage of energy in two forms, as magnetic and as dielectric energy, and the *energy storage* in the space outside of the conductor is as essential a part of the phenomenon of electric power, as is the *power dissipation* in the conductor, which directs the flow of power.

The magnetic field is proportional to the current, with a proportionality factor, which is called the *inductance* of the circuit, and denoted by L. That is:

$$\Phi = Li \text{ }^{(1)}. \qquad (1)$$

The dielectric field is proportional to the voltage, with a proportionality factor, which is called the *capacity* of the circuit, and denoted by C. That is:

$$\Psi = Ce. \qquad (2)$$

(1) In this equation, every line of magnetic force, which surrounds the conductor n fold, is counted n times, and as unit of flux is used the *volt line*, or 10^8 lines of magnetic force. Counting each line of magnetic force singly, the equation (1) would read:

$$n\,\Phi = Li\,10^{-8}. \qquad (1^a)$$

* A paper prepared for the International Congress of Electrical Applications, held at Turin, September 10-17, 1911.

The stored energy of the magnetic field is:

$$w_1 = \frac{Li^2}{2} \tag{3}$$

and the stored energy of the dielectric field is:

$$w_2 = \frac{Ce^2}{2} \tag{4}$$

while the power consumed in the conductor, by the electric current is:

$$p_1 = ri^2 \tag{5}$$

where r = *resistance* of the circuit.

Occasionally, power may be consumed also by the voltage, in the form of a leakage from the conductor, by corona and similar phenomena, and may be represented by:

$$p_2 = ge^2 \tag{6}$$

were g is the *shunted conductance*.

As seen, inductance L and capacity C are the proportionality coefficients of the magnetic and the dielectric field, or the coefficients of energy storage by the magnetic and the dielectric field respectively, while resistance r and shunted conductance g are the corresponding coefficients of power dissipation.

2.—Suppose, that to an electric circuit a second circuit is connected and the total current thereby increased: this also increases the stored magnetic energy. Closing the second circuit perhaps decreases the voltage and thereby the stored dielectric energy of the first circuit, but at the same time adds dielectric energy, that of the second circuit. Inversely, disconnecting a circuit, or an apparatus, decreases the stored energy. In general, any change made in an electric system, also changes the amount of stored magnetic or dielectric energy or both, increasing or decreasing it.

Stored energy cannot be increased or decreased instantly, however, because this would represent infinite power, and some interval of time must therefore elapse after every change of circuit conditions, during which, in case of an increase of the stored energy, this energy is supplied by the circuit as a flow of power into the space, or in case of a decrease of stored energy, the surplus energy is returned to the circuit by a return flow of power from the space into the circuit.

After every change in the condition of an electric circuit, which involves a change of the stored energy, there must therefore be a transition period during which the stored energy readjusts itself from the previous to the new value, and during this period power flows from the circuit into surrounding space, or returns from surrounding space into the circuit. This flow of power must be temporary, lasting only until the additional stored energy has been supplied, or the surplus stored energy returned to the circuit, thus it is a *transient*. Since the magnetic field is proportional to the current, the power required for its increase or decrease of stored energy is given by an *inductance voltage;* since the dielectric field is proportional to the voltage, the power which supplies or returns its stored energy, is given by a current, the *capacity current*.

An electrical transient therefore is the phenomenon, by which at a change of circuit conditions, the stored magnetic and dielectric energy of the electric system readjust themselves to the changed circuit conditions.

Herefrom it follows, that transients are not a specific electrical phenomenon, but must occur in any system of power flow, in which energy is stored, whether electrical, mechanical, thermal, etc., and are the phenomenon of the readjustment of the stored energy required by any change of the condition of the system.

For instance, in the supply pipe of a hydraulic turbine, energy is stored by the momentum of the moving water, $\frac{mv^2}{2}$. If the load increases and the gates open to admit more water, it takes some time before the velocity of the water in the pipe has increased to supply increased power, and during this time, energy has been drawn from the turbine supply, and stored as momentum of the water column. Inversely, the closing of the valves to reduce the flow of water, at a decrease of load, first results in an increase of pressure and therefore of power, until gradually the kinetic energy of the moving water column has been consumed. The problem of the governing of a water power thus is largely that of taking care of the transients resulting from the stored kinetic energy of the water column. Similarly, acceleration and deceleration are the mechanical transients of the trolley car or railway train; the period of firing up and of cooling down are the thermal transients of the steam boiler, of the blast furnace, etc.

Transients thus are not specifically electrical phenomena, but inherent in all those systems of power, in which storage of energy exists.

3.—Energy may be stored in one form only, or in two or more forms. In the railway train, energy can be stored in one form only, as mechanical momentum, and the only change of stored energy, which can occur, is an increase or a decrease. An instance of a system, in which energy is stored in two forms, as kinetic mechanical energy, and as potential gravitational energy, is the pendulum, Fig. 2. In end position b the weight w contains the potential energy of elevation, wh, but no kinetic energy. During its fall,

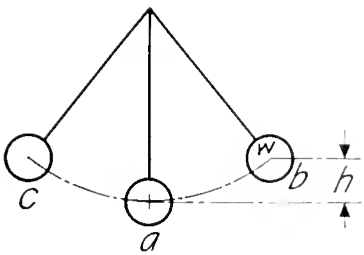

Fig. 2

it accelerates, the potential energy decreases, but the kinetic energy increases, until in the middle position, a, all the energy is kinetic energy $\frac{mv^2}{2}$. Moving further, the kinetic energy again decreases and converts to potential energy, until in the end position c all the energy is again potential, none kinetic, and in this manner periodically the stored energy changes between potential energy of elevation and kinetic energy of motion; but at the same time, the total stored energy steadily decreases, by being dissipated in friction.

In a system, in which energy can be stored in two or more forms, in addition to the increase or decrease of stored energy, a transformation of energy from one form to the other may thus occur, and usually does occur during the transient. Such transformation of energy generally is periodic, as illustrated on the pendulum Fig. 2. It may, however, be in one direction only. For instance, if we assume the pendulum submerged in a very viscous liquid: while the weight falls from position b towards a, its potential energy is converted to kinetic energy, and the velocity increases hereby, but at the same time rapidly decreases by friction, and if the friction is sufficient, the weight never passes beyond position a, but comes to rest in this position: the motion is aperiodic or deadbeat.

As we have seen, in the electric circuit, energy is stored in two forms, as magnetic and as dielectric energy. The discharge of a condenser through an inductive circuit of very high resistance is a transient, in which energy is transformed from one form, dielectric, into another, magnetic, but not back again, that is, is aperiodic, while usually the condenser discharge through an inductive circuit is a periodic transient. The aperiodic electrical double energy transients are of relatively little importance, since the condition of their existence is a very high rate of energy dissipation, as seen above, and they therefore are of short duration and limited power.

Applying the preceding general discussion to the electric circuit, we find two classes of transients:

(*a*) Single energy transients, in those circuits, in which energy is stored in one form only, usually as magnetic energy, and the transient thus can consist only of an increase or a decrease of the stored energy;

(*b*) Double energy transients, in those circuits, in which energy is stored in two different forms, as magnetic and as dielectric energy, and in addition to an increase or decrease of stored energy, a transformation of the stored energy from one form to the other occurs, which usually is periodic.

4.—In electric lighting circuits of 110 or 220 volts, in railway circuits of 600 volts, and even in primary distribution circuits of 2200 volts, the stored dielectric energy, $\frac{Ce^2}{2}$, is so small compared with the stored magnetic energy $\frac{Li^2}{2}$, that it can be neglected, except in very special cases, as lightning discharges, and the circuit thus can be treated as one storing energy in one form only, as magnetic energy.

Consider a simple case of such a circuit, a wire coil, Fig. 3, of resistance r and inductance L, traversed by a continuous current i_0. There exists then a voltage $e_0 = ri_0$ at the terminals of the coil, and a magnetic flux Φ_0 traverses the coil, which with the current i_0 has the number of magnetic interlinkages

$$n\Phi_0 = Li_0 10^8 \text{ (1)}. \qquad (7)$$

Now suppose we suddenly change the circuit condition by removing the voltage e_0, as by short circuiting the coil upon itself, as shown by A in Fig. 3. With no voltage

(1) The factor 10^8 comes in because L is given in henries and i_0 in amperes, which respectively are 10^9 and 10^{-1} absolute units.

impressed upon the coil and therefore no power supplied to it, the current in the coil must be zero, and thus also the magnetic flux interlinked with it. At the withdrawal of the impressed voltage e_0, the current and thereby the magnetic flux cannot instantly drop from its previous values i_0 respectively

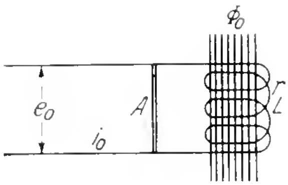

Fig. 3

Φ_0 to zero, as the magnetic flux represents an amount of stored energy $\frac{Li_0^2}{2}$, which cannot instantly be dissipated. The current and with it the magnetic flux thus must gradually decrease, from their initial values i_0 and Φ_0 to zero, as illustrated by curves A and B of Fig. 4. To cause a current to flow, a voltage is required, and thus, while the current i decreases from its initial value i_0 to 0, there must be a voltage $e = ri$ acting in the coil circuit, to produce the current. This voltage must start from the initial value $e_0 = ri_0$ and gradually decrease to zero, simultaneously with the current. As the impressed voltage has been withdrawn from the coil, this voltage must be an induced voltage, and is induced by the decreasing magnetic flux Φ. That is, the magnetic flux Φ, A in Fig. 4, decreases at such a rate as to induce in the coil the voltage $e = ri$, which is shown at C in Fig. 4. By the general law of induction, it is:

$$e = ri = -n\frac{d\Phi}{dt}10^{-8}$$

$$= -L\frac{di}{dt} \qquad (8)$$

or, re-arranged:

$$\frac{di}{i} = -\frac{r}{L}dt; \qquad (9)$$

integrated, this gives:

$$i = i_0\epsilon^{-\frac{r}{L}t} \qquad (10)$$

where i_0 is the initial value of the current, at $t = 0$, as the equation of the transient current in the coil. As Φ and e are proportional to the current i, it is:

$$\left.\begin{aligned} \Phi &= \Phi_0\epsilon^{-\frac{r}{L}t} \\ e &= e_0\epsilon^{-\frac{r}{L}t} \end{aligned}\right\} \qquad (11)$$

The question then is: how long does the transient last? Theoretically, it lasts forever, since the current i becomes zero only for $t = \infty$. Practically, it becomes negligible after some time, usually a very short time. The most convenient way of getting a conception of the duration of the transient is to ask, how long would the transient last, if it would not decrease, but retain its initial value. That is, we consider as the duration of the transient voltage e in C of Fig. 4, the time T, during which the voltage could be maintained at its initial or full value e_0. To maintain constant induced voltage e_0, the magnetic flux Φ and thus the current i would have to change at a constant rate, and at the same rate at which it drops in the first moment, at $t = 0$. Thus, if we draw the tangent on the curve i at the point $t = 0$, this gives the duration T of the transient, by its intercept on the zero line, as shown by the dotted line in Fig. 4B.

As the induced voltage e is the rate of change of the magnetic flux, the total induced voltage: $\int e\,dt$ is the total change of the magnetic flux, from its initial value Φ_0 to its final value 0: $n\Phi_0 10^{-8} = Li_0$, regardless in what manner, that is, at what rate the mag-

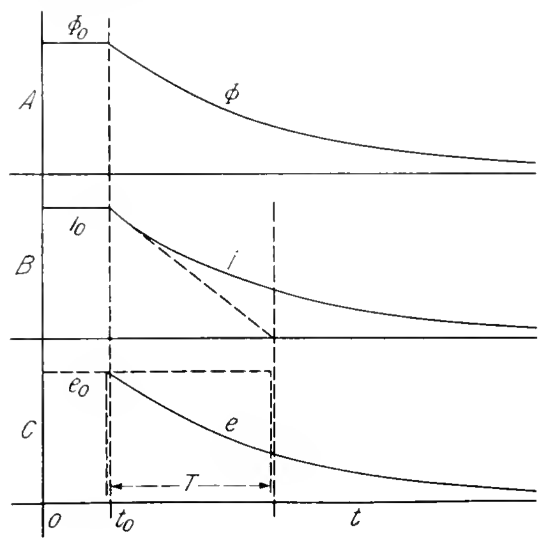

Fig. 4

netic flux Φ changes. Thus the total voltage ~~$\int e\,dt$,~~ or the area of the voltage curve, $\int_0^t e\,dt$

whether this be the curve e, or the rectangle e_0 T, is Li_0. This gives the expression:

$$e_0 T = L i_0$$

$$T = L\frac{i_0}{e_0} = \frac{L}{r} \tag{12}$$

that is, the duration T of the transient is the ratio of the energy storage coefficient L, to the power dissipation coefficient r.

This is a general law of transients. Thus in a transient resulting from the stored dielectric energy, the duration would be:

$$T = \frac{C}{g}. \tag{13}$$

Since the coefficient of the exponent of the exponential function, $\frac{r}{L}$, is the reciprocal of the duration T of the transient, the equations (10) and (11) can also be written:

$$\left.\begin{aligned} i &= i_0 \epsilon^{-\frac{t}{T}} \\ e &= e_0 \epsilon^{-\frac{t}{T}} \\ \Phi &= \Phi_0 \epsilon^{-\frac{t}{T}} \end{aligned}\right\} \tag{14}$$

These simple equations are based on the assumption that the magnetic flux Φ is proportional to the current i, that is, the inductance L constant. This is true only if the surrounding medium is not magnetic, and with magnetic materials only approximate below the range of magnetic saturation.

5.—Thus far, we have considered that only a single energy transient exists in the circuit, that is, the circuit is left to itself, without any power supply, and dissipates its stored energy. Usually, the final condition reached by the transient is not zero current and power, but some value of current and power, differing from the initial value. Thus for instance, in Fig. 3, if we open the short circuit A, the current again starts in the coil, and a transient represents the gradual increase of the current from its initial value 0, to the final value i_0. Or if in an alternating current circuit, at a moment where the current in the circuit has the instantaneous value i_1, we change the circuit condition so as to require at this moment the instantaneous value of current i_2 (for instance, by changing the resistance, the voltage, etc.). All these cases, however, can be reduced to the cases above considered: if at the moment of change the current in the circuit is i_1, but the changed circuit condition would require a current i_2, we can assume in the circuit to exist two currents, the current i_2, and the current i_0, which is the difference between the actual current i_1 in the circuit,

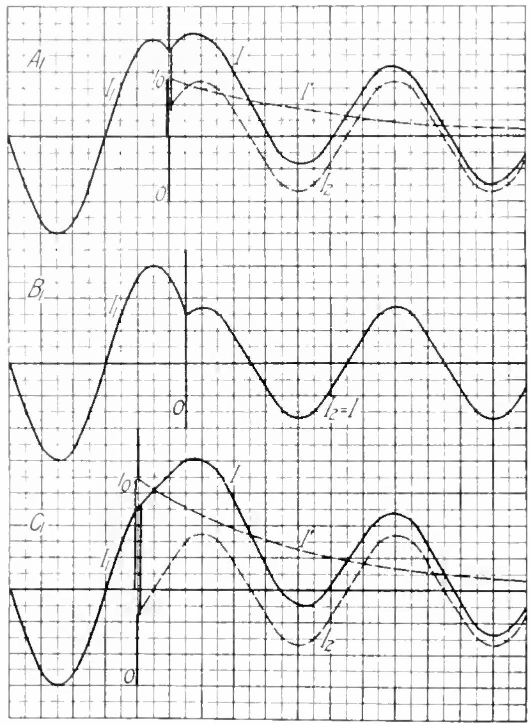

Fig. 5

and the current i_2, which should exist: $i_0 = i_1 - i_2$. The current i_2 is due to the circuit conditions, the voltage impedance, etc., and is a permanent current. That is, the voltage existing in the circuit produces, under the changed circuit conditions, the current i_2. The current i_0, however, has no voltage back of it, is a remnant of the previous circuit condition, that is, a transient current, and as such dies out by the equations above discussed, irrespective whether it is the only current existing in the circuit, or whether it is superimposed upon the permanent current i_2 (1).

Thus the phenomena occurring during the transition period of energy re-adjustment can always be resolved into the superposition of

(1) Permanent here means resulting from the conditions existing in the circuit, but may be an alternating current, or even a slow transient current.

a purely transient, and a permanent phenomenon. This applies to the single energy transient as well, as to the case, where energy is stored in two or more forms. It is based on the proportionality law of electric currents: if a voltage e_1 produces a current i_1, and a voltage e_2 produces a current i_2, the voltage e_1+e_2 produces the current i_1+i_2. It therefore does not apply any more in circuits, in which current and voltage are not proportional, as circuits containing magnetic materials at densities above saturation.

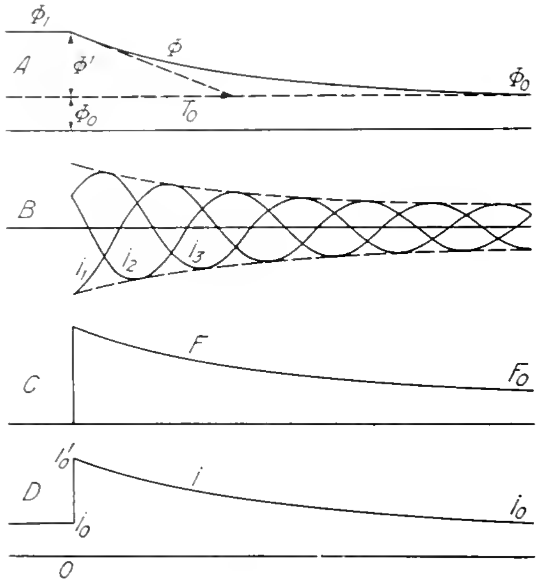

Fig. 6

In this manner, the single energy transients can be constructed or calculated for all conditions of circuit changes. For instance, in Fig. 5 let I_1 represent an alternating current, and at the moment $t=0$, where this current has the value i_1, a change is made in the circuit, its resistance changed, or voltage changed, etc., and the change is such that it causes the current I_2 to flow in the circuit. This current I_2 would have the instantaneous value i_2 at $t=0$. It is shown dotted in Fig. 5. At $t=0$ there thus exists in the circuit the instantaneous value i_2 of the permanent alternating current I_2, and the transient current $i_0=i_1-i_2$. This latter dies out by the equation discussed above:

$$i = i_0\epsilon^{-\frac{t}{T}} = (i_1-i_2)\epsilon^{-\frac{t}{T}} \qquad (15)$$

It is shown by the dotted line I^1 of Fig. 5, and the total current I then is derived by adding the transient current I^1 to the permanent current I_2, as shown in Fig. 5, for various conditions.

6.—The single energy transients of electric circuits are rarely of serious importance: as they are a gradual change from the previous to the after condition of the electric circuit, their inductive effects are usually small, their energy is moderate and is rapidly dissipated, and they usually require consideration only to avoid the annoyance which may be caused by them. For instance, when closing the field exciting circuit of a direct current shunt motor, an appreciable time—several seconds—elapses until the field magnetism has built up, and if the armature circuit is closed too soon, an excessive starting current would result.

Of serious moment these transients become if of considerable energy, as in highly inductive circuits, as magnetic fields of large machines, especially if they are forced to be of very short duration: the opening transient of the inductive circuit. The quicker an inductive circuit is opened, the greater the rate of dissipation of its stored energy, that is, the higher the voltage and power of the transient, and instantaneous opening would result in the induction of infinite voltage, that is, destruction of the insulation. To a considerable extent an inductive circuit protects itself against too rapid opening, by the

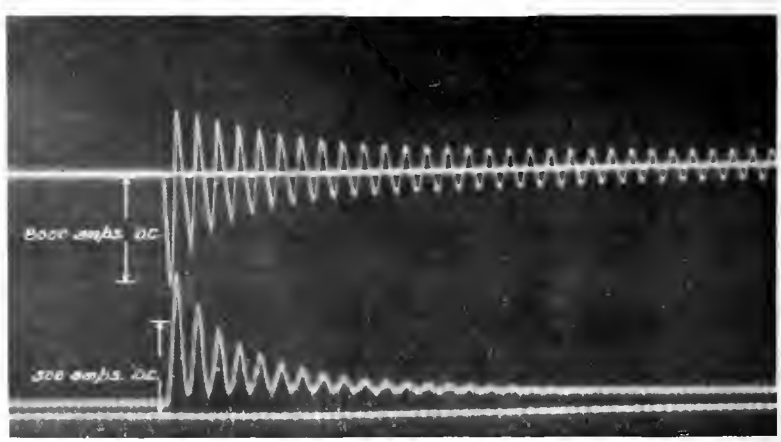

Fig. 7

arc of the induced voltage following the switch blades and thereby retarding the opening of the circuit. The problem of switching inductive circuits thus is, to produce a mechanism which opens quick enough to avoid damage from the arc at the switch, but slow enough to avoid dangerous induced voltages.

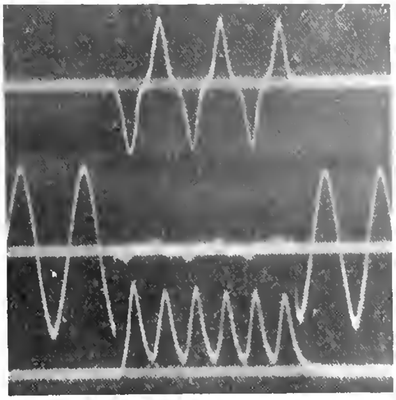

Fig. 8. Upper Curve, Armature Current; Lower Curve, Field Current

Occasionally single energy transients are of serious moment indirectly, by the power production which they cause. An instance hereof is the momentary short circuit current of alternators. At open circuit, the magnetic field of an alternator is that due to the field excitation alone. At short circuit, it is due to the resultant of the field excitation and the demagnetizing armature reaction of the short circuit current, and the magnetic field flux then is much lower, in large turbo-alternators occasionally only one-tenth as large as the magnetic field flux at open circuit with the same field excitation. At the moment of short circuit, the magnetic field flux can not instantly drop from its open circuit value to its short circuit value, since it represents stored energy, and thus gradually drops, as shown by Φ in Fig. 6 A. If the permanent short circuit current, which results from the final value Φ_0 of the field flux, is p times full load current, and Φ_0 is only $1/n$ of the open circuit field flux Φ_1, then in the first moment of the short circuit, when the flux Φ is still nearly equal to Φ_1, the armature short circuit current would rise to nearly n times its permanent value, or pn times full load current, as shown by i_1, i_2, i_3 in Fig. 6 B. The final short circuit flux Φ_0 is due to the resultant of field excitation and armature reaction. At the beginning of the short circuit, the armature reaction is n times the normal, as shown by F in Fig. 6 C, hence, the field excitation also must be n times the normal. That is, the magnetic field at the moment of short circuit begins to drop at such a rate as to induce in the field exciting winding a voltage which gives a momentary rush of field current as shown by i in Fig. 6 D. With polyphase short circuit, on this rush of field current then superimposes a full frequency transient pulsation, due to the starting transient of the armature current, as shown in oscillogram Fig. 7, which represents a short circuit of a large three-phase turbo alternator. With single-phase short circuit, due to the pulsating nature of the single-phase armature reaction, a permanent double frequency pulsation appears in the field current, as seen in oscillogram Fig. 8, and occasionally by superposition of full frequency starting transient on the double frequency pulsation, the latter appears with alternately high and low peaks, as seen in oscillogram Fig. 9. Figs. 8 and 9 give single-phase short circuits of the same alternator under the same conditions, differing from each other by the point of the wave at which the short circuit starts. From the equation of the single energy transients, and the constant of the machine, these short circuit phenomena can thus be predetermined.

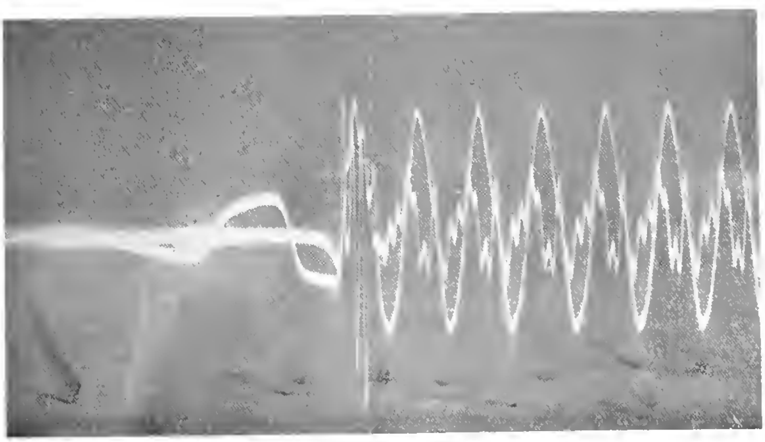

Fig. 9

(To be Continued)

THE GROUND CONNECTION IN LIGHTNING PROTECTIVE SYSTEMS

PART II

By E. E. F. Creighton

Consulting Engineering Department, General Electric Company

This paper was referred to in our editorial columns in the January, 1912, Review. Its purpose is to collect together the available data on ground connections and to make specific recommendations as to earths which should be employed in different cases. The first part of the paper, after considering the three elemental properties of an earth connection, gave a list of general laws concerning earthing based upon the results of extensive tests which have been made. General instructions for making a single earth connection were also given and eight specific applications of earths (*e.g.*, lightning arresters in electric stations, neutrals of electric systems, transformers on poles, etc.) were considered. The second part of the paper published this month now considers all the eleven laws in greater detail, giving the results of the tests upon which the laws are based.—Editor.

Grounds for Secondary Circuits

In the review of the specific applications of earths to various types of circuits contained in the first part of this paper, the subject of grounds for secondary circuits was intentionally omitted, as it is not at the present writing in a satisfactory stage of development. Some very important changes in practice will be possible within a short time and the subject will be reviewed when data upon these changes are available.

DETAILED INFORMATION OF THE LAWS OF PIPE-EARTHS

Resistance versus Depth of Pipe

For very small areas *the resistance of an earth connection depends* greatly upon the exposed area of metal plate to earth. A simple contact of a metal conductor with a normally moist earth will give a high resistance of enormously variable values due to the variations in contact. In several tests made with an iron pipe resting on the ground at different points, an average value of resistance of 2000 ohms was obtained. The same pipe driven 6 feet into the ground gave a total resistance of 15 ohms. Resting on a dry pebble the resistance was too many thousands of ohms to allow of measurement without the use of a sensitive galvanometer; the resistance, however, dropped very rapidly as the pipe penetrated the earth. A curve (Fig. 2) is given to show the variation in resistance relative to the depth of the driven pipe. It will be seen in this curve that *as the pipe penetrates the earth, each additional foot adds a conductance about proportional to the added length.* In other words, this means that a penetration of two feet gives about half the resistance of one foot; three feet about a third of one foot; and so on.

Looking at this from another standpoint, the fractions $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, $\frac{1}{5}$, $\frac{1}{6}$, etc. represent also the drop in resistance from the immediately preceding value. For example, at a depth of 3 feet the resistance is one-third the value at one foot, and it is also one-third of the drop of the previous value at two feet. Following this up, the total resistance at a five-foot depth is 20 per cent. less than at a four-foot depth. Between nine and ten feet there would be a 10 per cent. drop in resistance; between nineteen and twenty feet there would be only a 5 per cent. drop in resistance. Mathematicians will recognize in these statements the logarithmic law. It is due partially to the fact that only a small percentage decrease is obtained by each additional foot greater than six to ten feet, that the choice is made of this range for an established rule; and partially to the

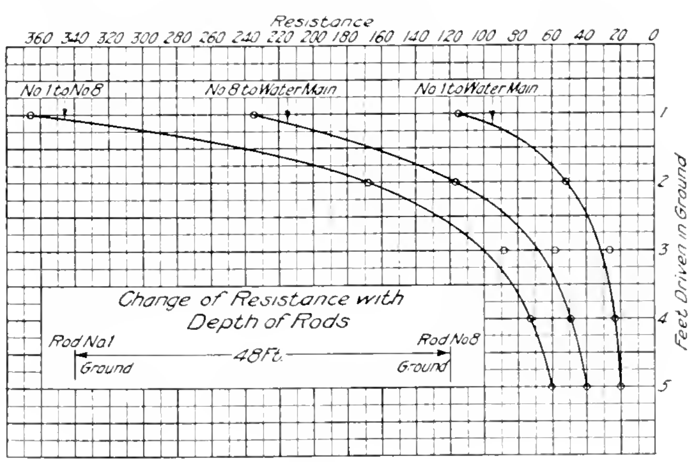

Fig. 2

fact that it is difficult, in general, to drive a pipe to a greater depth.

Now that this rule is established, the limitations should be noted. It applies only where the earth is uniformly conducting at all depths of penetration of the pipe. This is seldom the condition; there is often a layer of dry soil at the surface and a bottom of hard pan; not infrequently there are several feet of sand or gravel. From the point where the pipe strikes a uniformly conducting stratum the rule applies. The deviation from uniform conduction throughout the full length of the pipe is corrected and avoided by pouring a strong solution of salt water around the pipe.

The curves in Fig. 2 give the resistance of pipe-earth No. 1 to the water-main, pipe-earth No. 8 (48 ft. from No. 1) to the water-main, and pipe-earth No. 1 to No. 8. The resistance of the water-main earth is so much smaller than either of the pipe-earths that it is sensibly negligible in comparison. Therefore, the resistances shown for No. 1 and No. 8 were sensibly the individual resistances of these pipe-earths. In consequence, the curve of resistance from No. 1 to No. 8 is approximately the sum of the other two curves. The points at 3 ft. depth being off the curve indicate a layer of good conduction at this depth.

Resistance versus Specific Resistance of Earth

Variation in resistance of earth connection due to the nature of the ingredients and conditions. Since the conductance is, in general, by means of the electrolytes coming from the soluble acids, alkalis, and salts, the specific resistance will depend upon what chemicals exist around the metal plate and how much moisture there is present. In a dry sand-bank the resistance is practically infinite. In a salt marsh the specific resistance is extremely low, being about one ohm. Resistances of earth connections will vary greatly even in the same locality. The variations in kinds of earth baffle classification; but usually at the surface of the earth there is a layer of dry material which is non-conducting; then there comes a layer of semi-moist materials of fairly good conduction; then a wet layer in which water is constantly moving; and then perhaps a layer of rock.

In every case, in order to get a low resistance of earth connection, we are interested mostly in the earth in the immediate vicinity of the earth plate or pipe; because, in the main body of the earth, the area of cross-section through which the current flows is so enormously great that even if the specific resistance is very high, the total resistance becomes negligibly small. If the earth plate should lie in the dry non-conducting stratum of the top layer, it is advisable to get some means of introducing better conductivity, not only in the contact between the plate and the earth, but also between the earth in the immediate vicinity and some better conducting layer deeper down. The best means of accomplishing this is to pour a salt solution around the iron pipe and allow it to percolate down to a good conducting stratum. In order that this salt solution may not be washed out by the natural filtration of rain water, it is well to leave a considerable quantity of crystal salt around the pipe somewhere near the surface of the earth, so that rain water flowing through will dissolve the salt and carry it continuously to the lower strata. Salt has the additional value of holding moisture. Invalid objections have been made to the use of salt in stating that it would be destructive of the metal of the pipe. Under the usual conditions it is found that the chemical action on an iron pipe is of negligible value. Iron pipe is very cheap, both in its initial cost and in the labor in driving it; and it would be better practice to use the salt, even if it destroyed the pipes within a period of a few years, which it does not.

Old Form of Earth Connection. In the older method of making a ground, a large hole was excavated and a large expensive copper plate was placed in this hole and surrounded by a load of coke. Today such a method of grounding may, in general, be considered not only a waste of money, but of less efficiency than the multiple pipe-grounds already recommended. Furthermore, all the nice refinements relative to perforated copper, special compounds, etc., have no particular value. Their resistances are no lower, their current capacity no greater, and their life and constancy no better.

3. Resistance versus Multiple Pipe-Earths

If an iron pipe one inch in diameter is driven into normally moist earth to a depth of 6 or 8 feet, it will usually have a resistance of about 15 ohms. Eight ohms may be considered unusually low; while dry soils may give a resistance of 50 ohms and upwards.

In one particular case the resistance of such a pipe-earth was 20 ohms. A second pipe of the same dimensions was driven beside the first one and metallically connected to it. The resistance of these two pipes thus connected in parallel was only slightly less than the first one. This illustrates the law that doubling the area of the metal plates does not necessarily decrease the resistance correspondingly. The apparent anomaly is due to the fact that the resistance of a pipe-earth lies principally in the earth in the immediate neighborhood of the pipe. When a current flows between the pipe and earth, there will be a certain formation of current-stream lines which may be represented as shown in Fig. 3. The introduction of the second pipe in the midst of these stream lines brings in very little new conducting material in the neighborhood, and therefore the IR drop at every point shown in the figure, except right at the surface of the pipe, will remain constant. To those who are familiar with electrostatic flux around two isolated conductors on an overhead line, charged to the same potential, this phenomenon is easily explained by analogy. When the two wires are near each other, the electrostatic capacity of two parallel conductors connected together is only slightly greater than that of one conductor. One of these conductors being in the electrostatic field of the other does not materially increase the displacement current in the surrounding dielectric.

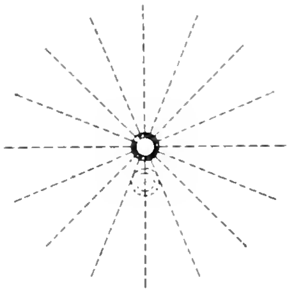

Fig. 3

If it is desired to decrease the resistance of earth connections, it is necessary to drive earth pipes that are separated by a distance sufficient to keep one out of the dense field of current of the other. In this way the second added pipe will bring in new areas of cross-section of unused earth, and will therefore decrease the total resistance of the two in parallel by an amount approximately in inverse proportion to the number of pipes. The current density in the earth around a pipe-earth drops off approximately as the square of the distance; at a comparatively short distance away, the current density is therefore reduced to a negligible amount.

Fig. 4 shows the reduction in resistance of two pipes driven at variable distances apart but connected together, the return circuit being through the water-main. It will be seen that the minimum resistance which it is possible to obtain with two pipes is one-half the resistance of one. This halving of the resistance nearly exists with a distance between the pipes of about 10 feet, and for all practical purposes is near enough one-half at a distance of 6 feet. The approximate law for decreasing the resistance of earth connections is: Drive multiple pipes at least 6 feet apart and connect them together, and the resistance will decrease almost in proportion to the number of pipes.

4. Distance Between Two Pipe-Earths versus Resistance Between the Two

Fig. 5 gives the resistance between two pipes spaced at different distances apart. It is to be noticed in this figure, that as the distance between two pipe-earths increases, the resistance tends to approach a constant value. This is one of the earliest facts determined by telegraph engineers. In order to reduce the resistance between pipes by a large percentage, it is necessary to bring the pipes very close together; which fact is one of the proofs that the resistance of a pipe-earth is mostly in the immediate vicinity of the pipe. As an illustration, it may be noted that in Fig. 5 it is necessary to come from an infinite distance to 6 ft. in order to reduce the resistance from about 48 ohms to 40 ohms, or 20 per cent., and it is necessary to come to a half-foot to reduce the resistance by 50 per cent. Half the total resistance of the pipe-earth, therefore, lies within 6 inches of the pipe.

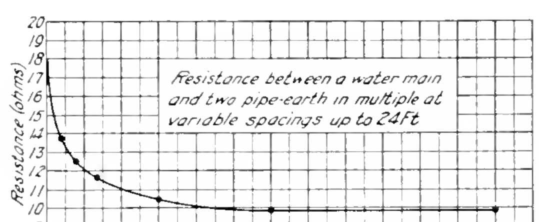

Fig. 4

5. Potential Distribution Around a Pipe-Earth

As already stated, the greatest proportion of the potential will be lost in the immediate vicinity of a pipe-earth, due to the fact that most of the resistance is concentrated in this neighborhood. The more salt water placed around a pipe-earth, the less the potential gradient near the pipe. Inversely, the drier the earth, the more the concentration of potential near the pipe.

With an applied potential of 1000 volts, the current was so great that the earth around the pipe was quickly dried out, and nine-tenths of the drop of potential took place within one foot of the pipe. The earth-pipe had lost its effectiveness as a ground. With 900 volts drop in the immediate vicinity, it was a dangerous condition.

In Fig. 6 are shown three curves. The upper curve is the potential distribution around a normal pipe-earth "salted." In the first quarter-foot, the drop in potential is only 5 volts, in a half-foot 8 volts, in three-quarter foot 17 volts, and in one foot 26 volts. At the other pipe-earth the potential gradient is even less. This condition is apparently contrary to the previous state-

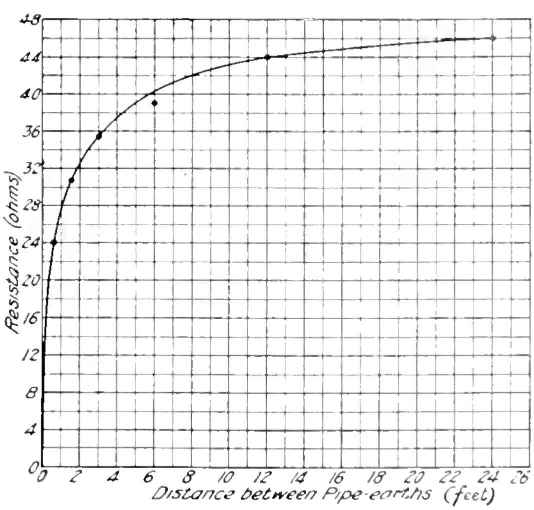

Fig. 5

ments, but its low potential gradient is due to the great increase in conductivity produced by the salt solution near the pipe. The other two curves show the potential distribution before the pipe-earth was salted and after it was somewhat dried out by the current. There is a 55 per cent. drop in potential in the first quarter-foot with direct current applied, and a 25 per cent. drop with alternating current

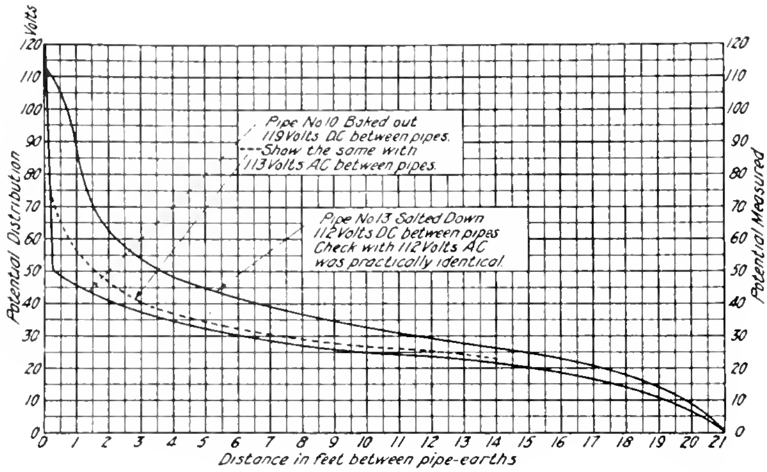

Fig. 6

applied. These curves illustrate the value of salt water around the pipe-earths.

The extreme condition of drying out is described later under the heading of accidental grounds.

6. Ampere-hour Capacity of a Pipe-Earth

As stated previously, the ampere-hour capacity increases with the amount of moisture in the earth around the pipe, and decreases with the resistance. The ampere-hour capacity is not independent of the current flowing. Each pipe-earth has a certain maximum critical value of current which it will carry continuously without drying out. Moisture is supplied by the surrounding earth as rapidly as it is boiled out and evaporated at the surface of the pipe. Within this critical value of current, the ampere-hour capacity is indefinitely great; and the limit is set only by the disintegration of the metal by electro-chemical action. As the current is increased more and more above this critical value, there is a gradually increasing tendency of the steam to keep the moisture away from the pipe. This vapor increases the resistance enormously. The point of formation is very marked in the test of pipe-earth No. 11, salted (Fig. 7), at the beginning of the fortieth hour. The ampere-hour capacity of this particular pipe-earth was 2200 ampere-hours at 55 amperes.

The applied potential was 550 volts direct current. Before this pipe-earth was salted the ampere-hour capacity was only 75 at 25 amperes. No better proof could be given

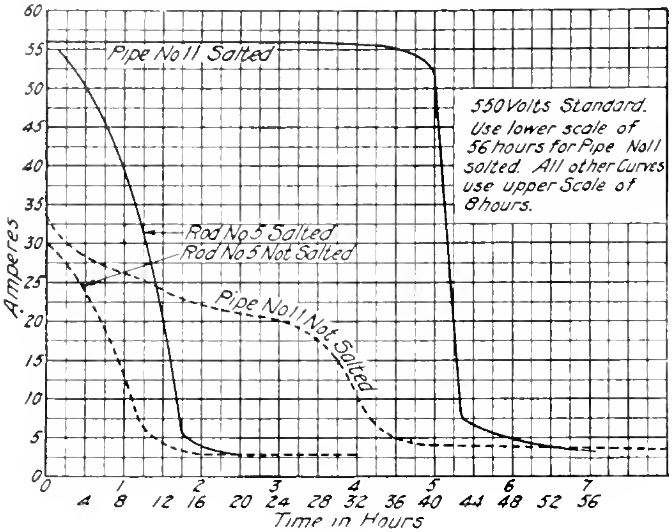

Fig. 7

of the value of the use of salt water. In Fig. 7 is given also the ampere-hour capacity of a rod one-half inch in diameter. The rod is much inferior in capacity to the pipe under both conditions of test. Before salting, it had a capacity of about 15 ampere-hours with a constantly decreasing current, and, after salting, of about 90 ampere-hours with a constantly decreasing current.

Part of the difference in capacity between the pipe and the rod used as an earth is due, in this case, to the fact that the pipe had twice the area of the rod. Furthermore, the earth around the rod may not have absorbed and held the brine as it did around the pipe. There is, however, an intrinsic advantage in the form of the pipe in giving greater ampere-hour capacity. The brine inside the pipe prevents the heat at the outer surface from driving the moisture away. This advantage would disappear if the earth had been such as not to maintain the brine in the pipe.

Where, for any reason, pipe-earths are required to carry much current over long periods, the foregoing experience suggests the use of feeding a little water into the pipe during the period of load.

7. Resistance of Pipe-Earth versus The Diameter of the Pipe

The diameter of the pipe affects the resistance comparatively little. Due to the variations in the materials and moisture, it is impossible to make accurate comparisons. In one case a one-inch pipe, $1\frac{5}{16}$ in. outside diameter, had a resistance 15 per cent. lower than a rod one-half inch in diameter driven at a distance of one foot to the same depth. In an average of four cases, however, the difference in resistance was 8 per cent., the range being 6 per cent. to 10 per cent.

Doubling the diameter of an overhead wire increases the capacity of the wire by a small percentage of the same order. The law of the variation in electrostatic capacity is logarithmic; and it is likewise so of the pipe earth. It is useless to state this law definitely, as there are many variables, and the law could not be used for calculations.

The choice of the diameter of pipes for earthing will depend somewhat on convenience so far as resistance per pipe-earth is concerned. A standard one-inch pipe ($1\frac{5}{16}$ in. outside diameter) drives easily, and two of them in multiple give the same superficial area for ampere-hour capacity as a two-inch

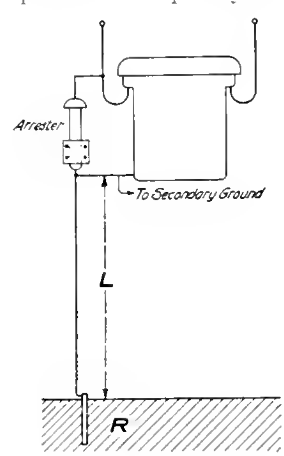

Fig. 8

pipe, while having at the same time only about half the resistance of the one larger pipe.

9. Electrostatic Capacity Factor, or How to Minimize the Objectionable Inductance of Long Leads to an Earth, and also the Resistance of an Earth Contact.

This is done by utilizing the electrostatic capacity of transformer cases, generator frames, etc., in conjunction with a lightning arrester of low equivalent needle gap. One instance is shown in Fig. 8, which is a sketch of the best method of protecting a transformer on a pole. When a discharge takes place through the arrester, the drop of potential between the primary winding and the iron case of the transformer is equal to the drop across the arrester itself. Momentarily the iron case may be charged up to a high potential, due to the drop of potential of the lightning current in the inductance of the long lead marked L, and through the earth contact resistance marked R; but the difference of potential that the transformer is subjected to depends on the efficiency of the arrester.

As another instance, surrounding a station with iron pipes, all connected together and joined to the apparatus cases and frames, will produce the same effect on the station as described above for the transformer case. The earths may have a considerable resistance, and yet lightning will not produce a high difference of potential between the leads of the apparatus and the station.

Algebraic Law, Data and Calculations

The standard instruction for determining the resistance of earths is to have a minimum of three earths, to measure the resistance between each two, and to substitute in three simple equations:

$$R_1+R_2=A \qquad (1)$$

$$R_1+R_3=B \qquad (2)$$

$$R_2+R_3=C \qquad (3)$$

It is presumed that the solution of these three equations for the respective resistances, R_1, R_2 and R_3, gives the correct value. This is seldom true, and unless precautions are taken the values calculated may be in error easily by 1000 per cent.

The error arises from the fundamental assumption that an earth-connection has a real and definite value of resistance. The fact is that it has not; and, the premise being wrong, the mathematical calculations are naturally erroneous. An earth has a fairly definite value of resistance if it is isolated from other earths, since the greatest proportion of its resistance is in the material immediately around the metal. For example, three pipe-earths driven at distances of 10 ft. apart may be said to have fairly definite individual resistances, and the solution of the equations do not give absurdities.

If, however, two pipe-earths are driven close together and the third earth is a water-main in the neighborhood, the resistance of the water-main calculated from the equations will have a value many times higher than its real value relative to one of the pipe-earths. On the other hand, if two pipe-earths are driven far apart, say 50 ft., and each is near the water-main, then the calculations will give an absurd negative resistance for the water-main. This matter must be treated by modern methods—"in the light of reason."

Fourteen earths were measured. Calculations were made and tabulated (see p. 72). The following data are given: Earths were made of both rods and pipes 5 ft. long. The rods and pipes were driven in two parallel lines one foot apart. Rod No. 1 was used as a common basis for measurements of the rods, and pipe No. 9 (one foot from rod No. 1) was used as a common basis for measurements of the pipe-earths. The spacing from rod No. 1, to each of the others in line, was 0.5 ft., 1.5 ft., 3 ft., 6 ft., 12 ft., 24 ft., 48 ft.; but two of the nearest pipes to No. 9 were left out, so that the corresponding spacing from pipe No. 9 was 3 ft., 6 ft., 12 ft., 24 ft., 48 ft. This brought a rod and a pipe one foot apart as follows: 1 and 9, 4 and 10, 5 and 11, 6 and 12, 7 and 13, and 8 and 14. The rods are standard for telephone work, of galvanized iron one-half inch in diameter. The pipes are standard for all power work, one inch inside diameter, and $1\frac{5}{16}$ in. outside diameter.

In the second and third columns of the table below the resistance measurements were made by 110 volts alternating current and an ammeter.

Comments on the Tabulated Values

In the first line and third column, the values of resistance between the water main (G) and rod No. 1 is 22.1 ohms. Between G and rod No. 2 the resistance is 20.7 ohms. From the second column is taken the value of resistance from rod No. 1 to rod No. 2, one half-foot apart, 24.1 ohms. The rods are so close together that the current from rod No. 1 to rod No. 2 does not utilize the same material that is utilized when the current flows from either rod to the water-main. The resistance of rod No. 1 relative to that of No. 2 is about half of 24 ohms, i.e., 12 ohms, but the resistance of rod No. 1 to the water-main is about 20 ohms. (This latter statement is known by other measurements.) With the same rod having actually two different values, it is evident that the solution in this case cannot be made by simultaneous equations. The calculated values from the first line in the table are: No. 2 = 11.35 ohms and No. 1 = 12.75 ohms (these are about the values of one relative to the other but not the values for lightning discharges). The resistance of the water-main by calculation is 9.35 ohms, which is much higher than the real value.

Following down the columns 6 and 7, the values of the individual resistances of rod No. 1 and the water-main (G) respectively, the variations in results are shown for the variation in the spacing between rods, shown in column 1. According to the calculations neither rod No. 1 nor the water-main has any definite value. Examining the extreme case, when the separation of the rods is 49 feet, the calculated resistance of the water-main is minus 2.45 ohms, an impossible value.

The practical question is how to choose the distance between earths such that the calculations will give an approximate idea of their individual resistances. The answer is to make the earth connection as individual as possible. That is to say, when measuring from No. 1 to No. 2, the current stream around No. 1 should be about the same as when measuring from No. 1 to No. 3. Where the three earths are pipe-earths, a favorable condition of test is easily obtained by placing them at a minimum distance of about 6 ft. to 10 ft. When, on the other hand, one earth is a water-main or a railroad track, a fairly good condition for test is obtained by making the distance between pipes at least 10 ft., and the distance from each pipe-earth to the water-main or track about twice as great.

In each case of measurement, the result sought must be the basis. For example, if the result sought in a signal circuit is the resistance in the path of lightning from a local ground or earth to the track, a direct measurement between the two suffices. If, on the other hand, it is a question of whether the tracks will pick up more of the ground-currents from a lightning stroke in the neighborhood of the tracks than the local ground wire at the signal tower, then the earth-pipe for testing should be driven at a considerable distance from the section of track, but in a perpendicular line; so that the current stream lines will be spread along the track as they would be from an actual lightning bolt striking the spot where the test-pipe is driven.

(1)	(2)	(3)	(4)	(5)	(6)	(7)
	MEASURED RESISTANCE IN OHMS				CALCULATED RESISTANCE IN OHMS	
Distance Between Earths Feet	Rod No. 1 to following	From G to following	Sums G to 1 (see col. 3) plus G to following	Calculation of Individual Resistance	Rod No. 1 at the Various Distances in Col. 1	Water-Main, G, at the Various Distances in Col. 1
		No. 1 = 22.1	Rod	Rod		
0.5	No. 2 = 24.1	No. 2 = 20.7	No. 2 = 42.8	No. 2 = 11.35	12.75	9.35
1.5	No. 3 = 30.5	No. 3 = 21.3	No. 3 = 43.4	No. 3 = 14.85	15.65	6.35
3	No. 4 = 35.4	No. 4 = 22.8	No. 4 = 44.9	No. 4 = 18.05	17.35	4.75
6	No. 5 = 39.0	No. 5 = 21.7	No. 5 = 43.8	No. 5 = 19.80	19.70	2.44
12	No. 6 = 44.0	No. 6 = 24.0	No. 6 = 46.1	No. 6 = 22.95	21.05	1.05
24	No. 7 = 46.6	No. 7 = 24.7	No. 7 = 46.8	No. 7 = 19.40	22.00	0.10
48	No. 8 = 68.8	No. 8 = 41.8	No. 8 = 63.9	No. 8 = 44.75	24.55	2.45
	Pipe No. 9 to.	From G to.			Pipe No. 9	Water-Main, G
		No. 9 = 19.2	Pipe	Pipe		
3	No. 10 = 31.5	No. 10 = 20.4	No. 10 = 39.6	No. 10 = 16.25	15.25	3.95
6	No. 11 = 34.3	No. 11 = 19.8	No. 11 = 39.0	No. 11 = 17.45	16.85	2.35
12	No. 12 = 40.4	No. 12 = 22.6	No. 12 = 41.8	No. 12 = 21.9	18.5	0.70
24	No. 13 = 42.1	No. 13 = 23.2	No. 13 = 42.4	No. 13 = 22.05	19.05	0.15
48	No. 14 = 54.0	No. 14 = 33.9	No. 14 = 53.1	No. 14 = 34.35	19.65	0.45

Methods of Testing Grounds

While there may be variations in the details of the methods, there are only two methods in very common use. These may be designated as, first, the voltmeter-ammeter method at a potential of about a hundred volts, and, second, the oscillating current Wheatstone bridge method. All the methods of measuring

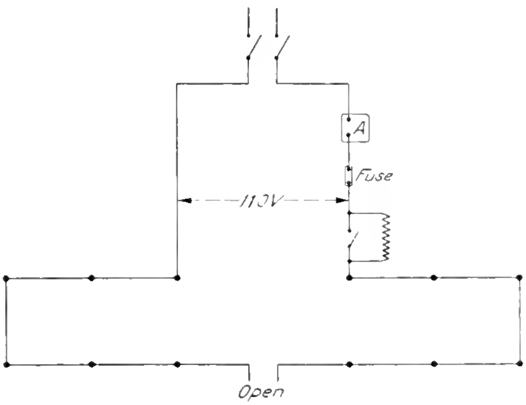

Fig. 9

resistance are not applicable to the measurement of ground resistances due to the electrolytic action and the consequent counter e.m.f. set up. The ordinary bridge method using a few primary cells, is not adapted to this measurement. The results are far in error.

The Voltmeter-Ammeter Method. In the voltmeter-ammeter method at about 100 volts, the counter e.m.f. of electrolysis of one or two volts becomes of comparatively negligible value. It is not a factor when alternating currents are used, and, for the usual conditions, need not be corrected for even when direct current is used. The diurnal changes in resistance may be many times greater than any error involved in the method of test. In order to limit the current to some reasonable value such as 25 amperes to 50 amperes, in the measurement of very low resistance grounds, a series resistance of about four to two ohms is necessary. The value of this resistance is subsequently deducted from the results. If, however, the kilowatt capacity and an ammeter of suitable rating are available, the series resistance is unnecessary for the measurement, although it is desirable as a protection to the ammeter in case of erroneous connections. A typical circuit is shown in Fig. 9.

The Wheatstone Bridge Method. In many isolated places 110 volts for testing is not available; and it then becomes necessary to resort to the bridge method. Both methods give the same value of resistance but the bridge method, owing to its small currents, gives no indication of the stability of the ground to dynamic currents. In the bridge method, alternating current must be used, and consequently it is convenient to indicate the balance of the arms of the bridge by the use of a telephone receiver. The alternating current is easily obtained by the combination of a primary battery, a make-and-break switch, such as a call-bell or buzzer, and a small transformer (see Fig. 10). These auxiliaries are most conveniently and economically obtained from a manufacturer of telephone apparatus. Engineers of the Western Electric Company recommend the use of a 4-ohm buzzer in series with three good cells of dry battery and an induction coil. High pitch buzzers do not give as satisfactory sounds in the telephone receiver as those of lower pitch.

The bridge method may give results in error as much as 5 per cent., but it is usually more accurate. It fails when, for any reason, there are induced from an external source alternating currents in the ground circuit which make the telephone too noisy to hear the buzzer. The method is not adapted to measuring resistances between earths situated many miles apart, due to the inductance and capacity of the inter-connecting wires.

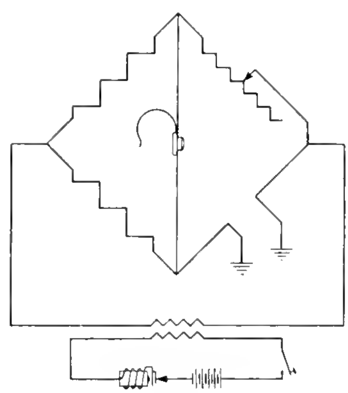

Fig. 10

Accidental Grounds

The subject of accidental grounds has its greatest interest and importance in the surges that are set up by such grounds. The severity of surges set up by accidental grounds depends in a great measure on the arc length, current, and resistance. It is only the factor of resistance and current that falls within the scope of this article. It has already been stated that a point contact with earth has a very high resistance. The passage of heavy currents through such a point of contact produces so much heat that the earth is melted up. This molten earth is a fairly good conductor, but its heat drives the moisture farther away and thus maintains a high resistance. When a line wire breaks and lies along the ground, it will touch the earth in a number of these spots. If the ground is very wet, the conduction is sufficiently great to prevent a large concentration of heat at the point of contact. There may be more or less spluttering of the arc at that point if the current density is sufficiently great, but the resistance in such cases will usually remain low. It is evident that there are all degrees of variation in accidental grounds ranging from a simple contact in earth too wet to dry out from the heat given out by the passage of the current, through all sorts of spluttering arcs of varying length, to a condition of a semi-conductor like a wet wooden pole, which gives fairly good insulation until it begins to burn.

MODERN TYPES OF SYNCHRONOUS CONVERTERS

By J. L. Burnham

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This article enumerates the various means by which d-c. voltage* may be controlled on a converter running from an a-c. supply, and proceeds to describe these means in detail. The "phase control" method, using an external artificial reactance, is used in variable load work. For conditions of more constant load a synchronous boosting generator may be used, or (more commonly) an induction regulator. The latest development is the split pole converter, and the principle on which it operates is fully dealt with. The latter part of the article discusses present practice with regard to the use of commutating poles.—Editor.

For the transformation of alternating to direct current, or, less usually, transformation from direct to alternating current, a synchronous converter is the most desirable piece of apparatus available where high efficiency and overload commutating capacity are of most importance. The power-factor may be maintained at unity except in cases where voltage control is obtained by change of power-factor. When specially designed, power-factor regulation may be obtained, although it is not usually recommended. At unity power-factor the armature reaction is negligible, and the mechanical torque is only that necessary to overcome losses in the machine. Through the absence of armature reaction and resulting field distortions better commutating conditions on heavy overloads result, and less field copper is required than is the case with a direct current generator, on which counter-excitation corresponding to the armature reaction must be provided. At unity power-factor the armature conductors of a polyphase converter may be made smaller than for a generator, to give the same heating; as the current in the converter armature is the integral of the instantaneous differences of the direct and alternating currents, which are in opposite directions.

Some of the older converters gave trouble from pulsation or hunting, due to the periodic speed changes per revolution of the alternator supplying the power. Troubles from this source are now practically eliminated through improvements in the design of the engines, the present general use of the steam turbine, and improvements in converter pole bridges or magnetic dampers.

As the ratio of a-c. voltage to d-c. voltage is practically fixed, the standard converter as first built could not be used in all cases for direct current supply on account of requirements of variable voltage, except by the use of an extra piece of apparatus for controlling the a-c. voltage. What little inherent voltage regulation exists is due to the reactance of the armature, and is obtained at a sacrifice of power-factor. By the use of external artificial reactance sufficient range in voltage control may be obtained to hold the d-c. voltage constant, with ordinary resistance drop in the a-c. line voltage, and without excessive variation in power-factor.

*It is, we are aware, incorrect to use "a-c." and "d-c." as adjectives, when referring to the relative voltages at the two ends of the converter, the alternating current end and the direct. But a paper on such a subject as this must necessarily abound with references to these quantities; and, for simplicity's sake, we have adopted the phraseology which has by now become habitual with machine engineers.—Editor.

This method is used at present in railway and other variable load work, to which it is adaptable on account of the usually lower load factors. For work where the load is more nearly constant and the voltage variation required is more than that due to the a-c. line drop, a separate piece of apparatus for changing the a-c. voltage is preferable to the variation of power-factor for securing the required d-c. voltage. It is possible to provide for varying the a-c. voltage by quick-break switches connected to taps on the high voltage side of the transformers, although this is not so desirable as an induction regulator, or as an a-c. generator connected as a booster, and driven synchronously either by the converter or by a separate synchronous motor. Of the latter two methods the induction regulator was developed first and is now being used more generally than any other means of voltage control, without change in the power-factor of the converter. Although the synchronous booster combination has many advantages in its favor, it has come too recently into use to have received as yet a very wide application.

The latest development for obtaining voltage control is the "split pole" converter, by means of which the ratio of a-c. volts to d-c. volts may be changed within the single armature without auxiliary devices of any kind. The different methods of voltage control now in use will be discussed in detail.

Phase Control

As indicated above this is most adaptable to variable load work, such as obtains on the smaller railway systems. In general the load factor is low, so that it is possible to adjust the excitations of the fields to give a lagging wattless current at light loads; this lagging current is reduced by the increasing excitation from the series field as the load increases, so that the heating due to the wattless current is reduced to a small value when the heating due to the load current is the greatest. Thus a balance in heating for the light and heavy loads is secured for both the converters and the generator, and the heating for momentary heavy overloads may be kept within safe limits. The artificial reactance that is used to reduce the amount of wattless current required for a given voltage variation, in itself introduces a wattless component (but of smaller value), which makes it impossible to hold unity power-factor on both generator and converter at the same time; and thus the system always has a wattless component equal to the percentage of reactance used. The amount of reactance has therefore been fixed at 15 per cent., which will usually give the desired voltage variation without producing objectionable difference in

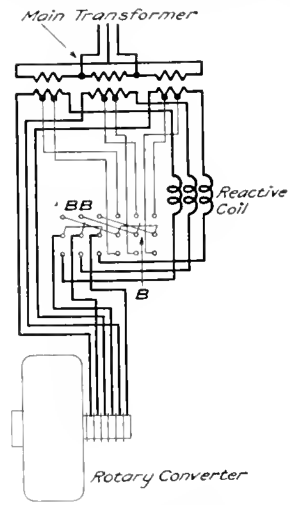


Fig. 1. Connections of Starting Switches and Reactive Coils for Six-Phase Converters

power-factor between the converter and the generator. Fig. 1 shows the connections of starting switches and reactance coils for a six-phase converter.

A-C. Voltage Control

The most obvious means of changing a-c. voltage consists in the use of quick-acting switches connected to taps on the transformers. These have been used but slightly, on account of the complication of the switching mechanism for shifting the tap connections, and the attendant risk of short-circuits started by arcing of the switches.

The induction regulator avoids the necessity of any switching and gives a smooth variation in a-c. voltage, which is preferable to the step-by-step variation obtained by taps. The induction regulator is a polyphase transformer in which the relation of primary and secondary may be changed by mechanically shifting the primary winding. The primary is excited at constant a-c. line voltage and induces practically constant voltage in the secondary, which is connected in series with the line. By changing the relation of primary and secondary windings, the secondary voltage is changed in phase relation to the line voltage, with which it adds vectorially. It is therefore possible to increase and decrease the line voltage by any amount, up to full secondary voltage of the regulator.

The synchronous booster, which may be driven either by being direct-connected to the converter or by a separate synchronous motor, has its winding connected in series with the source of supply, so that its voltage may be added to or subtracted from the supply

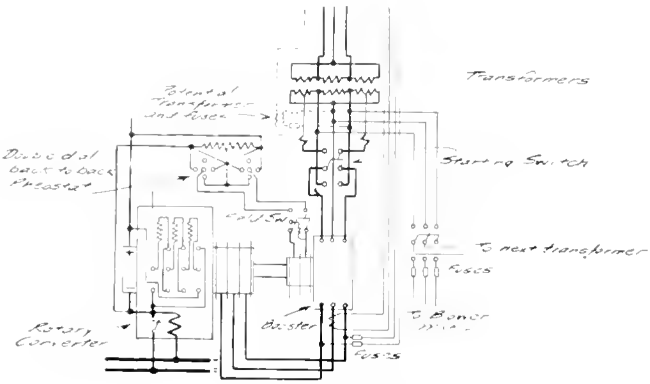


Fig. 2. Connection Diagrams for Converter and Series A-C. Booster Combination

voltage by the required amount, depending on the direction and amount of field excitation. This combination of synchronous booster, direct-connected to the converter, has the advantage over the induction regulator of greater simplicity and reduced amount of station wiring. The connection diagram for this combination is shown in Fig. 2; while the appearance of the set is shown in Fig. 3.

The Split Pole Converter

Until recently it has been assumed that the a-c. to d-c. voltage ratios available in the armature of a converter were fixed within close limits. By dividing the pole into parts with field winding for each part so that the flux distribution through the pole face may be changed, it is possible to obtain variable ratios and thus control the d-c. voltage, from a single armature, to the values desired, without any device having corresponding a-c. voltage control. It is possible to obtain variation by using any number of divisions of the field pole; but the simplest and most economical arrangement is to use two sections, which gives the least number of parts and field circuits, and at the same time provides the maximum amount of voltage control with the least distortion of the alternating current wave shape. Fig. 4 is an illustration of a regulating pole converter.*

In order to provide a clear understanding of the operation of the split pole converter it may be as well to explain in a little more detail the principle upon which it is based. Briefly, the action to accomplish d-c. voltage variation when constant a-c. voltage is applied to a split pole converter may be

* For further technical details the reader is referred to proceedings of A.I.E.E., Vol. XXVII, Part II, pages 959 and 987; and also to GENERAL ELECTRIC REVIEW, Vol. XI, pages 207 and 273, Vol. XII, pages 26 and 84 by Dr. C. P. Steinmetz.

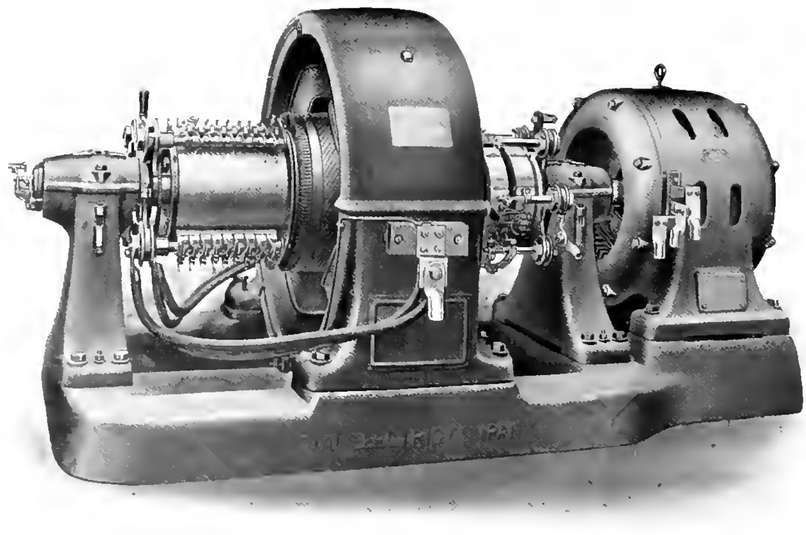


Fig. 3. Converter and Series A-C. Booster Set

explained by referring to Fig. 5 (*a*), (*b*) and (*c*), which represent the poles excited for the higher, intermediate and lower voltages respectively. Starting with the condition of no excitation on the regulating pole, as shown in Fig. 5 (*b*), the effective polar arc is that of the main section only. By gradually increasing the excitation of the regulating poles, with current in a direction to give the same polarity as the corresponding main poles, as in Fig. 5 (*a*), the effective length of polar arc is gradually increased. Longer polar arcs give a more peaked wave shape of a-c. voltage in a distributed winding such as is used in all converters. Since the d-c. voltage is the maximum value of the a-c. voltage, the longer polar arc will give higher d-c. voltage for a given effective a-c. voltage applied. Starting again with no regulating pole excitation, Fig. 5 (*b*), and exciting the regulating poles in the opposite direction, as shown in Fig. 5 (*c*), the d-c. voltage will be reduced. This change in d-c. voltage is not dependent on change in wave shape, but to the differential action of the voltages generated by the pole sections. The voltage generated by the regulating pole flux subtracts from that generated under the main pole in the portion of the armature winding between the d-c. brushes. The change in a-c. wave shape also has some influence on the voltage ratios, but its effect is small in comparison to the differential action. Under this condition of excitation the d-c. voltage is not the same as the maximum a-c. voltage, but is of some lower value.

The split pole converter, like the synchronous booster combination, gives the simplest

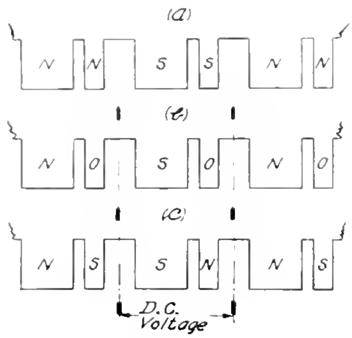


Fig. 5

station layout and wiring. When the split pole converter was first proposed predictions were made that it would produce very undesirable effects upon the system, due to distortions in wave-shape: but after several years of operation these forebodings have proven groundless. The troubles which might have arisen from wave distortions have been avoided by the selection of transformer connections to avoid short-circuiting the third harmonic voltage, which is the largest disturbing factor. Fig. 6 shows the d-c. connections of a split pole converter.

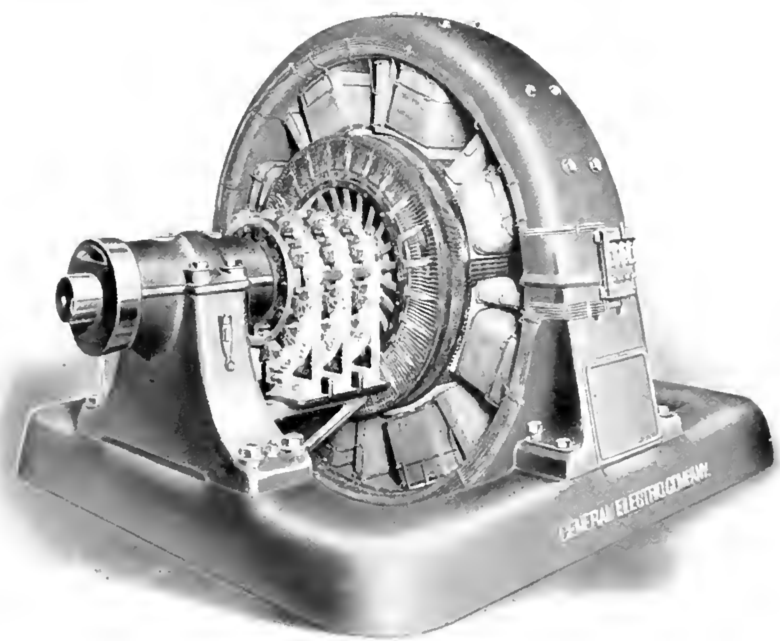


Fig. 4. Split Pole Converter

Comparison of Split Pole Converter With Synchronous Booster Combination

The commutating characteristics of these two types when converting from alternating current to direct current are very similar. Bearing in mind that a motor armature reaction aids commutation, the following comparisons may be made.

With theoretical sine wave of alternating current the armature reactions of alternating current and direct current cancel one another, if the losses in the converter are neglected. To supply the losses, the a-c. motor input must be increased by a percentage equal to the losses of rotation. The split pole converter has a motor armature reaction through a voltage range extending

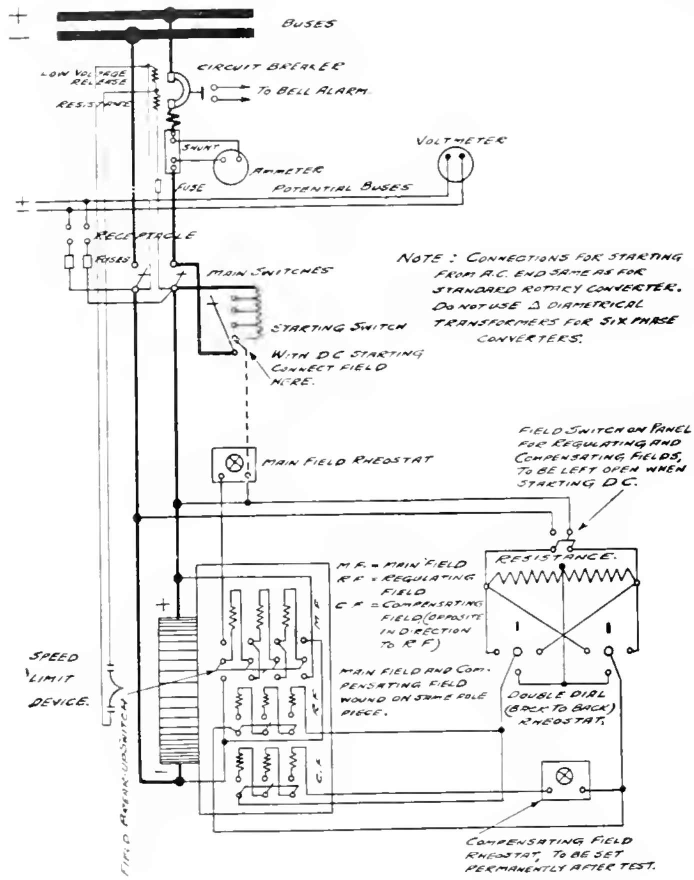


Fig. 6. Direct Current Connections of a Split Pole Converter

from maximum d-c. voltage to a value which makes the d-c. armature reaction greater than the a-c. armature reaction; that is, when the d-c. volts are reduced below the value given by the theoretical ratio with sine wave, by a percentage equal to the percentage losses in the converter. By greater reduction in d-c. voltage the d-c. armature reaction is the greater and gives a generator armature reaction which is opposed to commutation.

The synchronous booster-converter combination has a motor armature reaction at the higher d-c. voltages when the booster is acting as a generator; a motor armature reaction when the booster is inactive, or is acting as a motor giving an output less than the rotation losses; a generator armature reaction when the booster is opposing the line voltage and acting as a motor with an output greater than the rotation losses. At this point in d-c. voltage reduction the converter ceases to drive the booster, but, on the contrary, the booster commences to act as a motor and drives the converter, in addition to carrying the rotation losses.

From this it will be seen that both types of machines commutate best at maximum voltage, and grow worse as the d-c. voltage is reduced. The split pole converter, however, has a compensating feature which opposes the effect of armature reaction, in that the effect of the field excitation of the regulating pole for reduced d-c. voltage is in the proper direction to give a commutating field. Referring to Fig. 7 commutation is assisted when the armature conductors pass the brushes under the influence of the flux of the following pole. The regulating pole adds flux in the same direction as the following main pole when the d-c. voltage is reduced. In the booster-converter combination the generator armature reaction at the low d-c. voltage partially cancels this flux. In the split pole converter the flux required for commutation is increased by decreasing the voltage, so that, at a certain load and d-c. voltage, the effect of armature reaction is cancelled by this flux. At higher loads armature reaction reverses the commutating flux, and at lower loads the flux may be stronger than required; but the average commutating conditions at reduced d-c. voltage are more favorable in the split pole converter than in the synchronous booster combination, except possibly at light loads or at no-load, when the effect of armature reaction is negligible.

Although these machines are rarely used inverted, it may be well to examine the commutating conditions which are met when converting from direct to alternating current. With the split pole converter it is necessary to reverse the direction of rotation of the armature in order to secure proper commutating flux from the main pole, which should be behind the brush in this case. The armature reaction is that of a motor and assists commutation throughout the d-c. voltage range; while in addition the strength of commutating field produced by the regulating pole is increased as the voltage is reduced. For light loads this increase in commutating flux may reduce or reverse the ordinary conditions for poor commutation, in that the commutating flux may be too strong and cause sparking, due to the reverse generated voltage under the brushes.

When the synchronous booster set is inverted the brushes must be shifted backward in order to obtain the best commutation; the armature reaction will assist commutation at the higher d-c. voltages, but will oppose it when the booster drives the set at lower d-c. voltages, as explained above for the usual operation.

Mechanically the split pole converter is simpler and more accessible for inspection, cleaning, ventilation and repairs than the synchronous booster combination, only one field structure being employed.

Commutating Poles

On account of the inherently good commutating characteristics of the synchronous converter, it has not seemed necessary to resort to commutating poles until recently. The limit in the reduction of the number of poles, or the maximum output per pole, has now been reached, and by some manufacturers possibly even exceeded for economical maintenance. To obtain a further increase in the output per pole a rapidly increasing pole pitch is required, in order to reduce the reactance voltage generated in the slot portion of the commutated coil. This increase of pole pitch at the same time increases the reactance voltage of the end connections of coils outside of the slots; so that at a certain output per pole the gain in commutation by increase of pole pitch (and hence the diameter) is slight, and is only realized at greatly in-

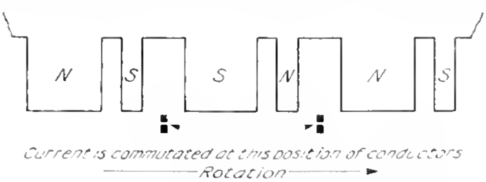


Fig. 7

creased cost. It is at this point that the commutating pole becomes very useful. Through this means the number of poles may be reduced with corresponding reduction in diameter; while, besides taking care of commutation at the desired loads, the commutating poles will usually cause such a great improvement in commutation that it ceases to be a limitation to the steady output of the machine, and will allow of greater momentary overloads.

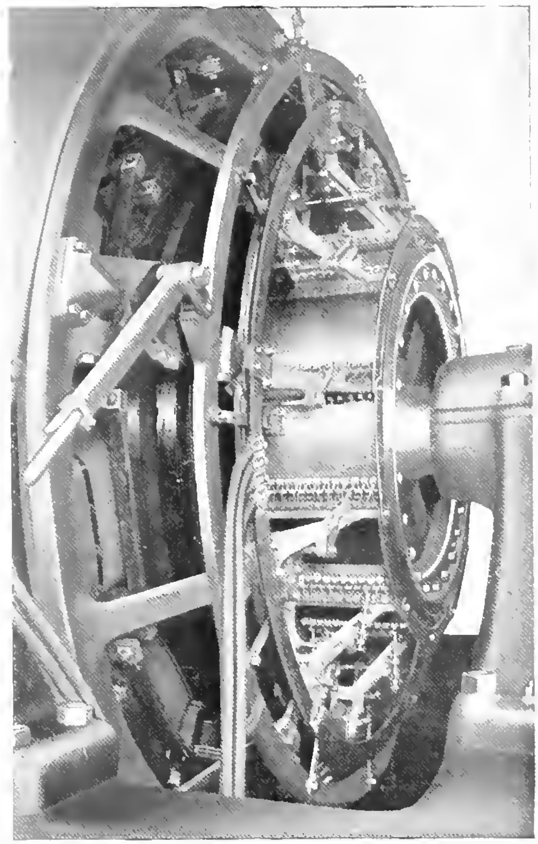


Fig. 8. Brush Raising Mechanism for Synchronous Converter

It will thus be seen that, by the use of commutating poles, (1) a machine much smaller in diameter may be built to do a given duty for widely fluctuating loads, and (2) the commutation being now less of a limiting feature, the load factor may be increased so that it is possible more nearly to realize full capacity, as limited by heating. The great advantages which result are, (1) saving of investment in land and buildings, with smaller parts to handle, and (2) saving in cost of converters, especially where very heavy overloads have to be handled.

The excitation of the commutating pole of a converter is only that required to give the necessary field strength to generate a counter voltage, such as will equal the reactive voltage generated by a reversal of the load current of the coil while passing a brush. Unlike the case of a d-c. generator, it does not require additional excitation to cancel the armature reaction. For these reasons the ampere-turns of excitation required on a commutating pole of a converter are about one-third of those required on a direct current generator having ordinary air-gaps between pole faces and armature. The effect of any disturbance which would unbalance the usual alternating current and direct current relations, would therefore give an armature reaction that would be a large percentage of the total excitation of the commutating pole, and which would greatly affect the commutation. To reduce the effects of these unusual disturbances it is of advantage to increase the excitation required. This may be done by the use of large air-gaps. Even with large air-gaps, however, it is not possible to reduce the sparking, when starting from the a-c. side, to the amount obtained when interpoles are not used. To insure low maintenance of brushes and commutator it has therefore been necessary to provide a brush-raising mechanism on machines intended for starting from the alternating current end. (See Fig. 8.)

In order to obtain current for exciting the fields and also to indicate polarity, two narrow brushes, one for each polarity, are allowed to remain on the commutator when starting. Being narrower than the main brushes, these pilot brushes short-circuit a lower voltage than the main brushes, and the sparking is harmless. As there is always some sparking when starting machines without commutating poles from the a-c. end, the brush-raising device with commutating pole machines gives better a-c. starting conditions than obtained in the past.

An inductive shunt to the commutating pole winding is used the same as with a direct current generator. The inductance of the shunt is made greater than that of the field, in order that the changes of the field strength may be more quickly accomplished. A greater percentage of the current will pass through the commutating pole windings for increasing loads than at steady load, and for decreasing loads the commutating pole current will be less than with the corresponding armature current at steady load. Some actual values taken by the oscillograph are shown in Figs. 9 and 10. In each case the upper curve represents the current in the shunt, and the lower curve the current in the commutating pole winding. The middle curve represents volts per bar and gives the time in terms of the frequency, which is 25 cycles. Fig. 9 is for load thrown on, and Fig. 10 for load thrown off. It will be seen in Fig. 9 that the current in the field windings immediately rises to the full load value when the load is thrown on, and re-adjusts itself to the steady load value in about eight cycles, or in one-third of a second; at the same time the shunt current increases to its steady load value. In Fig. 10 the field current is reduced to no value in about 0.05 seconds, and is actually reversed by the inductive discharge of the shunt, thus quickly forcing down the field strength. With a shunt of such proportions it is possible to throw heavy overloads on or off, without lag in change of field strength behind the armature current sufficient to cause excessive sparking. No more severe test than this will occur in operation, excepting short-circuits, which will cause any type of direct current machine to flash at the commutator unless the voltage is low.

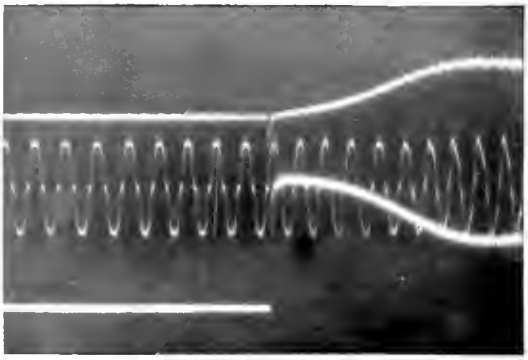


Fig. 9. Load Thrown On

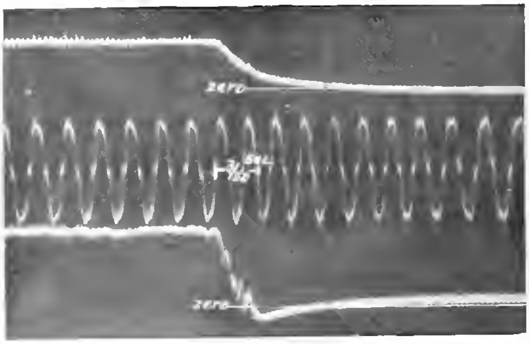


Fig. 10. Load Thrown Off

Oscillograms of Commutating Pole Converter, with Commutating Poles shunted by an Inductive Resistance. Upper curve, current in shunts; Lower curve, current in commutating pole; Middle curve, volts per bar

TESTING IN STEEL MILLS

WITH PARTICULAR REFERENCE TO THE POWER REQUIREMENTS OF ROLLING MILLS

By B. N. Westcott

Power and Mining Department, General Electric Company

The article deals with the problem of determining the power required to operate steel rolling mills, both steam engine driven and electric motor driven. The instruments required for the tests on the two types of prime movers are, of course, radically different; they are enumerated, and any parts that are peculiar to the work in hand are described; while the arrangement of the several instruments with respect to the machine under test is shown diagrammatically. The order of conducting the tests is outlined in detail, and the duties of each man engaged on the work are stated. Indicator diagrams and wattmeter records obtained from actual tests are submitted and discussed.—Editor.

The power required in the mechanical reduction of steel has been the subject of considerable investigation in recent years, both in this country and in Europe. To secure data bearing on this subject, a great number of tests have been made in rolling mills under actual commercial conditions, and as a result a large amount of valuable information has been secured.

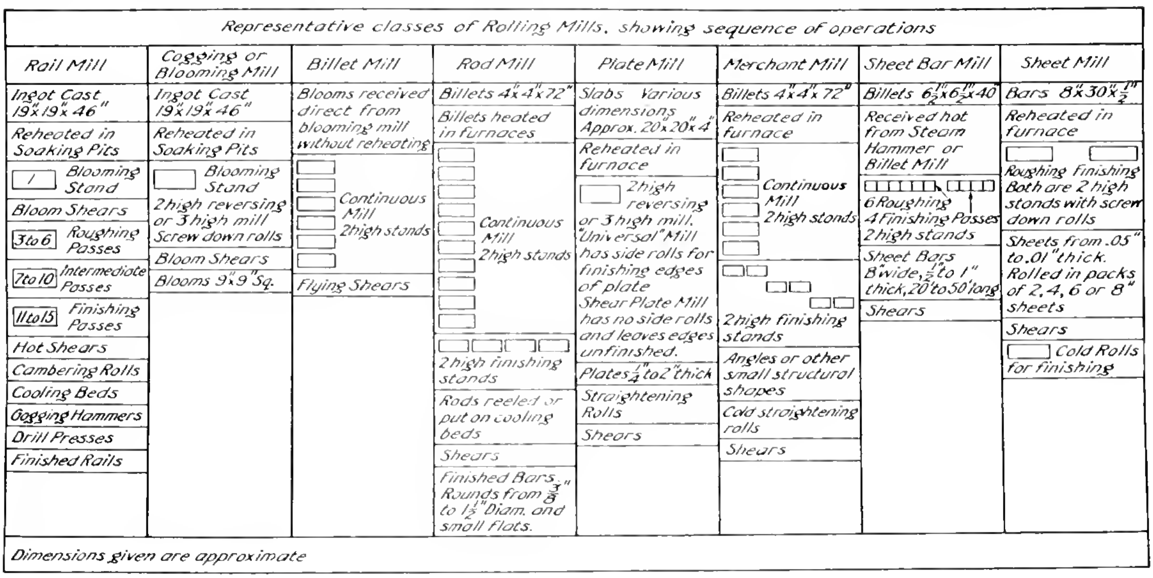


Fig. 1

There are, of course, many different kinds of rolling mills, depending upon the character of the product rolled. Fig. 1 gives a brief summary of a few of them. The arrangements of the stands, dimensions of the steel rolled, etc., for the various mills should not be considered as fixed for any one type of mill, as different companies use various modifications of the arrangements shown; but the tabulation will enable a good general idea to be formed of the various classes of rolling mills.

With regard to testing, rolling mills may be divided into two classes, steam driven and electric driven. The same information is sought in testing either type of mill, but the methods of test are somewhat different. In both cases we wish to determine the power that is required to roll a piece of steel of a given sectional area and length, to a smaller section of increased length, in a definite time.

As several passes are usually required to effect any considerable reduction, the total horse power-seconds represent the energy required for this work. If there is no flywheel effect in the system, the power developed by the prime mover while the steel is in the rolls is the actual power required to turn them. This condition is approximately realized when the steel requires 8 to 10 seconds to go through the rolls, so that even though there be a flywheel connected, its energy is entirely given up before the pass is completed and the total torque required to turn the rolls must be furnished by the prime mover.

When, however, there is considerable flywheel effect present and the passes are of short duration, the power developed by the prime mover while the steel is actually in the rolls may be only a small fraction of the total power required, the remainder of the power being supplied by the flywheel. With steam engine drive the proportion of the total power that is furnished by the flywheel is determined by the speed regulation of the governor, a tendency toward a large drop in speed as load comes on throwing load on the flywheel; while with electric motor drive the amount of power supplied by the flywheel is determined by the regulation of the motor, i.e., its tendency to drop in speed as it is loaded up.

In any case, the total horse power-seconds furnished by the prime mover will not be materially altered, because when a flywheel is used, power will be required for acceleration after the steel has gone through the mill. However, in many instances we desire to determine the actual torque required to turn the rolls while the steel is passing through them. If the total horse power-seconds necessary for a given pass be divided by the time in seconds during which the steel is actually in the rolls, the power required to turn the rolls will be determined. A rough check on this figure can be made by determining the horse power-seconds given up by the flywheel in slowing down.

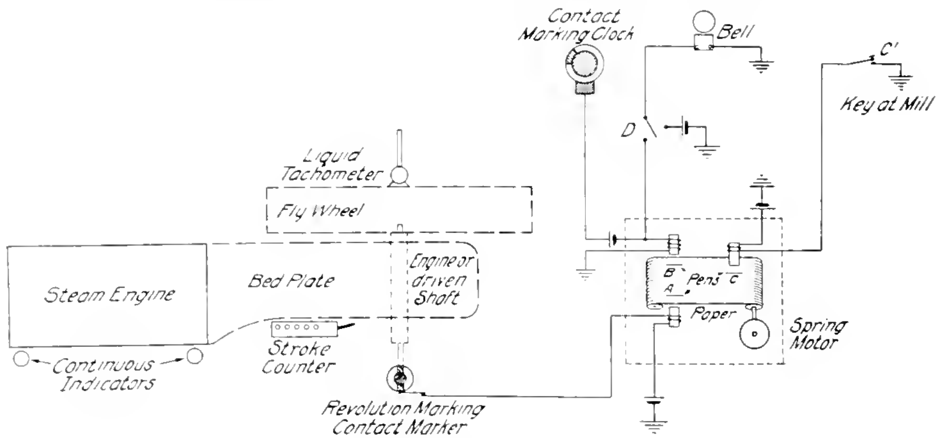


Fig. 2. General Layout for Testing Steam Engine Driven Mills

If

N_1 = revolutions per min. at start of pass
N_2 = revolutions per min. at end of pass
I = moment of inertia of flywheel.

$$\text{Horse power-seconds} = \frac{I \times (2\pi)^2 (N_1^2 - N_2^2)}{2 \times 3600 \times 550}$$
$$= 0.00000997 \times I (N_1^2 - N_2^2)^*$$

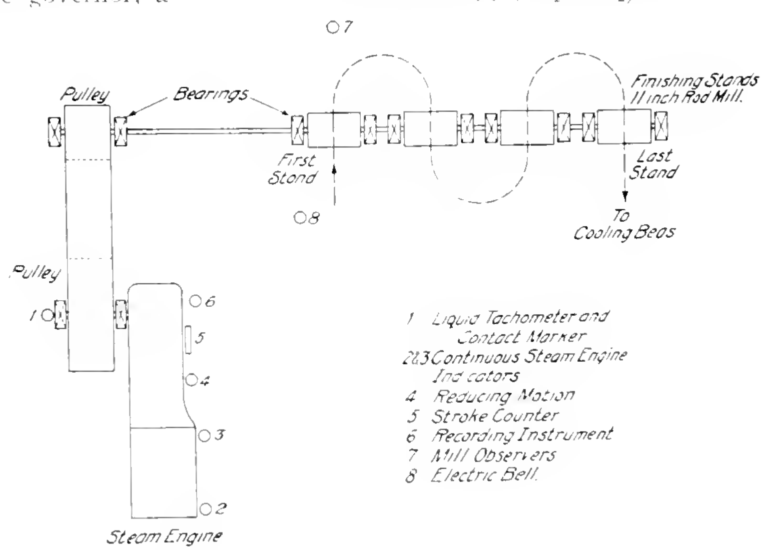


Fig. 3. Arrangement of Four Finishing Stands of 11 in. Rod Mill

* When taking account of the power supplied by flywheels in motor driven rolling mills, reference should be made to the article by Mr. E. J. Cheney, "Flywheels for Motor Driven Rolling Mills", September, 1911, REVIEW.

For the various classes of mills, changes in detail arrangements for testing must be made and these will be taken up under the headings of steam and electrically driven mills.

Steam Driven Mills

In steam driven mills, one of the first essentials is to secure a good record of the horse power developed by the driving engine while the steel is being rolled, and the best way to do this is to use a continuous drum steam engine indicator. This differs from the ordinary steam engine indicator in that the paper on which the indicator card is made is a long continuous strip, which is reeled inside the drum and feeds around the drum a quarter of an inch at each stroke of the engine. Fig. 2 shows the general layout used in testing steam driven mills, and a description of the methods and apparatus used will now be given.

A recording instrument for speed, time, and general information regarding work in the mill is used, which consists of pens, actuated by magnets, that mark on a strip of paper which is moved at a uniform rate beneath them by a spring motor. In most cases three pens are used, marked A, B, and C in the figure. A is actuated by a contact maker, which is driven from the engine shaft or other convenient place so as to complete the circuit of magnet A several times for each revolution of the engine, the number of contacts per revolution depending on whether the engine is high or low speed. Pen B is controlled by a contact making clock, which is regulated to close the circuit of B once in every 5 seconds or at shorter intervals if preferred. In addition to actuating B, the contact-making clock also closes the circuit of an electric bell, or in some cases that of an electrically operated whistle. The third pen C is controlled by a manually operated key located at the rolls.

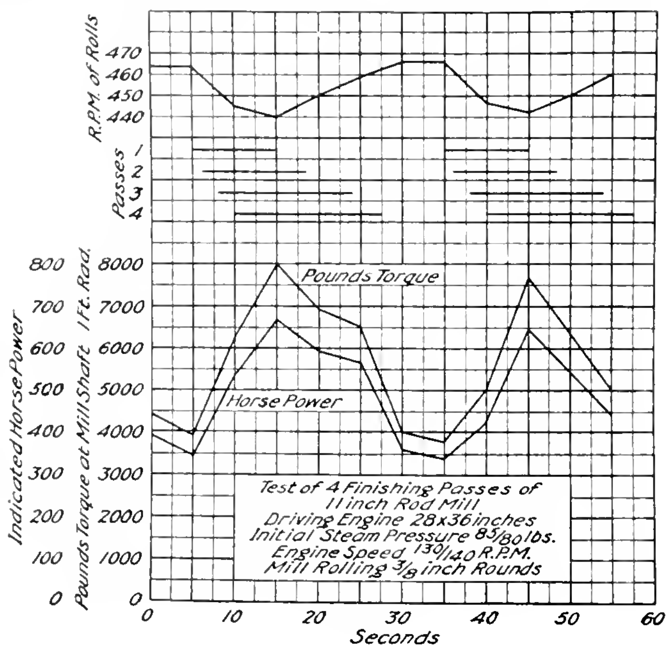
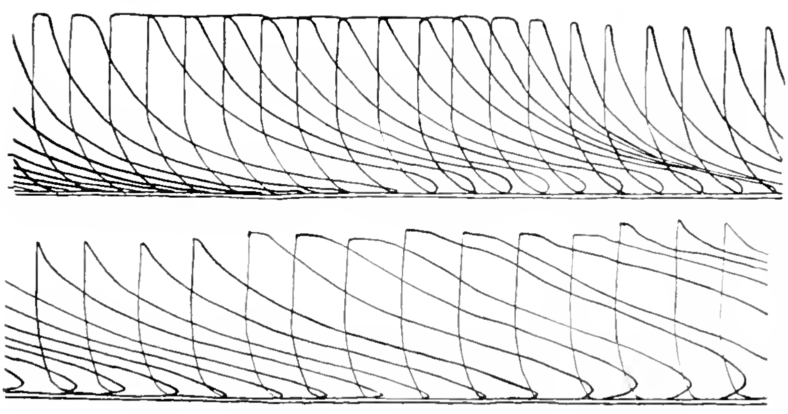


Fig. 6



Figs. 4 (upper) and 5 (lower). Steam Engine Indicator Diagrams

In addition to the above, a liquid tachometer, consisting of a small centrifugal pump which raises a column of colored alcohol to a height depending on the speed at which the pump is driven, is used to indicate speed variations of the engine. A stroke counter is connected to the engine to record strokes and furnish a check on the graphic instrument.

The equipment described will enable an accurate record to be determined of the power that is furnished the mill, but the work which the mill is performing must be noted by other means. In mills where the engine drives one set of rolls, and where the rolls are screwed down between passes and the ingot is reduced in the one stand by passing back and forth, the reduction data is secured as follows:

The weight of the ingot being known, and also the weight of a cubic inch of the steel

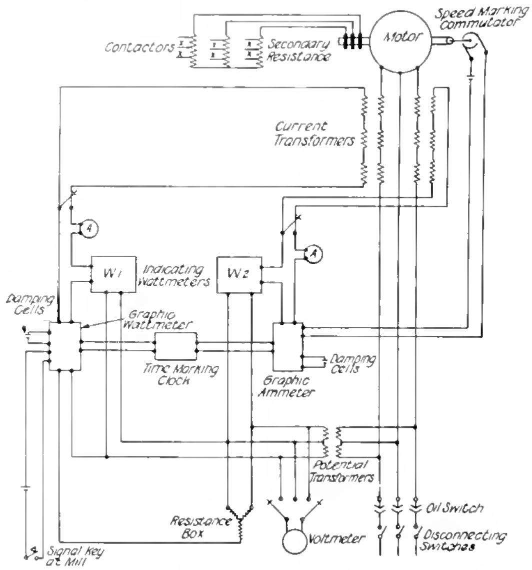


Fig. 7. Wiring Diagrams for Testing Electrically Driven Sheet Bar Mill

being rolled, the volume of the ingot is calculated and is made to serve as a check on the reduction measurements. Before the first pass the length of the ingot is measured with a hooked iron rod. The length is taken after each pass, and in addition, measurements of the width and thickness are made with calipers. The three measurements at each pass should check with the original volume.

Where the engine drives more than one stand it will be necessary to have measurements of the steel taken at each stand. In many mills to be found in commercial operation, steel may be in two or more stands at one time, all of the stands being driven by one engine. In such cases, if tests are being made simply to determine the power required by the mill as a whole, it will only be necessary to note what stands are occupied at any particular time and have observers at each stand to make the reduction measurements. However, in tests where the main object is to accurately determine the power required to reduce the size of a definite weight of steel by a given amount in a certain time, it is well to arrange to have only one stand occupied at one time. Most tests on steam driven mills are made with the first object in view, that is, to determine the total power required by the mill with an aim to supplying a satisfactory motor to replace the engine. The data on the steel which is being rolled is recorded merely to serve as a means of definitely determining the duty which the mill is performing. In most cases where a mill is made up of several stands driven by a number of different engines, it is best to test one engine at a time, in order to avoid impeding the output of the mill and also to reduce the number of men and instruments required for the tests. The methods used are best outlined by a description of the actual details of a rolling mill test.

Fig. 3 shows the layout of the four finishing stands of an 11 in. rod mill. In rolling the smaller sizes of steel, the rod is passing through all four stands at once, while in some of the larger sizes perhaps only two of the stands will be occupied by the same rod at the same time. At (1) is located the liquid tachometer and contact maker, both of which are attached to one end of the engine shaft; (2) and (3) are the continuous indicators, one for each end of the engine; (4) is the reducing motion for the indicators, in this case consisting of an inclined plane fastened to the crosshead, on which rests a steel roller supported from one arm of a bell crank lever.

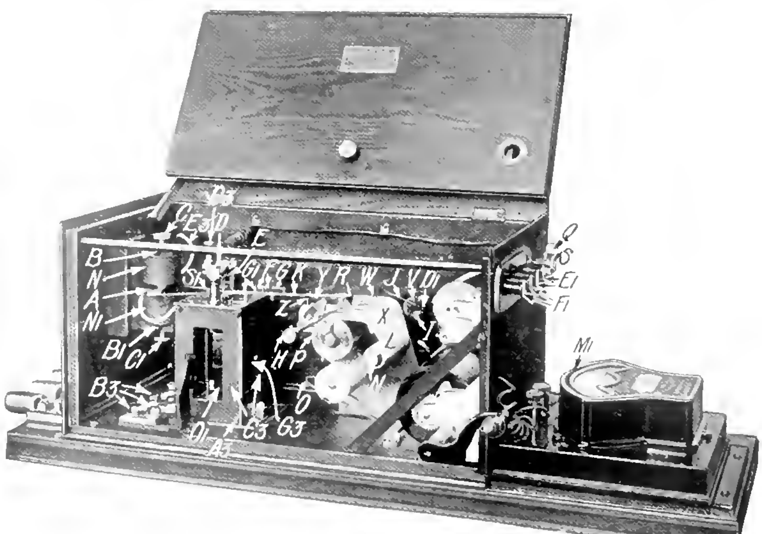


Fig. 8. Graphic Wattmeter

As the crosshead moves back and forth, the roller moves up and down on the inclined plane, this vertical motion being converted into horizontal motion by the bell crank lever and transmitted to the indicator. A stroke counter (5) is actuated from the reducing motion, and the recording instrument previously described and shown in Fig. 2, is located at (6); (7) is an observer stationed at the mill and having in his hand the key (C) Fig. 2, while (8) is an electric bell.

When the man in charge of the test has seen that the observers are in their places and that steel such as desired is coming through the mill, he rings the bell with a predetermined signal to warn the observers to get ready. He then throws switch (D) on the contact controlled by the clock, and the observers proceed as follows: The man at (1) reads the liquid tachometer every time the bell rings, that is, every 5 seconds. The men at the continuous indicators (2) and (3) have their indicators in working order, the reducing motion connected and, in fact, everything but the continuous feed operating. When the bell is first rung by the time clock, the feeds on both indicators are started simultaneously and from then on the indicators automatically record the torque developed by the engine. The stroke counter is read and a record made by a man at (5) every time the bell rings. The recording instrument at (6) has been making a chart of engine strokes against (5) second intervals, and from these stroke records, the speed of the engine at any instant may also be scaled off. In addition, the observer at (7) has been signaling by his key the instant at which steel enters each pass, and this has been recorded on the chart and is an accurate record of the location of the steel in the mill against time in seconds from the start of the test.

The graphic speed record, the tachometer readings and the stroke counter serve to check one another, and from them sufficient data may be obtained for calculating the flywheel torque developed, in case the flywheel effect is sufficiently great and the character of the load is such as to make it worth considering.

In a mill of this type, the rolls are set by trial at first, and when once the correct setting and reduction for each pass have been obtained, the rolls are not changed while the size of steel that is rolled remains the same—which may be several days, or perhaps only six or eight hours. Because of this fact, it is comparatively easy to get the reduction of the steel per pass. Before the first pass a sample is sheared from the rod and likewise after each of the passes, and from these samples the reduction may be determined.

The temperature of the steel affects to a great extent the power required for rolling. It is therefore the usual practice to make temperature measurements of the steel by means of a pyrometer. The best pyrometer for this purpose is some form of the spectrum or color type, where the color of the steel is compared with another color, such as an incandescent lamp filament, and the temperature determined from experimental data and tabulations. Another scheme is to focus the rays of light from the steel on a thermal couple, which is connected to a galvanometer calibrated to read temperature.

Figs. 4 and 5 show portions of continuous indicator cards from steel mill tests. Fig. 4 was taken from a 44 by 60 simple Corliss engine driving 12 stands of a continuous rod mill. The instant at which the steel enters the rolls is distinctly shown by the point where the engine begins to take increased steam. For about 12 strokes the engine does useful work and then drops back to friction load. Fig. 5 shows cards taken from a 28 by 36 simple slide valve engine driving the four finishing stands of an 11 in. continuous rod mill. The cards show what a large proportion of the total power developed by the engine was used in overcoming friction and other losses. This engine ran at 130 to 140 r.p.m. and was belted to the mill shaft so that the latter ran at 440 to 470 r.p.m.

In Fig. 6 are plotted curves from data secured in one of the tests of the 11 in. rod mill mentioned. The top curve is the roll speed in revolutions per minute, and below it is a graphical representation of the passes occurring in the mill at any instant. For instance, the rod entered pass 1 at five seconds, and the last end passed out from stand 1, ten seconds later; the head end in the meanwhile having entered stand 2 at six seconds, stand 3 at eight seconds, and so on. During the period from ten to fifteen seconds all the stands were occupied.

The next curve shows the pounds torque at one foot radius that was developed by the engine at the mill shaft, and beneath the torque curve is a curve of horse power determined by combining the torque and speed curves. By a consideration of all of these curves the proper size of motor to replace the engine may be determined.

Electrically Driven Mills

In testing electrically driven mills, the conditions are much more favorable for a close determination of the power required to reduce steel than in steam driven mills, because of the great accuracy of electric meters as compared with the steam engine indicator. The information obtained from testing motor driven mills is of extreme value in estimating the size of motors required in new mills or in mills at present driven by engines, where a certain tonnage for the mill is given, together with information as to the dimensions of steel rolled, number of passes, roll speeds, etc.

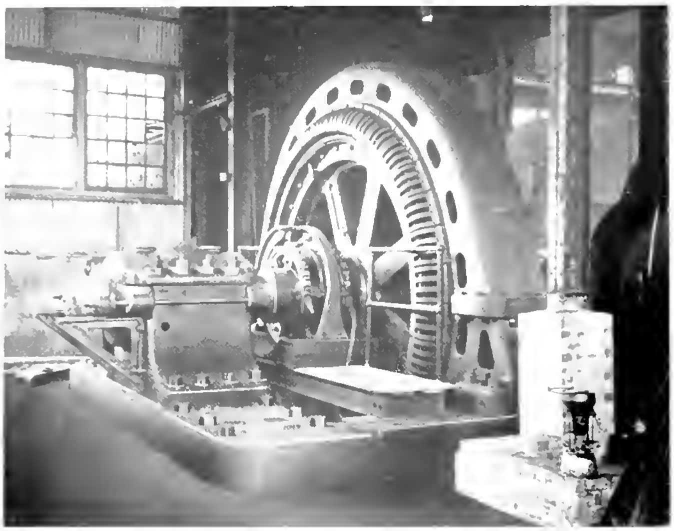


Fig. 9. 1000 H.P. Induction Motor Driving 20 in. Bar Mill

Fig. 7 shows the wiring used in testing an electrically driven sheet bar mill. This mill is two-high, with rolls from 16 to 20 in. in diameter, and is driven by an induction motor of 1000 horse power, 83.3 r.p.m. synchronous speed, operating from 2200 volt, three-phase, 25 cycle mains.

The power required to drive the mill is recorded by a graphic wattmeter similar to that shown in Fig. 8. This is a single-phase instrument, but is calibrated to record three-phase power, its voltage coil receiving potential across a Y resistance box. To check the recording wattmeter, single-phase indicating wattmeters are used, together with indicating ammeters; potential transformers stepping the 2200 volt supply down to 110 volts, and current transformers of suitable ratio being used for the current coils of the wattmeters and the ammeters. Each of the graphic meters is provided with two pens in addition to the main pens for recording power and current. On the graphic wattmeter one pen is connected to the time-marking clock and spaces off equal time intervals, while the other pen is controlled by a key located at the mill. In the graphic ammeter one pen is likewise connected to the time-marking clock and the other in circuit with the speed-marking commutator, which is connected to one end of the motor shaft.

A voltmeter is wired in circuit as shown, so that voltage between any two lines can be read; and in addition to the above equipment, a liquid tachometer is used to indicate the motor speed.

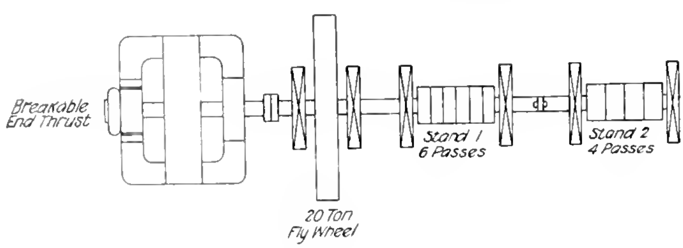


Fig. 10. Plan of 20 in. Bar Mill

The rolling mill motor may be designed for either direct or alternating current, the majority installed today being of the latter type. We will therefore outline first the methods used in working with alternating current apparatus.

The motor is started up with all resistance in the secondary, and as it comes up to speed, the contactors close and short circuit portions of the resistance, bringing the motor nearer to synchronous speed. Sufficient resistance remains permanently in the secondary circuit to cause a considerable drop in speed from no load to full load, thus allowing the twenty-ton flywheel to take some of the peak power demands.

speed and time, and the man at the mill signaled just what passes were occupied at any instant. As the billet went through each pass, the speed dropped and a man at the liquid tachometer noted the high and

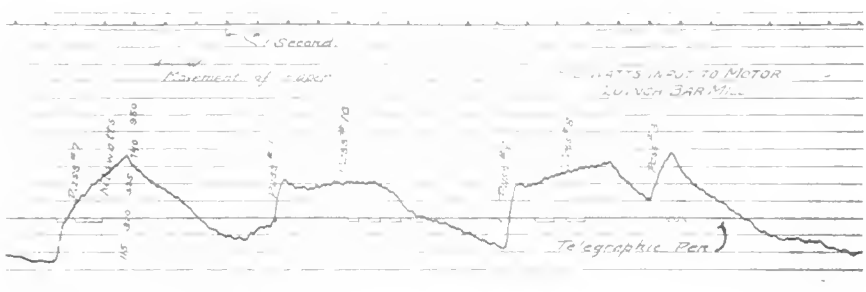


Fig. 11. Graphic Wattmeter Record taken on Motor shown in Fig. 9

The steel is rolled as follows: A billet about 5 ft. long and 6 in. square is brought to the first pass on stand No. 1 and sent through the rolls. It is caught on the other side, returned over the top of the rolls, and sent through the second pass. This procedure is kept up until the last pass, when the billet has been reduced to a sheet bar about half an inch thick and 40 feet long.

When the mill is in regular commercial operation, as many as three billets may be in the stands at once, but in most of the tests that were made, it was decided to have only

low speeds of the motor. In addition to these records, readings of voltage were taken, while two men took measurements of the billet at each pass, using calipers for width and thickness and a hooked iron rod for length. The recording instruments were checked with the graphic meters, by taking simultaneous readings during a long pass when the input to the motor was steady for a sufficient length of time to permit of good readings being secured.

In working up the data obtained, the characteristic curves of the induction motor were

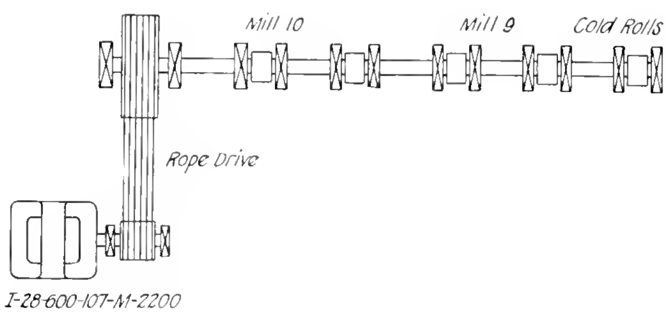


Fig. 12. Plan of 30 in. Four-Stand Sheet Mill

one billet in the mill at a time. With this understanding the mill was tested as follows:

Just before the billet entered the first pass, the spring motors on the graphic meters were started, the short circuiting switches on the secondaries of the current transformers opened and the time-marker clock started. At each pass from then on, these instruments recorded kilowatts and amperes input to the motor,

calculated. For any given pass the graphic records showed the kilowatts input to the motor, the time of the pass, and the drop in speed. The size of the flywheel was known, and therefore the value of all the factors for substitution in the formula.* (*Next page*)

* See article by E. J. Cheney, previously referred to, and also article by F. G. Gasche, Transactions A.I.E.E., June, 1910.

$$T = T_1 - \frac{T_1 - T_0}{e^{tA}}$$

Where

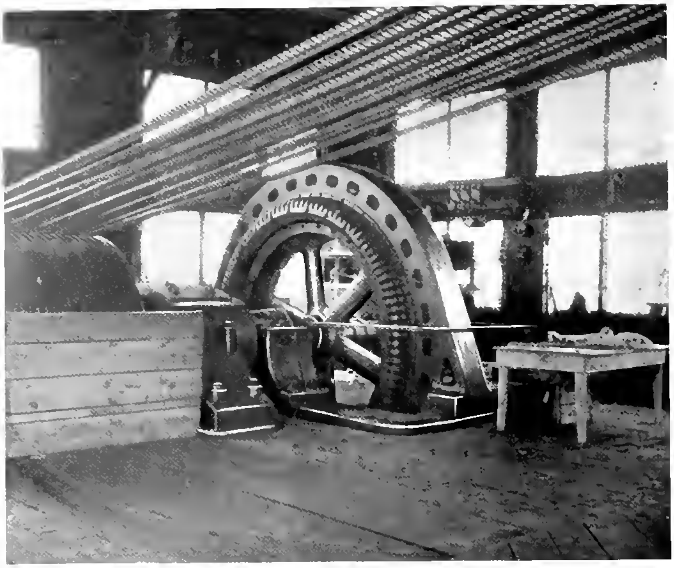


Fig. 13. Induction Motor Driving 30 in. Four-Stand Sheet Mill

$$A = \left(\frac{308\,T}{WNS}\right)$$

T = Motor torque at any time
T_1 = Total torque of the load
T_0 = Initial torque of the motor at zero time
E = Base hyperbolic log = 2.718
T = Motor torque at slip s
W = Flywheel effect in pounds at one foot radius
S = Slip at torque T
N = Synchronous speed in rev. per min.

When the total torque required in reducing the steel has been determined, curves of torque at each pass may be plotted against time, and from these, curves of horse-power-hours per ton against per cent. elongation can be laid out. The latter curves are extremely useful in estimating the power requirements of future mills.

With direct current motor driven mills, the testing apparatus and methods are very similar to those used for induction motor driven mills, with the exception that no potential or current transformers need be employed. The recording meters are similar in appearance to the alternating current meters.

Figs. 9, 10 and 11 relate to the test of a 20, in. bar mill. Fig. 10 is a plan view of the mill and Fig. 9 a picture of the driving motor. Fig. 11 is a graphic wattmeter record from a test made while the mill was in commercial operation. The first peak on the record was caused by steel entering pass No. 7. This pass required about three seconds, and the manner in which the flywheel took the peak load, causing the input to the motor to increase comparatively slowly and likewise decrease slowly, is clearly shown. The next peak was caused by steel in pass No. 1, and then a bar which had been waiting was sent through the mill for its last, or tenth pass, and so on as noted in the curve. At the top of the sheet the time is marked off in seconds and below may be seen the record of the telegraphic pen. The speed-marker record is on the graphic ammeter chart, which is not shown.

Figs. 12, 13, 14 and 15 relate to a test of a 30 in., four-stand sheet mill. Fig. 12 shows the layout of the stands, motor drive, etc.; Fig. 13 the motor driving this mill;

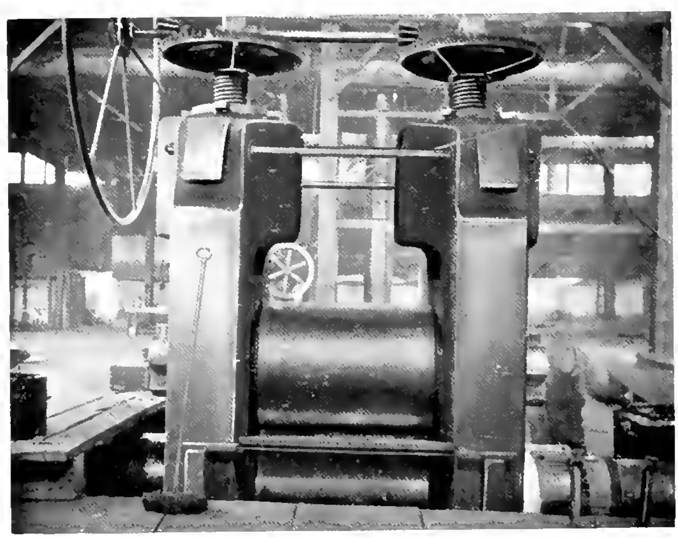


Fig. 14. One Stand of Rolls, 30 in. Sheet Mill

Fig. 14 a detail view of one of the stands of rolls; and Fig. 15 a portion of a graphic wattmeter record made while mills Nos. 9 and 10 were in commercial operation. The speed marker is shown at the top of the record, and time intervals below. The telegraphic pen in this case was on the graphic peaks should be noted; in about one second on the 10th pass the input to the motor jumped from 100 kw. to about 750 kw.

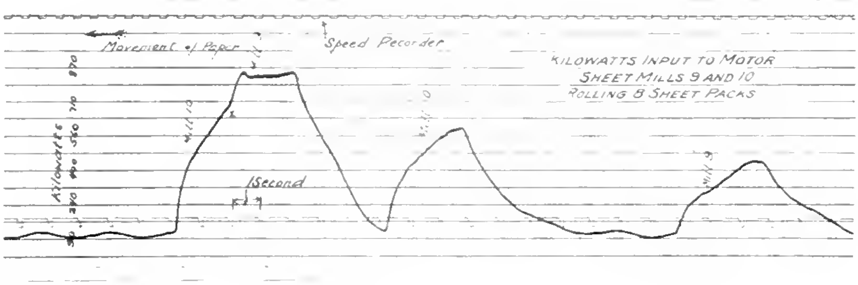


Fig. 15. Wattmeter Record of Power Supplied to Two Mills

ammeter record. The first peak was made exceptionally heavy by reason of the fact that a "pack" of steel sheets in mill No. 10 pulled the speed of the mill down, and before the motor had time to accelerate, another "pack" was sent into mill No. 9, the result being that the motor had a dead drag of about 800 h.p. to pull through. The difference in character of the load on the motor when the flywheel is able to supply part of the torque is well shown by the next peak, produced by sheets in mill No. 10.

Conclusion

This article will serve to give a general idea of the methods used in testing rolling mills. It will be noted that the general scheme of testing either steam or electrically driven mills is the same; and may be summed up as follows:

(1) To secure a continuous record of the power required to drive the mill.

(2) To secure a continuous record of events taking place in the mill.

(3) To definitely and positively connect records of (1) and (2).

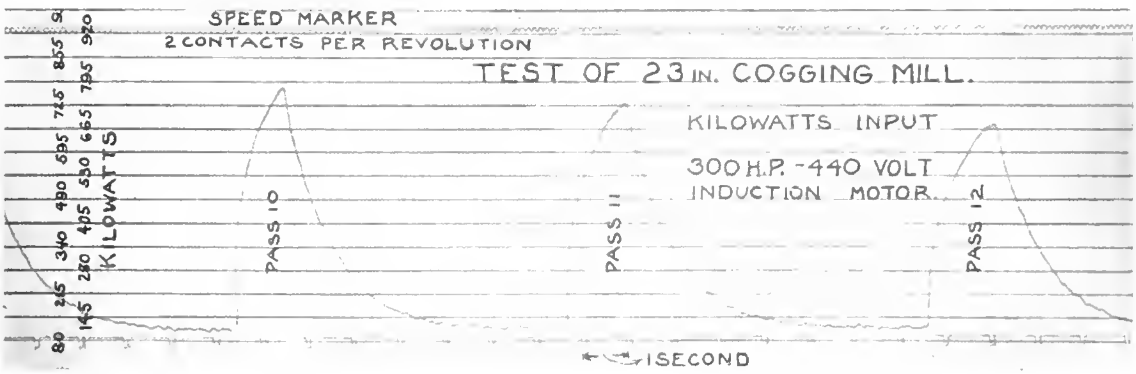


Fig. 16. Example of Insufficient Flywheel Effect

Fig. 16 is given as an example of a mill in which the flywheel effect is insufficient. The mill was a 23 in. cogging mill, with short passes requiring high torque. The very sharp

As a final word, it might be well to note that all apparatus and equipment that is used should be as simple and reliable as possible, in order that the tests may run smoothly.

ALTERNATING CURRENT APPARATUS TROUBLES

Part VI, By W. Brooke

SYNCHRONOUS CONVERTERS

We are resuming this month our series of articles on Alternating Current Apparatus Troubles, and are publishing the first instalment of a paper dealing with the operation of synchronous converters. This paper has been specially prepared for the Review by Mr. Wilfrid Brooke, of the British Thomson-Houston Co., Ltd., Rugby, England, who has had considerable experience in investigating running troubles of synchronous converters. The author's work, however, has made him more familiar with English practice than with American; and it must be clearly pointed out that none of the statements made in his paper are to be taken as in any way official utterances of the General Electric Company. So far as we are aware, this is the first attempt which has ever been made to classify the difficulties which are met with in operating this type of alternating current apparatus; and we think that the subject is now covered in a fairly comprehensive manner in the following pages.—Editor.

It is a somewhat difficult task to attempt a classification of all the troubles which may be met with in operating synchronous converters, as by now there are a very large number of different commercial types of this machine in use. The introduction of the various improvements in design have usually been for the purpose of obtaining better regulation and control of the continuous current voltage. In this paper a few words will be inserted where necessary, briefly outlining the principle on which these various designs are based, in order to afford a better understanding of the procedure which should be followed to remedy such troubles as may arise, either in connection with the converter itself or with its auxiliaries. Probably the following classification will take care of all ordinary troubles which are likely to be met with:

1. Overheating.
2. Accidental earthing of electrical parts.
3. Excessive voltage drop on a-c. end.
4. Difficulties with regulation of direct current voltage.
5. Sparking at commutator.
6. Difficulties with starting.
7. Difficulties with synchronizing.
8. Difficulties of parallel operation.

SECTION 1. OVERHEATING

Overheating of the converter armature may be due to any one of several causes, as follows:

(1) Converter overloaded on d-c. side.
(2) Converter operating on low power-factors.
(3) Unbalanced current on a-c. side.
(4) Incorrect position of brushes on the direct current side.
(5) Internal short-circuit in the armature windings.
(6) Short-circuit of one or more field spools.

Cause 1. Converter overloaded on direct current side. This can usually be investigated from the volt and ampere readings on the direct current side, by noting whether or not the converter is overloaded in respect to its nameplate rating. This may occur when the machine is operating in parallel with others and is taking more than its share of load.

As machines for parallel operation are usually compound wound, the trouble may be due to the fact that the compounding is not correctly adjusted. A compounding test should be taken on the machines separately, in order to determine if each is taking its share of load, by investigating its characteristics. The field excitation should be adjusted so as to give a power-factor of unity on the converter at some particular load, depending on the nature of the load on which the machine is usually expected to work. By thus putting each converter on load separately it may be ascertained whether they are alike in phase relationship and voltage at this particular point. The most important thing is to ascertain the connection between the direct current voltage and the load, and this information can be obtained from the direct current ammeter and voltmeter. For machines on a railway load the field excitation should be adjusted so as to give a lagging current of, say, 30 per cent. of full load current when on no-load; while for machines operating on loads of a more steady character the fields should be adjusted so as to give a lagging current of, say, 20 to 25 per cent. at no-load; the effect of load is to cause the current to lead and hence bring the power-factor to unity at some intermediate load. When this has been found the other machines can be adjusted to give the same result, as explained above. It is not necessary to make the characteristics agree throughout, since, if the machine of low voltage tends to take more load, the automatic regulation of the reactances will increase the voltage so that the load will not be very unevenly divided.

The brushes on the direct current side should be in the operating position when taking this test, and should be operated in the electrical neutral. The adjustments of the compounding can be effected by diverting the series field current, or by changing the resistance of the shunt, where such exists; although the equalizer circuit, which connects points of all the machines between the series fields and the armatures, performs incidentally the function of taking care of variation brought about by the inequality of the series fields.

Cause 2. Converter operating on low power-factor. This can be investigated by noting the alternating current amperes, moving the shunt field rheostat so as to strengthen the field, and noting if the input amperes decrease, which would indicate that a lagging current was being drawn. In cases, however, where machines are operating with external reactances, or where they are fitted with compound windings as well, it should not be forgotten that at low loads the current is made to lag for the purpose of obtaining regulation of voltage at high loads; and the adjustment of field excitation should not be tampered with until a check is first made to see if proper adjustment has been made. It should be borne in mind that the wattless current in the armature, equally with the energy current, is the cause of overheating; and the magnitude of this current should be ascertained by inserting a wattmeter in circuit, with the potential and current coils connected up as required.

Cause 3. Unbalanced currents on the alternating current side. Where machines are operating from transformers this can be investigated by noting whether or not the input amperes in all phases are balanced. Test may also be made by shutting down the machine, feeling the equalizer rings with the hand, and noting if they are warm. Under normal conditions the equalizer rings should carry practically no current. If the potential points become unbalanced the equalizers carry the difference of current so as to maintain balance; and, if this is found to be the case, ammeters may be connected in the secondary phases from the transformers in order to find out whether or not there is a defective circuit, such as might be caused by a failure of part of the transformer. If the equalizers are quite cool the trouble is evidently not that described, and should be sought for elsewhere.

Cause 4. Incorrect position of brushes on direct current side. When the converter is working under a fairly heavy load it is advisable to operate with the brushes in the neutral position, or otherwise an interference may be caused with the super-imposition of the motor and generator currents in the converter armature. Trouble from this cause might be evidenced by the appearance of sparking at the brushes. These should be moved in the direction of the spark by a forward "lead," as in the case of a direct current generator, note being made as to whether the sparking becomes less. If so it is evident that the brushes were not previously set in the neutral position. If the converter is working at a power-factor less than unity, field distortion may be responsible for the sparking through the fact that this shifts the electrical neutral so that it ceases to coincide with the magnetic neutral, which is the point practically opposite the center of the pole.

Cause 5. Internal short-circuit in armature winding. An internal short-circuit in the armature manifests itself in the same way as in the case of a continuous current generator, viz.: by scorching the coil and smoking. If the point at which the short-circuit has occurred is not obvious when the shorted coil has been found, i.e., if it is not at the point where the beginning and finishing ends of the coil enter and leave the slots, probably the best thing to do is to remove the coil and replace it by another one.

Cause 6. Short-circuit of one or more field spools. A short-circuit of one field spool, or of a part of one spool, renders a portion of the field winding inactive and thus decreases the resistance of the field circuit; consequently, a greater field current flows. This may cause a circulating current to flow in the armature, since the potentials generated across the ends of the various paths are not equal, and hence may cause a flow of current through the equalizer circuit to balance up potentials. It may also, if the case is a bad one, unbalance the current in the alternating current line. Overheating of the armature may result, in which case the equalizer rings may also be found to be heated; or a magnettizing current may be drawn from the alternating current side, flowing from each phase alternately as the machine turns round. If the fault is not of such a nature as to manifest itself in any of the above mentioned ways, it should be noted, in order to differentiate this defect from others of a similar nature, whether some of the field spools are hotter than normal, or if any particular one is cooler than normal. By means of a voltmeter, readings should be obtained across the terminals of each field coil. The one giving the least drop in potential is the defective coil.

SECTION 2. EARTHING OF ELECTRICAL PARTS

Usually no trouble will be caused through the earthing of one point in the electrical circuit of the machine, unless this occurs in an armature already operating with one earth connection. In any case, however, the condition is a defect which should be remedied without loss of time. Usually the switchboard is provided with ground detectors, by means of which an earth anywhere on the system will show itself to the station operator.

1. Earthing of Armature

A galvanometer or testing lamp may be used to determine whether the armature or any other part of the machine is earthed. This should be done by disconnecting the alternating current side; or, better still, by raising the slip ring brushes so that the armature winding is alone taken into account. If it is found to be earthed the operator should proceed to find the defective point by leading, through a pair of brushes (positive and negative) a current of about 10 per cent. of full load current from some external direct current source, leaving all other brushes, in the case of multiple machines, raised around the commutator. With the armature stationary, readings should be taken between each segment and the shaft with a millivoltmeter or other low reading instrument, and note made as to where the zero readings occur. These readings will vary at different points of the commutator, but no reading should be obtained if the armature is not earthed. On the other hand, if it *is* earthed, a zero reading will be found, corresponding to the earthed point or points; and it will be noticed that the deflection of the instrument increases on each side of the earthed point, which can thus be determined. If the exact location is not obvious the armature of the machine should be taken out, the binding bands taken off one at a time, and galvanometer readings taken each time to see if the earth has been removed. If not located there it will be necessary to remove the coil which was found to be the defective one.

Earthing of Field Spools

When converters are started from the alternating current side, the field switch which breaks the field circuit into sections should always be left open during the starting period. The field spools act like the secondary of a transformer, and as the turns per pole are considerably greater than the number of armature turns per pole the voltage is likely to be excessive if all the spools are connected in series. If the field switch has been accidentally left in whilst switching on the alternating current supply at starting (so that all the field spools are in series) it is possible that there will be a potential difference of several thousands of volts across the ends of the field circuit if the direct current brushes are lifted, which may break down the insulation to earth. It is a good practice to test the fields to earth periodically; and if a coil is found to be earthed it should be removed, repaired and re-insulated.

SECTION 3. EXCESSIVE VOLTAGE DROP ON A-C. END

If a field circuit should happen to become broken whilst the machine is running, there will be a heavy magnetizing current drawn from the alternating current line, the function of which is to magnetize the field system and provide flux to serve to generate a back e.m.f. A heavy voltage drop on the alternating current end results. In such cases the field circuit should be explored with a voltmeter whilst the machine is running. The best way to do this is to connect one side of the voltmeter to the negative brush or brushes on the direct current side, and measure between poles of the field switch and the connections between the spools. Between the points where the reading is obtained and where the reading is not obtained is then the place where the open-circuit may be looked for. If the machine is shut down all the switches should be withdrawn and a similar sort of investigation made as mentioned above, with a galvanometer.

SECTION 4. DIFFICULTIES WITH REGULATION OF D-C. VOLTAGE

Div. 1. Voltage Low on Reactance Controlled Converters—D-C. End

In reactance controlled converters, cases may arise where the direct current voltage is not high enough within the ordinary limits of regulation. It is not advisable to maintain a high voltage by altering the field excitation and taking wattless currents. Such a course reacts unfavorably on the power-factor, and results either in overheating of the machine or in reducing the kilowatt rating. When a higher voltage is required, it can best be obtained by changing the connections from the transformer secondary winding to a point of higher potential. In cases where transformers are not used (which is not often the case), a series booster transformer or an induction regulator should be installed in place of the reactance. Obviously this is a somewhat costly remedy.

Div. 2. Failure to Obtain Regulation on Reactance-controlled Converters

Trouble of this nature is usually caused through an open circuit in the field system, in which case a large current is taken from the alternating current side. The method of investigating for this cause is the same as already given under Section III of this paper. The same trouble might also be caused through a short-circuit in the regulating rheostat, which would cause the direct current volts to be normally high. This can be located by connecting a voltmeter across the terminals of the field rheostat, if of the ordinary series type, and noting if the voltage reading varies when the rheostat handle is turned around. If the rheostat is in order, the voltage will vary, while a zero reading obtained for all positions of the field rheostat will indicate that the latter is short-circuited. If, on the other hand, the rheostat is of the potentiometer type, the fault would not evidence itself in this way; a short-circuit of the rheostat would result in short-circuiting the direct current line, unless only a comparatively small portion of the rheostat were involved.*

Div. 3. Insufficient Range of Voltage Control on Compound Wound Reactance-controlled Converters

The regulation or compounding in this class of machine takes place, not in the machine itself, as is the case with a direct current generator, but in the reactances. The principle is the same as in the case of the shunt converter, except for the fact that the wattless currents are controlled by the variation of field excitation caused by the series windings. Trouble in obtaining the desired amount of voltage regulation may be overcome in one of two ways. Either the amount of excitation produced by the series field may be increased by increasing the resistance of the shunt across the series fields, so as to make more current go through the latter; or, if no shunt is used, the amount of reactance in the lines of the converter may be increased, as the amount of raising or lowering of the potential is proportional to the reactance in circuit over a given adjustment of the series field.

Div. 4. Failure to Obtain Regulation on Shunt Wound Converter Controlled by Induction Regulator

In this combination regulation is effected by means of a transformer with a movable primary. Failure to obtain regulation may be found to be due to a short-circuit of a portion of the series winding of the regulator, or to an open-circuit in the primary winding (since the boosting flux is contributed by the latter). A short-circuit in the secondary, or series, winding would probably result in heating up and burning out that winding; while an open-circuit in the primary would cause a heavy voltage drop across the regulator, and thus bring down the direct current voltage.

Div. 5. Failure to Obtain Regulation on Synchronous Booster-controlled Converters

This system of control consists of a booster with separate field magnets, having the same number of poles as the converter, so that the conductors of the booster armature run straight through and are in direct connection with the main conductors on the converter itself. The e.m.f's generated in the booster are therefore exactly in phase with those in the converter, and failure to obtain regulation would point to a fault in the field circuit. The connections between the source of supply and the field terminals should be examined for open-circuit. These can best be explored with a direct current voltmeter, commencing from the negative line with one lead of the voltmeter, and exploring each point through which the current should pass with the other lead. From this test it can be noted where potentials are obtained and where potentials are not obtained, from which the fault can then be located. This type of machine is usually provided with a separate exciter† from which constant voltage can be obtained, since the direct current voltage of the converter is probably being varied, depending

† Not General Electric Company's practice.—Editor.

* This same trouble might, in given circumstances, be caused in a number of other ways too numerous to mention. In order to assist towards an understanding of the effect of some of these, it may be as well briefly to touch upon the principle underlying regulation in this style of combination. The principle depends on the production of wattless currents, which lead or lag, depending on whether the field is over or under-excited. As the current entering the converter has first passed through a reactance coil in each line, a voltage across the reactance is obtained, which either opposes or assists the line potential in the following way: If the field excitation is lower than normal, a wattless current is drawn from the alternating current line which is lagging, i.e., is 90 deg. behind the impressed voltage. In this case the e.m.f. of self induction produced in the reactances is 90 deg. behind the current, and hence 180 deg. behind the impressed voltage, i.e., is directly opposing. If the field is over-excited, then a leading magnetizing current is drawn from the line, 90 deg. behind the impressed volts; and since the e.m.f. of self-induction across the reactance is 90 deg. behind the current, it is hence in phase with the impressed e.m.f. and, therefore, increases it. So that if the e.m.f. across the converter terminals, that is, in phase with the line, is varied, the direct current voltage may be caused to decrease or increase in almost constant ratio. The load does not alter the adjustment to any considerable extent, as it has virtually no effect on the wattless current, which is the medium of obtaining regulation.—AUTHOR

upon the purpose to which it is put. In such cases the fault may be found in the exciter. (See GENERAL ELECTRIC REVIEW, June, 1911.) A further cause which might be responsible for such trouble is the failure of the field rheostat to make proper contact. Reversible potentiometer rheostats are used in most cases for booster controlled converters; and though the exciter circuit across which the field resistance of the rheostat is permanently connected may be quite in order, and the field circuit up to the rheostat may be continuous, it may be found that the contact arm of the rheostat is not making proper contact, owing to the pressure springs of the plunger in the rheostat arm having become stuck or damaged. In such cases it is necessary to find out with a direct current voltmeter where the potential exists, and where it does not exist, from which readings the trouble may be located.

Div. 6. Unbalanced Voltage on Synchronous Booster-controlled Machines Due to Incorrect Phase Relationship

There is another type of machine similar to the one last described, with the exception that the booster is mounted on the pillow-block or out-board bearing of the converter, and is arranged so that its boosting winding is in the stator, and its field a revolving one. This arrangement makes it possible to connect up to the mains incorrectly in such a way that the phases of the booster do not correspond to those in the converter, i.e., so that the phase rotation of the booster is opposite to that of the converter. This is really more a factory defect than a running defect, and would always be detected and remedied on the test-plate. In given circumstances outside, however (such as shifting a converter from one location to another, repairs to the booster or the converter, etc.) the same trouble might be met with, and it may be well to indicate the procedure which should be followed. The condition would show itself by setting up unbalanced voltages, i.e., the internal voltages in the machine would not check up with one another; and would cause an unbalanced current to be taken from the alternating current side. The best way of determining whether these are correct is to take the three ends of the incoming booster leads, if it is a three-phase machine, and connect them together to make a star point. The converter should then be run up to speed either from the alternating current rings or direct current side, and the polarity of the machine checked up by a voltmeter, in the same way as would be done in checking up synchronizing connections, i.e., by exciting the booster. The latter is then a star-connected alternator. By connecting one of the three free ends to the alternating current side of the converter, then measuring between one of the remaining converter rings and one of the remaining free ends of the stator winding of the booster, it should be noted if the reading is the sum of or difference between the voltage on the converter and the voltage across two phases of the booster. If it reads the sum, the connection is correct. If it reads the difference, the other booster lead should be selected and will be found to be the correct one. The remaining lead should be finally connected to the remaining ring on the converter. The machine should then be shut down, the supply leads disconnected from the rings, and the booster leads connected to the appropriate rings, as found by above test. The temporary neutral should then be opened up and connected to the three phases of the supply. It may be noted that this method is exactly opposite to testing out for synchronizing, although it is done in a similar manner. When checking up for synchronizing the smallest voltage will indicate correct phase rotation, though with machines working in parallel they are opposite in voltage when boosting one another. On the other hand, the correct polarity is given by the sum of the voltages, instead of by the difference.

In either of the foregoing types of booster-controlled machines, unbalanced currents may sometimes be met with, which may be due to a reversal or short-circuit of one of the field spools of the booster. This will manifest itself in the same way as a similar fault in the main converter itself (see Section 1, Cause 6). Unbalanced currents of smaller magnitude may be caused by inequality of the air-gap of the booster machine. This should be checked up all the way round, on the converter itself as well as on the booster; measurements being taken at each side of the machine if possible, between each pole and the top of one armature tooth, using the same tooth under each pole by moving the armature round. If the variation for either machine is more than 10 per cent. of the average air-gap, the magnet frame should be shimmed up to make the readings more consistent. If the smallest gaps are at the bottom the bearings on the converter should be shimmed up a little, in order to bring the rotor into a more central position.

ELECTRIC POWER IN THE CANNON MILLS

By John P. Judge

Baltimore Office, General Electric Company

Careful tests at these cotton mills, carried out on the relative power consumption of individual and group drive, confirm previous conclusions, viz.: that the increased production resulting from individual drive far more than compensates for the increased power cost resulting from the maintenance of the maximum speed. —Editor.

The Cannon Mills comprise an aggregation of cotton mills located in the Southern States and conducted under the general direction of Mr. J. W. Cannon, of Concord, N. C. The mills are not banded into a corporation, although they employ a common selling agency with stores and offices on Worth Street, New York City, in the heart of the wholesale dry goods district.

The electrical equipment for the mills was decided upon about three years ago and has been in service about two years. Prior to this installation, several northern mills had installed some individually driven machines and two other southern mills had determined to power their new plants with this system. The Cannon mills, however, were among the first large new mills in this country to be so driven. The principal argument in behalf of the system was that the elimination of all belts would effect the maximum production, which in turn would amply justify the cost involved.

These arguments were not based on theory, as the above mentioned experience in this country and a much wider experience abroad have shown satisfactory results in practice. It was found, however, that the increased production called for more power, due to the maintenance of the maximum speed. This necessitated some changes, which were completed about eighteen months ago, and since that time the equipment has been entirely satisfactory to the owners. About one year ago an elaborate series of tests were made, comparing the spinning rooms using individual drive with a spinning room of the Cannon mills at Concord using group drive. These tests were made simultaneously in order that the weather conditions would be the same, and covered one week's production, both mills using the same make of frames,

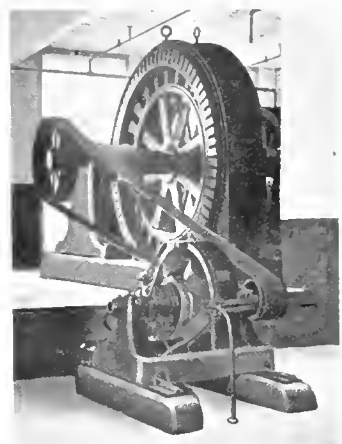


Fig. 1. 1250 Kw. Alternator, Wiscassett Mill

	Spindles	Looms	Generator Capacity in Kw.	Installed	Motor Capacity in Horse Power	Ind. Drive No. of Motors	Steam Engine Horse Power
Cannon Mfg. Co., Concord, N. C.	30000	1000	S 540	1907 1908	1580		
* Cabarrus Cotton Mills, Concord, N. C.	28000	850	S 1140	1906 1907	1220		
Gibson Mfg. Co., Concord, N. C.	37000	500	S	1907	803		700
Franklin Cotton Mills, Concord, N. C.	13000		S	1907	490		
† Cannon Mfg. Co., Kannapolis, N. C.	32000	900	S	1908	1985	S.F. 125 P. 12	
† Patterson Mfg. Co., Kannapolis, N. C.	20000	400	S	1908	865	S.F. 88 P. 8	
Patterson Mfg. Co., China Grove, N. C.	10000	175	S	1907	558		
Kesler Mfg. Co., Salisbury, N. C.	26000	606	S	1908	949½	P. 12	
Tuscarora Cotton Mills, Mt. Pleasant, N. C	4000						200
† Amazon Cotton Mills, Thomasville, N. C.	5500		S	1910	668		
* Wiscassett Mills Co., Albermarle, N. C.	65000		S 1250	1910	2970	P. 14	750
* Efird Mfg. Co., Albermarle, N. C.	25000		S	1910	3021½	10	500
Imperial Cotton Mills, Eatonton, Ga.	6500	150					300
Total	292000	4581	2930		12386	269	2450

Mills marked † were designed for electric drive throughout; those marked * have additions that were designed for electric drive; all other mills using electric drive were changed over from steam-mechanical drive. S.F., spinning frames. P, pickers. S, mill takes power from Southern Power Company.

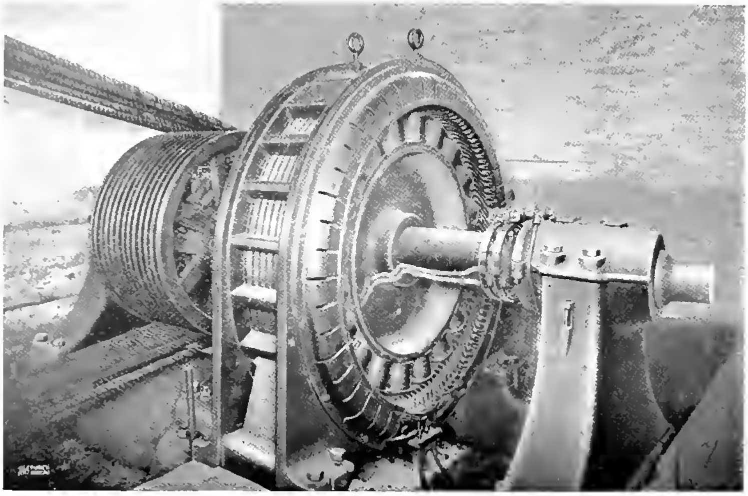


Fig. 2. 580 Kw. Generator at Cabarrus Mill

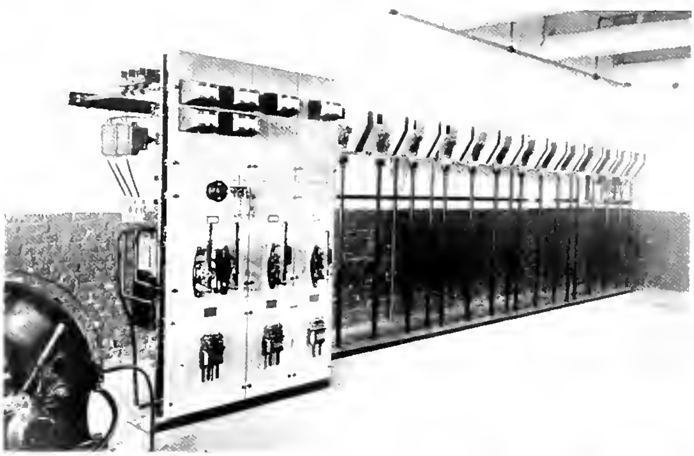


Fig. 3. Switchboard at Wiscassett Mill

belting, with the care and expense of renewals, oiling, etc., would also doubtless make a good showing in favor of individual drive. Some persons have feared that the large number of small motors would tend to heat the spinning room excessively. Careful tests with reliable thermometers showed lower temperature rise with the individual drive than with group or engine drive.

The table on page 95 gives a list of the mills and general information pertaining to the mechanical and electrical equipment.

All the generators listed are three-phase, 60 cycle, 2300 volt machines and are held in reserve to furnish current to the motors when the hydro-electric service is not available. With one exception, namely, a 600 kw. generator at Cabarrus mill, they are connected by ropes to the engines that were formerly used for driving the mills; this arrangement, involving a relatively small additional investment, permitting the utilization of the boilers and engines originally installed, in case of necessity. Continuous electrical operation is thus assured, while the best possible layout of the mill is effected, as no unnecessary shafts and belts need be retained.

same counts, and the same grade of cotton. The tests were made by a competent engineer and every detail was checked by the operating forces of the mills. An increased production per spindle on the individually driven frames of over 12 per cent. was shown and an increased consumption of power per pound of yarn of 10 per cent. These figures confirm previous observations; namely, that the power curve of a spinning frame rises faster than the production curve; but the value of the increased production is much greater than the cost of the extra power. The elimination of shafting and

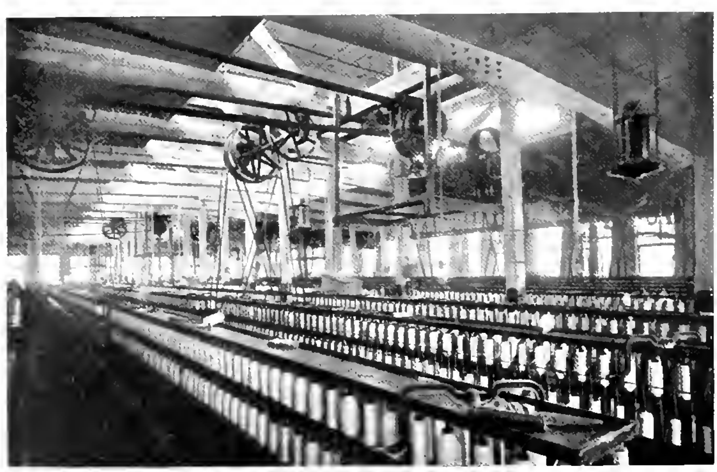


Fig. 4. Group of Spinning Frames in Cabarrus Mill, Driven by Motor Located Overhead

Fig. 1 shows the 1250 kw. generator at Wiscassett mill, and Fig. 2 the 580 kw. generator at Cabarrus mill.

In the Cabarrus and Wiscassett mills, large low voltage motors are used in part; but all motors above 15 h.p. that have been installed since the service of the Southern Power Company has been available are wound for 2200 volts. All motors above 20 h.p. are of the wound rotor type, squirrel cage winding being used only on the small motors. Each motor, large or small, is controlled by an oil switch, most of these switches being of the automatic type with overload and low voltage trips.

In all mills where 2200 volt motors are used, the current is first brought to an incoming line panel, on which are mounted an automatic oil switch, an indicating wattmeter and a watthour meter. From this panel, busbars are carried to a line of fuse panels, each of which is equipped with expulsion fuses and two marble barriers. One panel is provided for each motor. The feeders from the panels to the motors consist of triple conductor copper cables with varnished cambric insulation and lead sheath; they are drawn into iron conduit, which is continuous from the fuse blocks to the motors. As the fuses are solely for the protection of the circuit and are much larger in capacity than the motors, they seldom blow. In fact, so rarely does this occur that the average for three years is less than one fuse per motor. This system does away with all fuses in the mill

Fig. 5. Pickers Driven by Individual Motors

Fig. 6. The New Picker Room in the Kesler Mill - Individual Drive

proper, and at the same time is simple, clean, inexpensive, and has proven very satisfactory.

Fig. 3 is a view of the switchboard in the Wiscassett mills, showing the combined incoming line panel, generator panel, feeder panel and fuse panels. The wiring tubes to the motors are carried down under the old belt-way, to the mill.

Fig. 4 shows a group of spinning frames in the Cabarrus mill driven from a motor located overhead. By the use of slower speed motors in the weave room of this mill, considerable countershafting was eliminated and much better results obtained, the motors originally installed being discarded. The individual motor drive (through belting) in the picker rooms is shown in Fig. 5. In every instance the countershaft and "A" frame were omitted from the picking machines. Fig. 6 shows the new picker room in the Kesler mill, with individual drive, this system being universally approved by all who have used it.

Fig. 7 is a bird's eye view of the Kannapolis mills. In these mills an individual motor is mounted on each spinning frame in most cases direct connected to the cylinder, but so designed that gears may be used if it is necessary to vary the speed considerably. All motors have a synchronous speed of 1200 r.p.m., with the exception of those on 25 frames, which have a speed of 1800 r.p.m. and are geared to the cylinder shafts. Each motor is controlled by a triple-pole single-throw oil switch connected to the shifting rod of the frame. These equipments are shown in Fig. 8.

Fig. 7. A Bird's-Eye View of the Kannapolis Mills

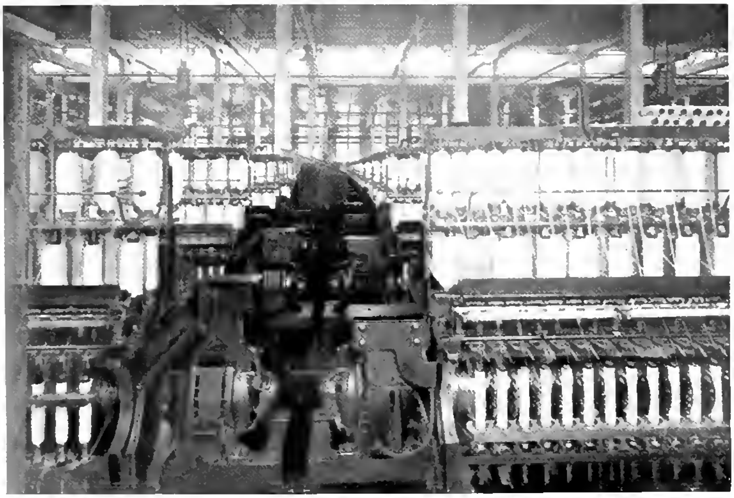


Fig. 8. Spinning Frames in Kannapolis Mills, Driven by Direct Connected Induction Motors

Current is taken from a main on the ceiling, through a switch, to the distributing board, each distributing board feeding eight motors through armored cable run in ducts under the floor. This arrangement causes no obstruction of the long longitudinal isles. In both mills the spinning is performed on the ground floor of a concrete, moisture proof building, which fact made the wiring problem difficult.

All small motors in the two mills are wound for 550 volts and receive power through three 375 kw. oil and water-cooled transformers, which are shown in Fig. 9. This illustration also shows the only switchboard in the two mills. All power lines, both 2200 volt and 550 volt, as well as the 115 volt lighting circuits, are carried underground in conduits from the main switchboard to the mills; the Southern Power Company service being supplied to this switchboard by an overhead line.

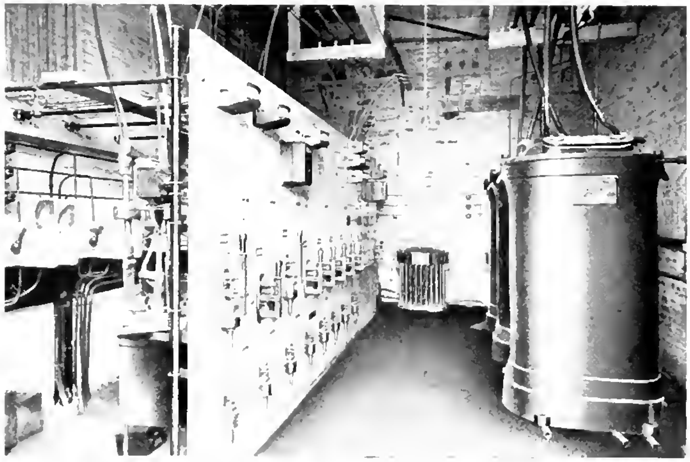


Fig. 9. Switchboard and Transformers for Wiscassett and Cabarrus Mills

The only group drive in these two mills is in the card and weave rooms. Fig. 10 shows a view in the Patterson card room, and Fig. 11 the interior of the Cannon weave shed. Motors are used for driving fire and other pumps, all power used in both mills being distributed electrically through General Electric apparatus.

Fig. 10. View in the Patterson Card Mill

In general, the success attending the operation of the Cannon Mills since the introduction of electric power is a plume in the cap of the advocates of individual motor drive. The absence of the unsightly network of belting, everywhere common before the introduction of the electric motor; the saving of energy for a given quantity of production; and the cleanliness, flexibility, and reduced risk to life and limb resulting from the employment of this form of drive are advantages that in most cases far out-weigh the cost involved in substituting it for steam engine drive.

Fig. 11. Weave Shed in the Cannon Mill

THE INTERPRETATION OF OSCILLOGRAPH RECORDS

By Taylor Reed

Standardizing Laboratory, General Electric Company

It is the purpose of this article to indicate the scope of usefulness of the oscillograph by reproducing a few typical oscillograph records, and discussing briefly the peculiar conditions indicated by the various periods in the photographed curves. Before doing this it may be well to introduce a few notes on the general scope of the instrument, and the measurement and calibration of the recorded curves.

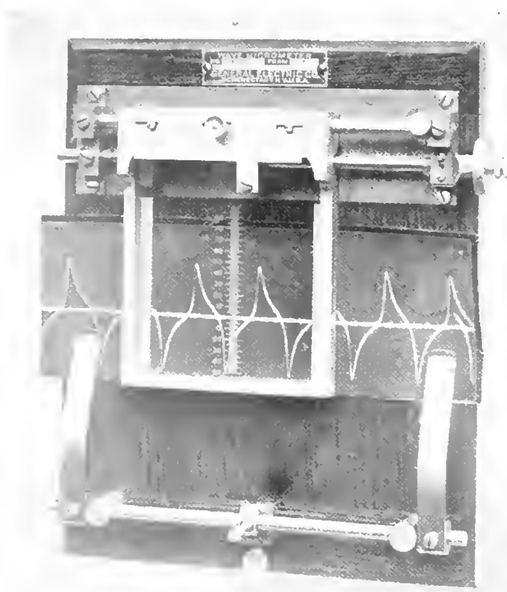


Fig. 1. Micrometer for Measuring Oscillograph Records

Application of the Oscillograph

The oscillograph as an instrument of very short period is applied where variations are too rapid, or phenomena too short in duration, to be followed by the more usual instruments, such as ammeters or voltmeters. It is applied to the study of both recurring and non-recurring phenomena. In the recurring class are included waves of voltage, current and flux; and examples of measures of the records may be for analysis, form factor, and power. In the non-recurring class are included a great variety of phenomena of short duration, such as generator short-circuits, switching phenomena, current rise in generator fields or in magnets, current rush in lamps, etc.

The form of two or more curves, or the relation between curves, is required in a large proportion of cases. It is therefore necessary that the oscillograph be constituted of more than one element in order to record simultaneous curves. The most serviceable form has been the three-element oscillograph, which can record one or two or three curves as desired. The curves, when two or three are taken, are usually placed as far apart as possible on the record to avoid confusion, though there is ordinarily some overlapping with a good amplitude of curve. When, however, a close estimate or measure of phase or time relation of the curves is to be made, as in Fig. 5, for computation of the power, they are placed with their zero lines close together. The zero lines should not be brought to coincidence, as the coincident position is not exact, and the line from which measurement should be made is therefore to some degree doubtful. A fairly successful case of coincidence, however, is shown in Fig. 7.

A few cases arise, where, for adequate understanding of the performance of the apparatus, it is necessary to have more than three curves simultaneously; as, for instance, in some switching tests where the relations of various voltages and currents are required, and where the curves at one operation of the switch are not identically repeated at another operation. In such cases two oscillographs can be operated together. With two three-element oscillographs, six simultaneous curves may be obtained on two films; or, if one curve is taken in common on the two records to tie their phases or times together, five curves may be secured.

Measurement of the Records

The majority of oscillograph records, which are mainly qualitative in character, are studied by inspection or by rough scaling or by comparison. When measures are required, as for form factor, or for power in watts, they may be obtained in a number of ways with various degrees of precision and convenience, such as by scale and triangle, by superposition of squared paper (which may be made transparent by waxing), or by micrometer. A micrometer of simple form which has been found serviceable for measures of oscillograph records is shown in Fig. 1. A glass scale placed over the record is drawn along the record, horizontally, by a screw with a range of about 2½ in. Vertical measures on the record are read on the glass scale, and horizontal measures on the screw. The screw engages with the scale frame by a half-nut, allowing the frame to be disengaged for quick motion along the record. For measurement the print or film is placed on the base of the instrument under the scale, and is adjusted in position so that the zero of the scale follows the zero line of the record. The vertical index line of the scale is set at the proper points along the record by the screw, and in each case its intersection with the curve is read on the glass scale together with the setting of the screw. A portion of the scale should be negative for convenience in reading negative ordinates. For instance, in the measures of Fig. 5, the index was set at successive equidistant points of a half-wave on the voltage record (at distances of one revolution of the screw, 30 settings, in this case); and at each setting a reading was taken of the voltage ordinate, and of the current ordinate, reckoned from the current zero.

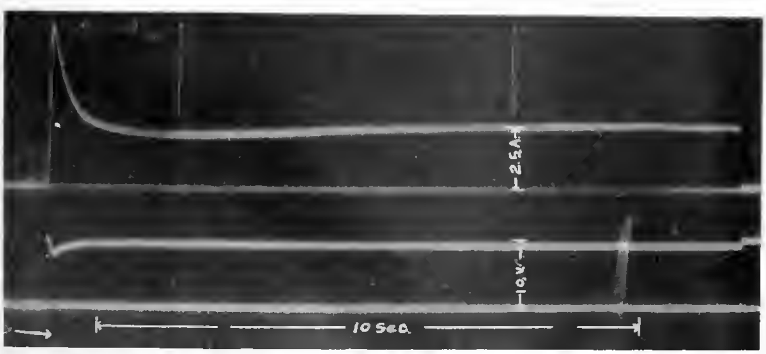


Fig. 2. Small Direct Current Motor Operating a Signal. Upper Curve, Current; Lower Curve, Voltage

Calibration of the Records

Calibration to fix the values of the curves in volts or amperes, where this is required, is accomplished by taking a curve of a d-c. voltage or current, measured by a voltmeter or ammeter, with the oscillograph circuit in the same state as for the original curves. For instance, when the curve is a wave taken with a five-ampere shunt in the secondary of a current transformer, the shunt is disconnected from the transformer circuit and is given a measured d-c. current, of which a record is made; the distance between the straight line so obtained and the zero line represents the d-c. current measured. Similarly, for a voltage curve a measured d-c. voltage is used. In a few cases the calibration line is placed on the original film, although this is seldom desirable or convenient. Instead of the film a reading of the deflection on the screen can be taken, where permanent record for subsequent reference is not essential. For heavy currents, where it is not possible to obtain measured d-c. currents of the magnitude of the short-circuit currents, the oscillograph leads are disconnected from the shunt and are connected to a measured source of small d-c. voltage, such as a dry cell, storage cell, or a small portion of a d-c. lighting voltage; and the corresponding current is computed from the shunt resistance. When the d-c. source is a generator the commutation is usually quite prominent in the

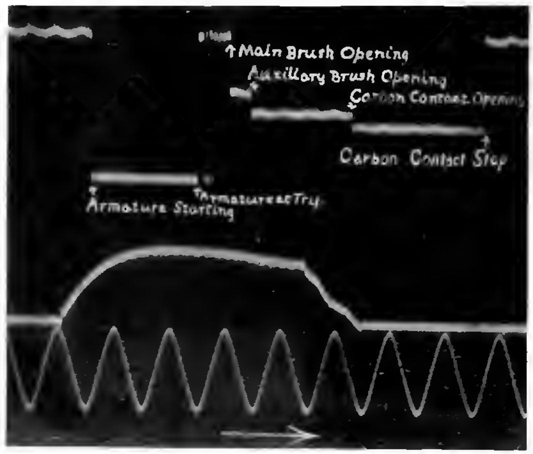


Fig. 3. Illustrating Use of Oscillograph as a Chronograph. Opening of a 4000-Ampere Circuit Breaker. Upper Curve, Time; Middle Curve, Current; Lower Curve, 25 Cycle Timing Wave

calibration line. For a series of observations where the amplitude of curve is kept constant by adjustment of the oscillograph circuit,

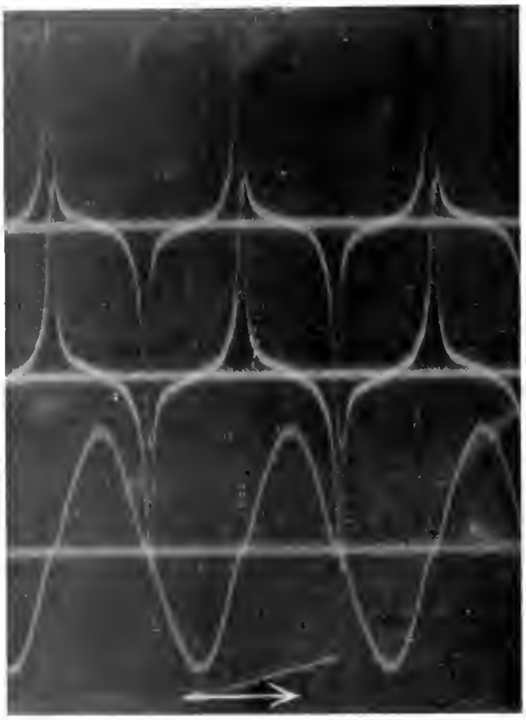


Fig. 4. Saturated Iron Reactance, Sine Wave Magnetizing Current. Upper Curve, Secondary Voltage; Middle Curve, Primary Voltage; Lower Curve, Current

calibration curves can be taken for two or more points; intervening points being obtained by interpolation.

Interpretation of Some Representative Records

The current and voltage curves of a small direct current motor, running from a storage battery and operating a signal, are given in Fig. 2, where the energy demanded from the battery for the operation is desired. The running current of the motor could be read by an ammeter, and the time of operation by a stop-watch. Owing to the acceleration of the motor, however, there was a kick of the ammeter which made the computation of the energy uncertain. It is evident, from inspection of the figure, that the initial rush does not seriously increase the energy computed from the total time and the running current—about 3 per cent., as determined by measures of the curves.

An illustration of the use of the oscillograph as a chronograph for registering small periods of time is given in Fig. 3. A circuit-breaker, whose time of action was to be determined, was fitted temporarily with small switches or contacts so placed as to be opened or closed, mechanically, by parts of the circuit-breaker at points in their action whose times were desired. The switches, connected in series, were placed in an oscillograph circuit with a d-c. source, and across each switch a suitable resistance was connected. The opening or closing of a switch was attended by a change of the resistance of the oscillograph circuit, as indicated by a shift or break in the line of the record. The time can be determined from observation of the speed of the film, or better, as in this case, from a timing wave of known frequency given on the record by another element of the oscillograph. Or, instead of the timing wave, the beats of a clock or chronometer, or the vibrations of a tuning fork, may give the time reference on the record.

Another application of the oscillograph as a chronograph is in measuring its own free period. An oscillograph element, without damping liquid, is connected to a d-c. source in series with an interrupter, which sets the element vibrating freely. The period is computed from a count of the vibrations on a measured length of the high speed record.

For a transformer core at high saturation with a sine wave of magnetizing current,

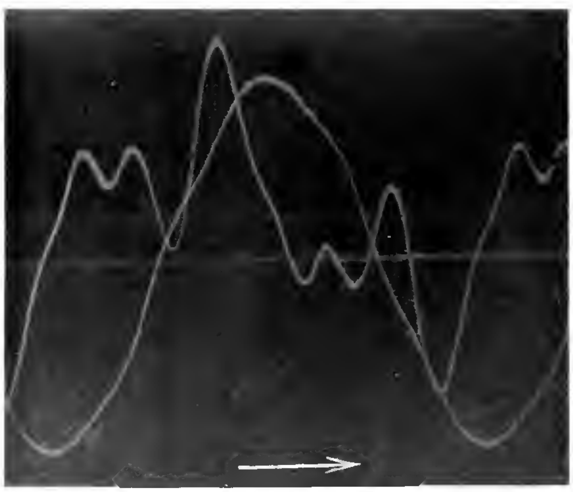


Fig. 5

Fig. 6

Fig. 5. Transformer with About 50 Miles of Transmission Line at 122,000 Volts. Upper Curve, Current; Lower Curve, Voltage

Fig. 6. Current Calibration for Fig. 5. Current Transformer 40:1. Current 3.1. Oscillograph Series Resistance 0.2 (Upper); 0.6 (Middle); and 1.5 (Lower)

secondary and primary voltages and current are given in Fig. 4. The very sudden reversal of flux as the large magnetizing current passes through zero is shown by the needle-like peaks of the voltage waves. In another observation where the core was again at high density, but with a sine wave of voltage and consequently a distorted wave of magnetizing current, a voltmeter on the secondary read 430 volts; under the conditions of the figure it read 720 volts. The form factor of the peaked voltage wave from measures of the ordinates, to some extent uncertain on such a wave as this, was computed to be 1.90. As there was high magnetic saturation of the core, the total flux variation would be approximately the same in the two cases, and so also the average values of voltage. The form factors, 1.11 for the sine wave, and 1.90 for the peaked wave, are approximately in the ratio of the effective, or *r.m.s.*, voltages given by the voltmeter.

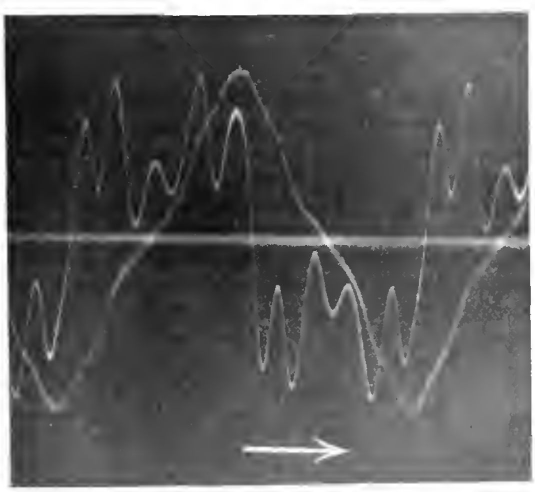


Fig. 7. Wave of Current Charging an Aluminum Electrolytic Condenser, and of Voltage on the Condenser

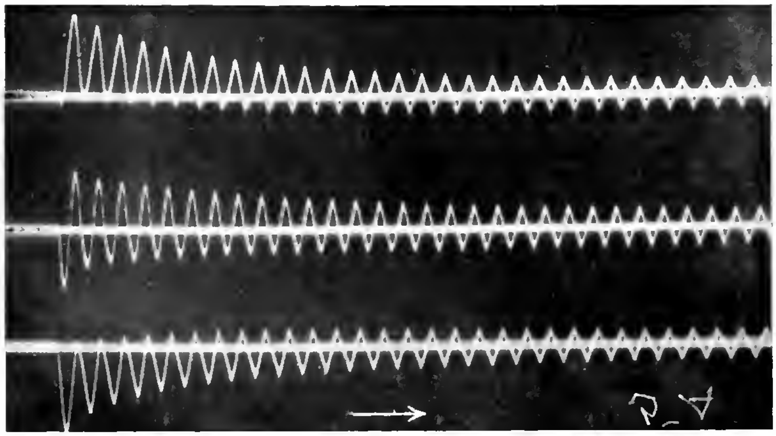


Fig. 8. Three-Phase Short-Circuit of 25 Cycle Turbo-Alternator at One-quarter Voltage. Currents in the Three Lines

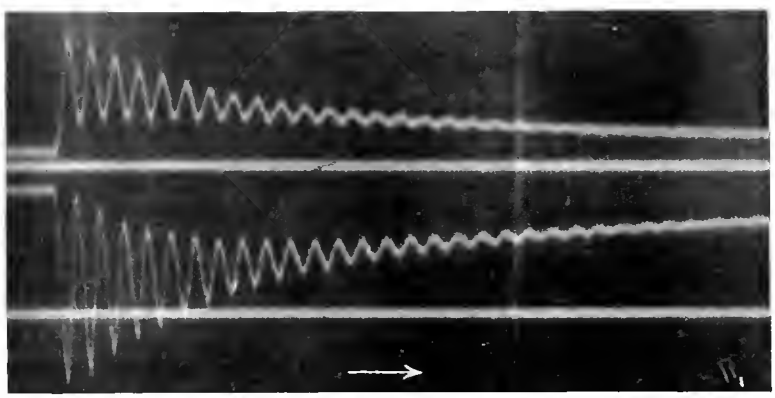


Fig. 9 (With Fig. 8) Upper Curve, Field Current; Lower Curve, Field Voltage

Curves of voltage and current of a transformer and about fifty miles of transmission line at 122,000 volts are shown in Fig. 5. The curves were placed rather close together on the film to obtain a good measure of the power, with a view to evaluating the corona loss, similar waves of the transformer without line being taken on a subsequent record whose power was measured and deducted. At frequent points the values of both voltage and current were taken. The voltage values were squared and the *r.m.s.* value of voltage was obtained, as well as the *r.m.s.* current value; and the products of the corresponding voltage and current values were taken for the power values, which were averaged. Comparison with indicating instruments gave, on the secondary side of the instrument transformers:

	From Curves	From Indicating Instruments
Volts.	134.7	134
Amperes	2.05	1.9
Watts	65.3	65

The calibration record for current is shown in Fig. 6. As a series of observations was taken at increasing line voltages a number of resistances were used in the oscillograph circuits; and for calibration three resistances were used giving the three lines of the figure, the values for any other resistances being readily obtained by interpolation. The resistance of the current curve in Fig. 5 corresponds to the middle line of the calibration record.

The wave of charging current of an aluminum electrolytic condenser is shown in Fig. 7, together with the wave of voltage. The corresponding wave on an ordinary condenser was found to be practically identical in form. A strong ninth harmonic can be detected by inspection, from the number of peaks in a cycle. and on closer examination a large third harmonic can also be seen. The measures for analysis consist in obtaining the ordinates of the wave at carefully determined equidistant points on the half-wave, which, in the computation of the harmonics, are multiplied by the sines and by the cosines of their angles, and of their multiple angles corresponding to the successive harmonics. Summation is made of the sine products and of the cosine products. The amplitude for each term is obtained as the square root of the added squares of the sine sum and cosine sum; and the tangent of the phase angle as the ratio of the cosine sum to the sine sum. Analysis for harmonics to the thirteenth gives:

$$\begin{aligned} I = & 80.0 \, sin(\alpha - 5.5°) \\ & + 45.1 \, sin(3\alpha + 10.5°) \\ & + 6.7 \, sin(5\alpha + 26.7°) \\ & + 11.4 \, sin(7\alpha - 14.3°) \\ & + 35.2 \, sin(9\alpha + 38.0°) \\ & + 10.6 \, sin(11\alpha - 35.6°) \\ & - 8.3 \, sin(13\alpha + 52.4°) \end{aligned}$$

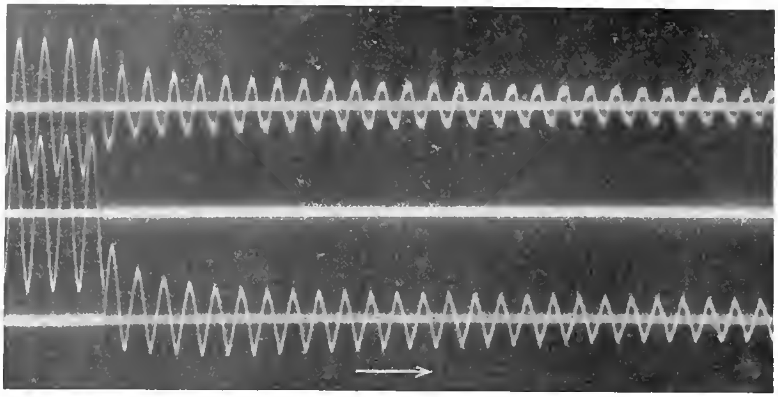


Fig. 10. Single-Phase Short-Circuit (on Phase B-C) on 25 Cycle Turbo-Alternator. Upper Curve, Voltage of Phase A to Neutral; Middle Curve, Voltage of Phase B to Neutral; Lower Curve, Current

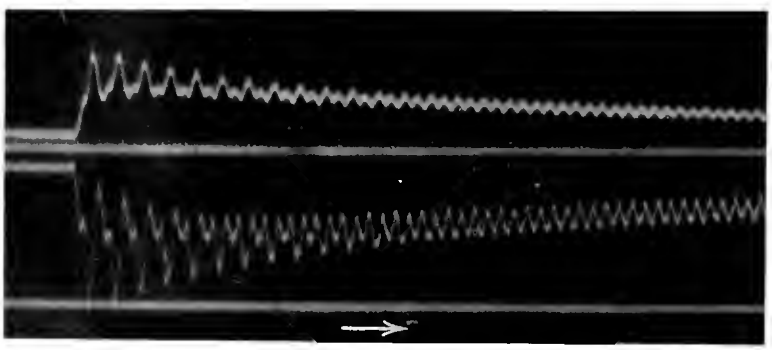


Fig. 11. (With Fig. 10) Upper Curve, Field Current; Lower Curve, Field Voltage

Short-circuit curves of a turbo-generator are given in Figs. 8, 9, 10 and 11, taken with two oscillographs. The alternator field was connected directly to the exciter in parallel with a resistance. On a three-phase short-circuit, the three curves of Fig. 8 are the currents in the three phases. The upper curve of Fig. 9 is the field current, and the lower curve the field voltage. On a single-phase short-circuit, the upper curve of Fig. 10 is the voltage from the idle line to neutral, the middle curve the voltage from one of the short-circuited lines to neutral, the lower curve the current. The upper curve of Fig. 11 is the field current, and the lower curve the field voltage.

ELECTRIC POWER IN THE IRON MINES AND MILLS OF WITHERBEE, SHERMAN & CO., MINEVILLE, N. Y.

By John Liston
Publication Bureau, General Electric Company

A description of the substitution of electric power for steam power, and its extended application, in the operation of the mining properties of this concern, comprising four separate mines that produce magnetite ore exclusively. Electric energy, generated at four widely separated points interconnected by transmission lines, has practically supplanted steam for all operations in the mines, as well as for the performance of all other work connected therewith. The system of power distribution is clearly outlined, and the principal electrical apparatus in service, both in the power houses and in the mines and mine buildings, is described in detail as to size, etc.; the use to which each is put being also specified.—Editor.

For more than a century the ore beds in the vicinity of Port Henry, New York, have yielded a high grade magnetite iron ore, the earliest recorded work having been performed in 1804 at the Cheever mine, situated about two miles north of Port Henry, while the Old Bed mine at Mineville, New York, which formed the nucleus of the properties now held by Witherbee, Sherman & Company, was first developed in 1824.

Work on a commercial scale was not undertaken, however, until the incorporation of the present company in 1849, at which time a systematic development of the ore beds at Mineville was inaugurated and steam power plants provided for the various workings.

Subsequent to the purchase of the Old Bed mine three other mines were acquired and transportation to shipping points provided for, and, as the ore beds were of considerable extent and presented conditions favorable to economical mining, the volume of the output increased steadily until in 1910 it reached 750,000 tons, while the present capacity is in excess of 1,000,000 tons per annum.

As development work progressed, it became necessary to add to the number of power stations and isolated boiler plants, because of the limitations of steam power transmission over long distances. It was realized that this system involved an unnecessarily heavy expense for supplying power at widely separated points of application, and therefore the engineers of the company determined to take advantage of the economies of the electrical transmission of energy over long distances and provide a number of inter-connected generating plants, utilizing for this purpose prime movers already installed, supplemented by available water power and such additional steam power as would suffice to meet the growing demands of mines and mills.

Fig. 1. Joker, Bonanza and Clonan Shaft Houses, Nos. 1 and 2 Mills, and No. 1 Power Station, Mineville, N. Y.

Early in 1903, the first generating unit was installed in the Central power station at

Mineville. It consisted of a three-phase, 25 cycle, 3300 volt alternator of 750 kw. capacity, direct driven by a 1000 h.p. engine; this generator supplying current for motor-

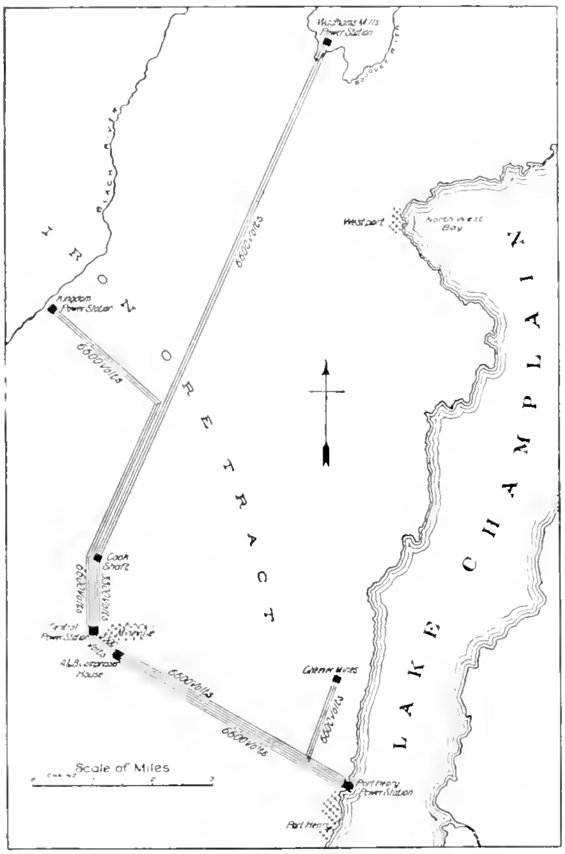


Fig. 2. Arrangement of Transmission System

driven air compressors and for motors which were installed to drive the machinery in mills Nos. 1 and 2.

The electrification of the properties has been carried out consistently and the system adopted is representative of modern engineering practice throughout; alternating current generators and induction or synchronous motors being used for practically all power applications. There are, of course, some small motor-generator sets supplying direct current for magnetic separators and for locomotive haulage, but the total capacity of direct current motors is less than 100 h.p., whereas the generating plants with a combined output of 4475 kw. serve alternating current motors totaling more than 5500 h.p.

The use of steam, except for prime movers, has been now practically abandoned; there being only two units, a hoist and a compressor, of the old steam driven equipment still in service. There are also a few small pumps operated from the air lines for the pneumatic drills, but with these few exceptions electricity is used for all power purposes in both underground and surface work.

At present active work is carried on at four mines, three of which are situated at Mineville while the fourth lies a short distance north, the total area extending north and south about two miles, and east and west less than a mile. The mines and shafts are designated as follows: Old Bed mine with two shafts; Joker and Bonanza (these shaft houses being shown in Fig. 1); Harmony mine served by two shafts, "A" and "B"; New Bed by Barton Hill tunnel; and Smith mine by Cook shaft.

The relative location of the power stations and the arrangement of the transmission lines is clearly indicated on the chart, Fig. 2. It will be noted that current is received from four widely separated points, all interconnected, however, through the transmission system; the generators are all operated in parallel, and, with the exception of those in the Central power station, generate current at 6600 volts, three-phase, 25 cycles.

The generating equipment of the various power plants is as follows:

At the Central power station the original 750 kw., 3300 volt, engine-driven alternator already referred to has been supplemented by a 750 kw., 1500 r.p.m. mixed pressure turbine operated from the exhaust of the engine, which is run non-condensing; a varying amount of live steam, depending on the load conditions, being taken directly from the boilers. By means of this turbine the effective output of the plant is doubled and when the turbine is operated only on the exhaust steam, it develops about 600 kw. The original boiler outfit comprised three 250 h.p. units, and when the turbine was installed, additional boiler capacity to the extent of 400 h.p. was provided; so that with slightly more than a 53 per cent. increase in boiler equipment 100 per cent. was added to the available current supply from this station. The two generating units are shown in relative proportion in Figs. 3 and 4, and as they are identical in capacity they afford a striking illustration of the compact construction and small amount of floor space required by the turbine set when compared with the engine-driven unit.

Situated on the Black River about $5\frac{1}{2}$ miles north of Central power station is Kingdom power station, a hydro-electric plant generating 375 kw. at 6600 volts. The available water power, however, is considerably in excess of the plant capacity and the present generator will be superseded by a 750 kw., 2300 volt machine; the potential of the six mile transmission line being raised to 13,200 volts by step-up transformers.

The most distant power plant is at Wadhams Mills, located on the Bouquet River about $10\frac{1}{2}$ miles north by east from Central power station, and containing a 300 kw., 6600 volt waterwheel-driven alternator. Current is transmitted at the generator voltage over a single circuit line $9\frac{1}{2}$ miles to Cook shaft substation at the Smith mine, which is also connected with Central power station by a single circuit line.

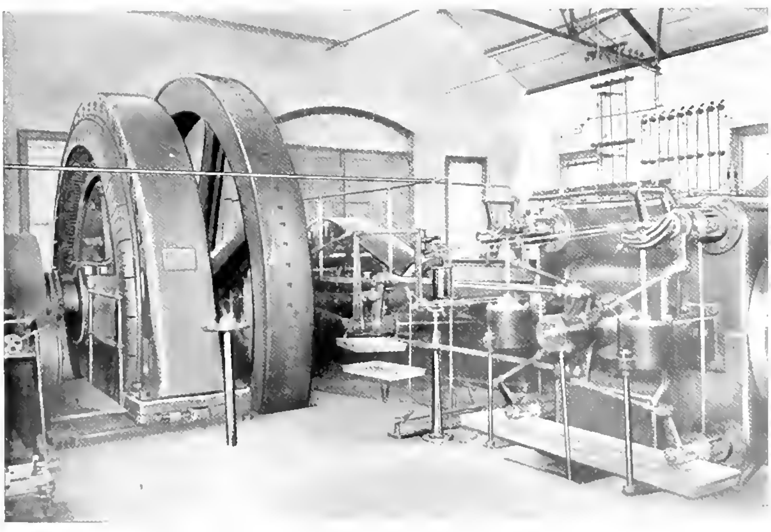


Fig. 3. 750 Kw., 3300 Volt, 94 R.P.M Alternator driven by 1000 H P. Engine, Central Power Station, Mineville, N. Y.

The water power plants at Kingdom and Wadhams Mills are not owned by Witherbee, Sherman & Company, but their entire output is purchased, payment being based on meter readings at incoming primary voltage.

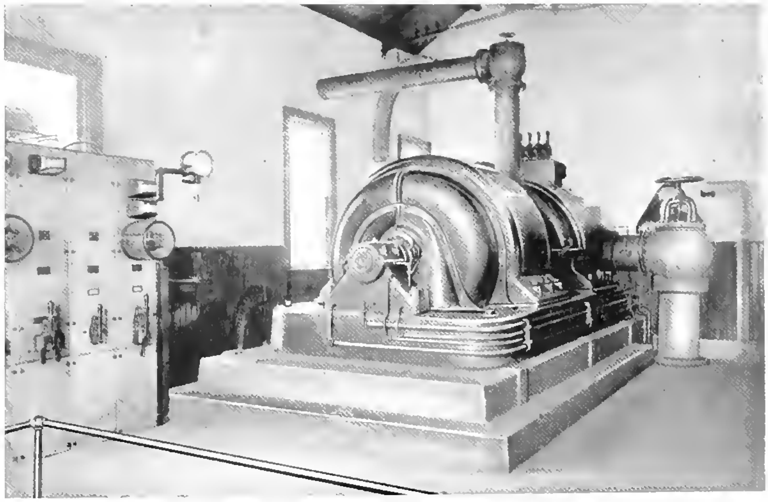


Fig. 4. 750 Kw., 3300 Volt, 1500 R.P.M Mixed Pressure Turbo-Generator, in Central Power Station, Mineville, N. Y.

The latest and most important generating station is located on the shore of Lake Champlain at Port Henry and consists of a thoroughly modern concrete power house (see Fig. 5) containing one 800 kw. and one 1500 kw., 6600 volt vertical shaft turbine alternator; provided with both turbine and motor-driven exciters. The compact arrangement of the machinery is indicated by Fig. 6. The switchboard equipment is typical of those used in the other generating and substations of the company.

From Port Henry a 6600 volt twin circuit transmission line is run about $4\frac{1}{2}$ miles west to "A and B" compressor house, which is in turn connected with the Central power station by a single circuit 3300 volt line, thus completing the interconnection of the four power plants. A short distance from Port Henry one circuit is tapped by a feeder line running to the Cheever Iron Ore Company's workings, where alternating current motors aggregating about 1150 h.p. are used.

The power transformers have a total rated capacity of 3875 kv-a., and are all delta

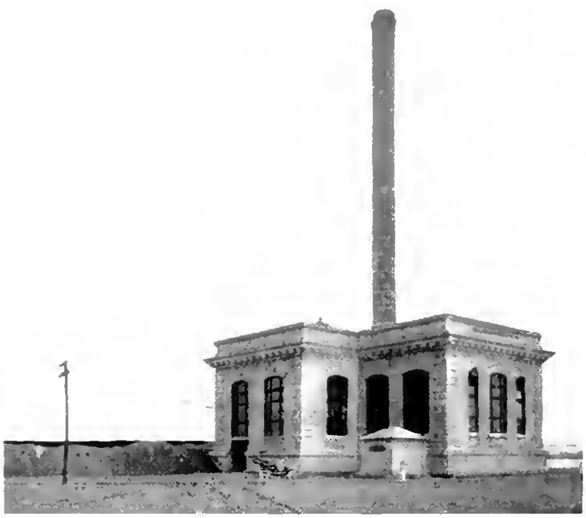


Fig. 5. Port Henry Power Station, Port Henry, N. Y.

connected; three single-phase units being ordinarily used for each power circuit, while a few three-phase units have been adopted for small isolated motors. All alternating current lighting is done through single-phase transformers and the demand distributed on the three phases so as to obtain the nearest feasible approach to a perfect balance of the load.

The step-down transformers for the Port Henry lines are installed in a small concrete house just outside of the "A and B" compressor house, and are arranged in two banks, with a duplicate blower set for supplying the air blast. The incoming lines are first brought to the switchboard in the compressor house and from there run to the two banks of transformers and back to the feeder panels on the switchboard, from which current is distributed at 3300 volts.

In running the transmission lines cedar poles with wooden cross-arms and solid bare conductors have been used throughout, and lightning arresters have been installed in the various power stations and substations.

An unusually high efficiency has been maintained throughout the generating and transmission system, and the cost of power delivered at the busbars, after allowing 10 per cent. for interest charges and depreciation, has averaged 1.33 cents per kw-hr., while at the Port Henry power station an average operating cost of 0.988 cents per kw-hr. has been maintained.

The effect of this low cost for power is clearly reflected in the expense of production: with meter records to indicate the exact current consumption of the various driving motors, the power cost for milling alone is 3.70 cents per ton crude, while that for high concentrate, including all operations from the receiving bin to the finished product, is 5.00 cents per ton.

For the distribution of current at Mineville there are seven main feeders operating at 3300 volts, as shown in Fig. 7. These feeders terminate in banks of step-down transformers from which re-distribution circuits are run to the various alternating current motors; which, with the exception of four 3300 volt machines, are all wound for 440 volts.

Fig. 6. One 800 Kw. and One 1500 Kw., 6600 Volt Three-Phase 25 Cycle, 1500 R.P.M. Vertical Shaft Turbo-Generators in Port Henry Power Station

In the Central power station a motor-generator exciter set is used, the driving unit being a 50 h.p., 3300 volt induction motor, while the auxiliary equipment includes a

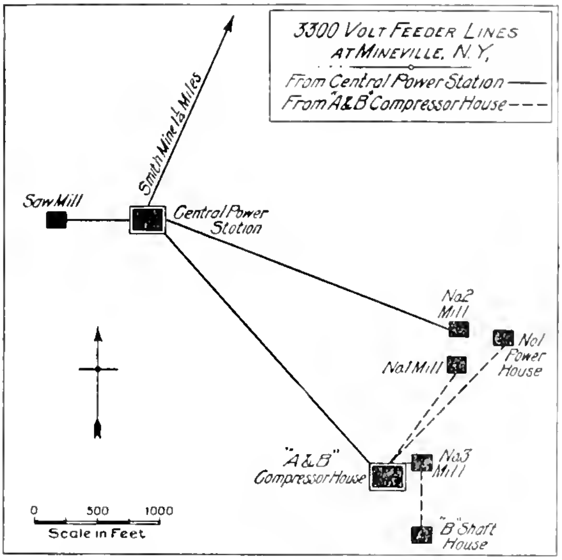


Fig. 7

centrifugal pump for the condenser direct driven by a 5 h.p. motor, and a 10 h.p. motor operating an ash conveyor and elevator through belting.

The shortest feeder runs to a saw mill west of the power station, in which all machinery is group driven by a 60 h.p. motor, while an adjacent carpenter shop and planing mill is similarly served by a 22 h.p. motor.

From the Smith mine substation, current at 440 volts is supplied to two 75 h.p. motors belted to air compressors, and to a 100 h.p. motor geared to a double drum hoist and a 30 h.p. motor driving a triplex pump. The feeders run to Barton Hill tunnel, where a third compressor is driven by a 125 h.p. motor; and two electric hoists, one installed inside the mine on a slope and the other outside, are geared respectively to a 22 h.p. and a 35 h.p. motor. The third compressor has been superseded by the air service from the large machines in "A and B" compressor house and is now held only as a reserve.

The tunnel is provided with a 4½ ton direct current haulage locomotive fitted with a double trolley which operates on a 220 volt metallic return circuit; current for its operation being supplied by a motor-generator set in No. 1 power house. This light locomotive gives ample service and is able to handle loads in excess of present requirements, inasmuch as the grade of the tunnel is uniformly in favor of the load.

The locomotive feeder is tapped to supply a 5 h.p. direct current motor which drives a small triplex pump in the tunnel; the

Fig. 8. Five Ton, 220 Volt Double Trolley Direct Current Locomotive at Barton Hill Tunnel

lighting of the tunnel being accomplished by tapping one of the compressor transformers for a 110 volt incandescent lamp circuit. The method used to carry the locomotive, power and lighting feeders is indicated in Fig. 8, which also shows the locomotive at the tunnel entry.

The third feeder from Central power station runs to Mill No. 2, in which all machinery, including crushers, rolls, elevators, conveyors, separators, screens, etc., is driven in groups by three 100 h.p., 440 volt motors; and where, in order to haul the ore cars from the Bonanza shaft to the receiving bin at the mill, a 30 h.p. motor-driven hoist is installed.

The half mile line from Central power station to "A and B" compressor house serves to connect the two centers of distribution and thereby minimizes the danger of interrupted service due to a shut down in any of the power plants, or injury to the main transmission system, which runs through hilly country and may be subjected to a varying amount of lightning trouble.

From "A and B" compressor house, one 3300 volt feeder is run to No. 3 mill, one to No. 1 mill and one to No. 1 power house, as shown in Fig. 7. In the compressor house itself there are five important motor applications: two 200 h.p., 440 volt induction motors drive two 1250 cu. ft. compressors, while two machines of 2500 cu. ft. capacity are driven by two 400 h.p., 3300 volt synchronous motors with direct connected exciters. One of these sets is shown in Fig. 9, together with the compressor house switchboard.

The fifth application consists of a 300 h.p. 440 volt, 250 r.p.m. motor geared to a compactly grouped four drum hoist (see Fig. 10), which serves "A" and "B" shafts of the Harmony mine. Each drum is 10 ft. in diameter and carries 2500 ft. of 1⅛ in. steel cable for hoisting 3½ ton ore skips; the resistance for speed control being installed in a separate room. The drums may be operated singly or in combination, and hand actuated brakes and clutches are used throughout.

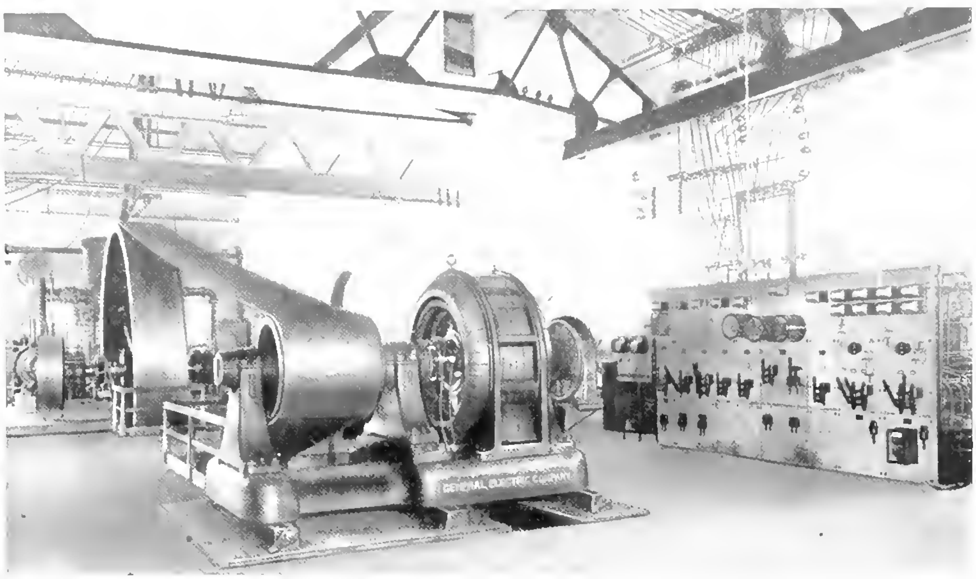


Fig. 9. 400 H.P., 3300 Volt, 500 R.P.M. Synchronous Motor Driving 2500 Cu. Ft. Compressor in A and B Compressor House

The use of numerous induction motors, which, owing to the fluctuating character of the load that is inseparable from the operation of hoists, ore crushers, etc., frequently run for considerable periods at varying percentages of their normal rating, had a serious effect on the power-factor of the system, and it was found impossible to maintain a power-factor much above 65 per cent.

With the bulk of the load at Mineville grouped within a few thousand feet, however, it was entirely feasible to provide synchronous condensers to supply the wattless component of the current and thereby obtain a close approximation to unity power-factor; and, as the air compressors constituted an ideal load for synchronous motors, the engineers of the company determined to utilize them, of a size sufficient to carry the compressor load and at the same time compensate for low power-factor. The two units of this type in the compressor house are operated at 80 per cent. power-factor, leading current, with the result that the power-factor is now maintained at from 88 per cent. to 90 per cent. throughout the system at Mineville.

From the compressor house a short feeder line is run to a substation in Mill No. 3, in which all the machinery is driven in two groups by two 200 h.p., 440 volt motors which are separated from the mill machinery by a wall and operate it through counter-shafting. Mill No. 3 is constructed of reinforced and block concrete throughout and is typical of the form of construction adopted as standard for future work by the company; it is a double mill, each half being capable of independent operation, and served by its own driving motor, so that work at partial capacity can be carried on with only a proportionate demand on the power system, and injury to any part of the machinery will not involve a complete shut down. In the event of injury to either driving motor it can be readily replaced by a 300 h.p. machine which is held in reserve in the motor room.

As all the ore at Mineville is magnetite, the mills are equipped with magnetic separators, direct current for the separators and for lighting being supplied by a 35 kw., 125 volt motor-generator set in Mill No. 3, the driving unit of which is a 50 h.p., 440 volt induction motor.

This mill receives ore from two nearby shafts ("A" and "B" of the Harmony mine) and is situated between the shaft houses. In the "A" shaft house, which has a 440 volt supply line, there is a gyratory ore crusher belt driven by a 35 h.p. motor, while the 20-inch belt conveyor to the mill is operated by a 20 h.p. motor. The "B" shaft house is similarly equipped, except that a 3300 volt feeder is run to it from No. 3 mill, and a three-phase step-down transformer and control panel installed in the shaft house. A 35 h.p. motor-driven hoist is utilized for hauling ore cars up a low graded trestle to the receiving bin above the crusher.

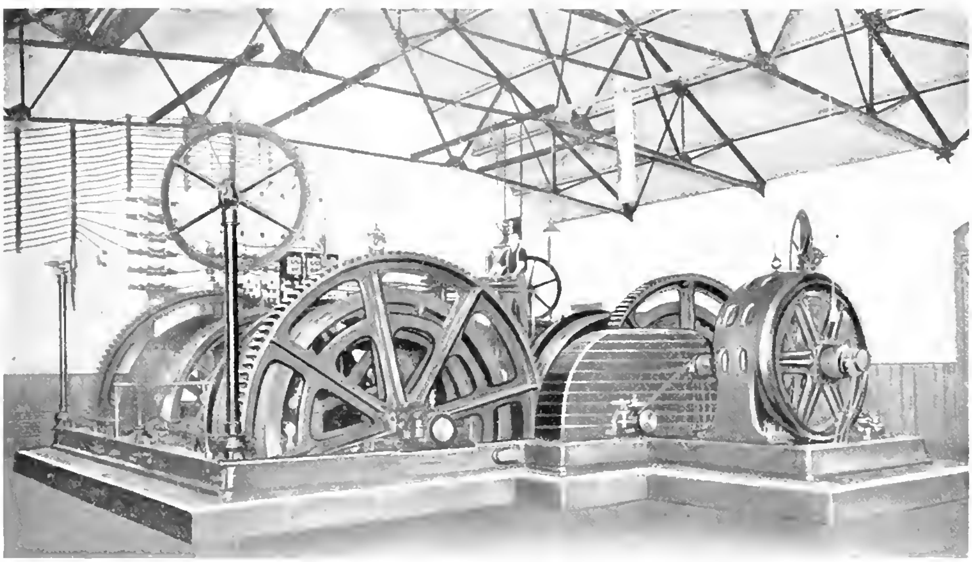


Fig. 10. 300 H.P., 440 Volt, 250 R.P.M. Motor Driving Four-Drum Hoist For A and B Shafts, Harmony Mine

It will be noted that the motors in this service are not housed in or in any way protected from the dust which is inevitably prevalent during their operation, and it has been found inexpedient to clean them except at such times as when repairs are being made or motor bearings changed. The simplicity and durability of the induction motor is such that in spite of these conditions they operate with unimpaired efficiency and safely withstand the heavy overloads which recur at frequent intervals in this service. The motors in the power stations and compressor houses, however, are cleaned at least once each week, the work being usually performed with compressed air.

Fig. 11. 500 H.P., 440 Volt, 250 R.P.M Motor Driving Double-Drum Hoist, for Joker Mine Shaft, No. 1 Power Station

The geological conditions at Mineville are such that only comparatively small volumes of water collect in the mines and the drainage requirements do not constitute a serious factor in the power supply, as the largest pumps used operate against a maximum head of 750 ft. with a capacity of 100 gal. per min. In "B" shaft, one 400 ft. head, 200 gal. per min. pump is driven by a 30 h.p. motor and in "A" shaft a 12 h.p. motor drives a 100 gal. per min. pump. All mine pumps are of the reciprocating type, with motor and pump mounted on a common base and connected through gearing.

The conductors in the mine shafts for the pump motors, lighting, and locomotive circuits are lead covered cable, which is used to insure maximum protection, while iron conduit is utilized for signal wires in shafts and for the wiring of mills and power houses.

The machinery in mill No. 1 is operated in five groups by three 75 h.p. and two 60 h.p. motors fed from the secondaries of 3300/440 volt transformers located in the mill, while in the Joker shaft house a jaw type crusher is driven by a 35 h.p. motor.

The No. 1 power house is served by a separate 3300 volt feeder and contains two motor-generator sets, the larger unit supplying direct current at 220 volts for the operation of two locomotives (one at the Barton Hill tunnel and the other at No. 7 level of the Old Bed mine) and other machinery, as well as for lighting in the Old Bed mine and shafts. A small hoist at this mine is used for sinking, which is semi-portable in type, and is driven by a 15 h.p. motor. A 20 h.p. hoist serves a slope at the No. 7 level in the Bonanza shaft, while a 20 h.p. motor drives a three-car tipple at the No. 7 level of the Joker shaft.

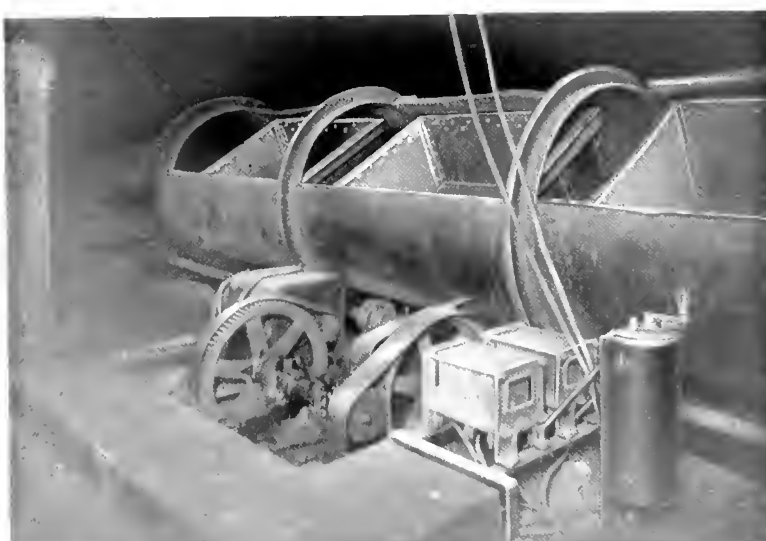


Fig. 12. 20 H.P., 220 Volt Enclosed Motor Operating Three-Car Tipple in the Mine Serving Joker Shaft

The larger set consists of a 110 h.p., 3300 volt induction motor driving a 75 kw., 250 volt three-wire direct current generator at 750 r.p.m. The smaller set is used solely for lighting and comprises a 50 h.p., 440 volt motor driving a 35 kw., 125 volt generator at 1500 r.p.m.

In this power house there is also a 1250 cu. ft. compressor belt connected to a 200 h.p. motor, and a double drum hoist (see Fig. 11) serving the Joker shaft and driven through gearing by a 500 h.p., 440 volt, 250 r.p.m. motor. This hoist has 10 ft. drums, each with 2500 ft. of $1\frac{1}{8}$ inch steel cable, the normal hoisting speed being 900 feet per minute. Unlike the hoists previously referred to, it is equipped with pneumatically actuated brakes and clutches, operated from the air line to the mines: but in the event of a failure of this service, a self-contained emergency 6 in. by 6 in. air compressor set driven by a 5 h.p., 440 volt motor is automatically cut in.

For the control of the hoist motor a contactor panel has been installed, that provides for seven point acceleration and is equipped with current limiting and overload relays. The entire hoisting outfit is compactly arranged and every unit is fully in view from the operating platform.

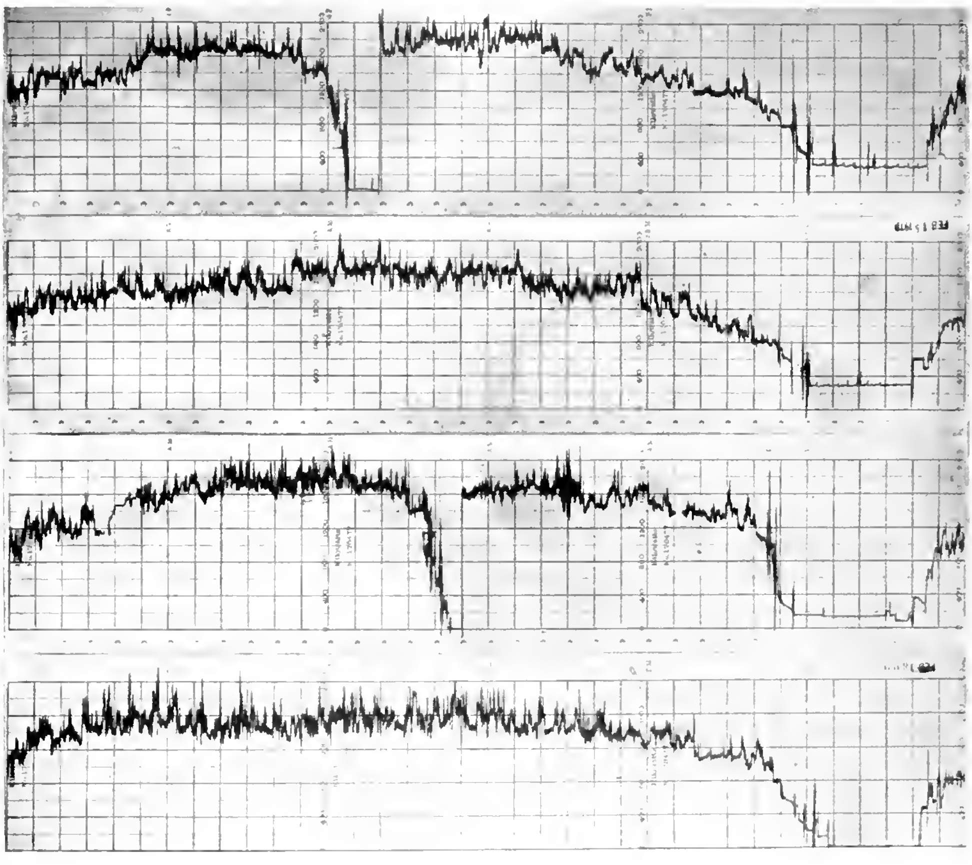


Fig. 13. Typical Load Curve (Feb. 15, 1911) Port Henry Power Station

One of the most interesting applications underground consists of the three-car tipple already referred to, which is installed in the Old Bed mine at the No. 7 level near the Joker shaft. To this point the loaded ore cars, carrying $2\frac{1}{2}$ tons each, are hauled by the mine locomotive and pushed into the tipple three at a time, where they are clamped fast by a hand lever at one end of the tipple. The operator then manipulates the controller and the tipple is turned 180 deg. so that the total content of the cars is delivered to a receiving bin beneath the tipple platform, after which the cars are returned to a horizontal position and pushed from the tipple. The entire cycle is accomplished in about $1\frac{1}{2}$ minutes, so that approximately 400 tons of ore per hour can be handled in this way.

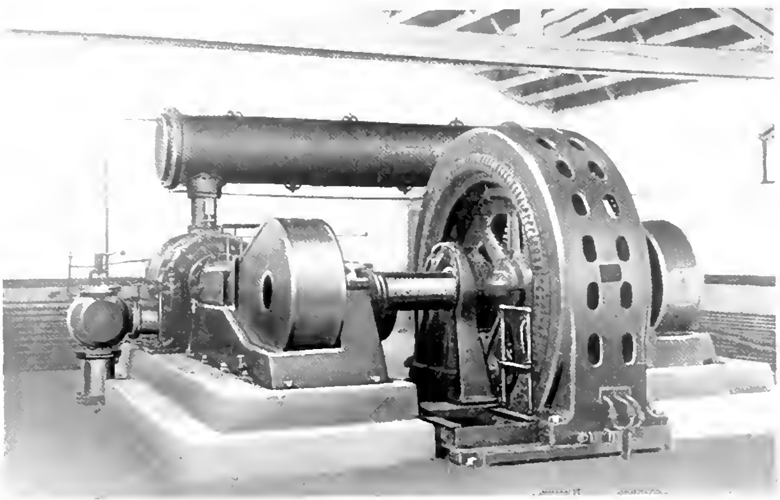


Fig. 14. 400 H.P., 6600 Volt, 136 R.P.M. Induction Motor Direct Connected to 2500 Cu. Ft. Compressor in Cheever Substation

The arrangement of the 20 h.p. direct current motor, which is a standard railway type, and the controller, resistance and driving mechanism are shown in Fig. 12. As in all motor applications by Witherbee, Sherman & Company, the equipment is provided with a substantial concrete base.

In view of the number and diversity of the motor-driven machines for both mining and milling operations and the fluctuating character of the loads of many of the driving units, it is evident that the generating system must be capable of safely carrying heavy overloads for varying periods, especially as the total rated capacity of the motors installed is about 20 per cent. greater than that of the generators. In illustration of the character of the power demand, Fig. 13 shows a curve-drawing wattmeter record of the load on the 1500 kw. turbo-alternator at Port Henry for twenty-four hours. It will be noted that during a considerable portion of the time the demand was much in excess of the rated capacity of the machine, even passing above 2000 kw. for short periods, and twice tripping the circuit breakers.

The load factor of the system is unusually high for mining service, and is maintained at about 70 per cent. The men work in two shifts of ten hours each, and when the steam power plants are shut down on Sundays and holidays, the necessary current for lighting is supplied by the water power stations.

A liberal use of meters has been found indispensable to accurate apportionment of the power cost among the various operations, and recording wattmeters are connected on all feeder circuits, while all motors except those in the mills are individually metered; the mill motors being metered in groups for each mill. In addition to giving reliable data in regard to power consumption, the meters afford a means of readily ascertaining whether or not the machinery is operating at its normal efficiency, as an unusual power demand often serves as an indication of injury or mechanical defects which can then be investigated and corrected before becoming serious enough to interfere with production.

In lighting the mines, 110 volt and 220 volt incandescent lamps are operated from direct current circuits, but 220 volt lamps will eventually be used throughout. At present there are twelve 220 volt direct current arc lamps in the "A" and "B" shafts of the Harmony mine, but in the future no arc lamps will be used underground.

Reference has been made to the extensive use of concrete for building and for machinery foundations: All new buildings will be constructed of concrete blocks with floors and foundations of reenforced concrete. In the manufacture of the concrete, only mill tailings and cement are used, it being unnecessary to add sand or broken stone. Old cables are utilized for reenforcing. Two $7\frac{1}{2}$ h.p. induction motor-driven portable concrete mixers are included in the auxiliary equipment, and leads are provided so that they may be connected in any convenient 440 volt circuit.

In addition to supplying the electric power requirements of their own equipment, the transmission system of Witherbee, Sherman & Company delivers current at 6600 volts to a substation at Cheever, which serves the mines of the Cheever Iron Ore Company where induction and synchronous motors aggregating 1150 h.p. are used. Current is delivered at primary voltage and is metered at the receiving end.

In the substation the general arrangement of incoming and feeder lines, lightning arresters, transformers, switchboard and disconnecting switches is similar to that found in the substations of Witherbee, Sherman & Company, and with two exceptions, 440 volt three-phase, 25 cycle motors are used for all applications, both on the surface and underground. The exceptions consist of two air compressors, one of which is shown in Fig. 14, which is of 2500 cu. ft. capacity and direct driven by a 400 h.p., 6600 volt, 136 r.p.m. induction motor. It constitutes the only example of a direct connected compressor, as all the other air units are driven through belting. Both compressors are installed in the substation; the second unit of 1250 cu. ft. rating being belt-driven by a 250 kv-a., 6600 volt synchronous motor, which is partially loaded and utilizes its excess capacity for the improvement of the power-factor of the local system.

The equipment on the surface comprises five hoists, driven by three 37½ h.p., one 75 h.p., and one 225 h.p. motors; a machine shop group driven by a 15 h.p. motor; a repair shop served by a 5 h.p. motor; and a small triplex pump for water supply, geared to a 4 h.p. motor. Underground there are two triplex pumps and a 440 volt alternating current five ton single motor locomotive, driven through double reduction gearing on account of the inherent high speed of the three-phase induction motor with which it is equipped.

The selection of an alternating current locomotive for this work was due to the fact that the haulage requirements, while of great importance, were limited in extent, and if a direct current locomotive had been provided it would have been necessary to add a synchronous converter or motor-generator set solely to furnish current for the haulage system; and as the remainder of the equipment was alternating current, the expenditure for haulage power would have been disproportionately heavy. The operation of the three-phase locomotive has been attended with complete success, and the service has been secured with a minimum initial cost.

In conclusion, it should be stated that in planning the system of power transmission and applying motors to the various machinery, each division of which had widely different load characteristics, the engineers of Witherbee, Sherman & Company have endeavored to develop thoroughly practical standards in the size and type of driving unit employed, so as to obtain the maximum economy in the cost of power commensurate with high efficiency in the operation of the motors, as well as freedom from interrupted service and a uniformly high rate of production. The results have fully justified the abandonment of steam drive, except for prime movers; and, in future extensions now being arranged for, electricity, except for the air service in the mines, will constitute the sole source of applied power.

All the electrical apparatus in the present equipment is of General Electric manufacture.

NOTES

NEW ENGLAND SECTION OF THE ELECTRIC VEHICLE ASSOCIATION OF AMERICA AT THE LYNN WORKS OF THE GENERAL ELECTRIC COMPANY

At the invitation of the Small Motor Department of the General Electric Company, about sixty members of the New England Section of the Electric Vehicle Association of America and of the New England Electric Vehicle Club, accompanied by a delegation of executives from the Boston Edison Company, attended an informal dinner at the Lynn River Works, which was followed by a technical meeting and factory inspection of automobile apparatus and accessories. All the Boston visitors motored over the road from Boston to Lynn in a procession of some twenty electric vehicles of diversified types, ranging from the light runabout to the enclosed limousine model.

Mr. Fred M. Kimball, toastmaster of the evening, following a felicitous toast to "clean, economical, speedy and effective transportation," introduced Professor Dugald Jackson, of the Institute of Technology, as the opening postprandial speaker. Professor Jackson covered briefly and pertinently the inventions, road improvements and general progress of the day on matters relevant to transportation and intercommunication.

Mr. Day Baker, President of the New England Electric Vehicle Club, responded to his introduction as a "veteran in the electric vehicle field" by sounding as a key-note, the essential necessity,—now that the electric vehicle is a success both from the standpoint of design and manufacture,—of enthusiastically and persistently pushing its commercial exploitation wherever possible.

Professor Elihu Thomson touched, in a humorous way, upon his experiences and vicissitudes with the electric "ice wagon" of fifteen years ago, and forecasted a bright outlook for electric vehicle transportation in the future, with especial regard to the very important field of general traffic in the large cities.

Mr. E. S. Mansfield, Secretary of the New England branch of the Electric Vehicle Association of America, emphasized the necessity of improving electric vehicle tires; traced briefly the rapid advancement in construction of battery, motor, control and chassis: and closed by felicitating manufacturers and agents upon the present splendid opportunities to meet the growing demand for a product universally accepted as commercially practicable and successful.

Mr. W. B. Potter, Chief Engineer of the Railway and Traction Department of the General Electric Company, laid stress upon the importance in electric vehicle design, in contra-distinction to trolley practice, of laying out the motor with due reference to the battery limitations, since voltage and output are so sensibly affected by the rate of discharge. Mr. Potter also drew attention to the gratifying results following the careful consideration by manufacturers of all the factors involved in a comprehensive detail arrangement of the various component parts employed in the latest type of electric vehicles; all making for decreased maintenance, increased mileage and general economy of operation.

Mr. W. C. Francis, Purchasing Agent of the Boston Edison Company, in a pleasing vein, sketched the successive stages through which his company had passed, dating from brief year-ago experiments with the heavy, clumsy, inefficient vehicles of limited mileage, to the present-day vehicle of pleasing design, comparatively light weight, and vastly improved operating radius.

Mr. Lucius T. Gibbs, representing the Advertising Department of the Boston Edison Company, emphasized the need of still more enthusiasm and "push" on the part of vehicle manufacturers and their agents in overcoming the excessive caution of the purchasing public in more universally accepting this down-to-date solution of the city transportation problem.

Mr. Frank J. Stone, Eastern representative of the Electric Storage Battery Company, in an interesting paper compared the growth of the electric vehicle business to a rich, partly developed mine in the commencement of the producing stages; greater production being retarded only by insufficient developing forces. He then sketched some shining examples of change over from gasolene to electric vehicles by prominent merchants, express companies and public service corporations, and closed his paper by outlining the scope and object of the Electric Vehicle Association of America and its essential object, to wit: the conjoining of central stations, manufacturers and the public in a triple alliance for the greater development and generalized use of electric propulsion.

Following the after-dinner speeches, the delegates adjourned to the River Works assembly room where, under the chairmanship of Mr. E. S. Mansfield, a series of interesting technical papers and remarks were listened to. Mr. H. S. Baldwin, Engineer of the Automobile Department of the General Electric Company, besides tracing the history of electric automobile development for the last fifteen years, gave a detailed description of the vehicle motors, controllers and accessories which the Company has developed, illustrating his remarks by the use of disassembled motors and such accessory parts as controller, voltmeters, charging plugs, etc. Mr. Alexander Churchward, Consulting Engineer of the General Electric Company, followed Mr. Baldwin with an interesting fifteen minute technical dissertation on the specialized design required for vehicle motor work. Mr. R. E. Russell then described the mercury arc rectifier as manufactured by the General Electric Company. The evening's exercises were closed by Col. E. W. M. Bailey of the Bailey Electric Vehicle Company.

SCHENECTADY AND PITTSFIELD JOVIANS ORGANIZE

The order of the "Rejuvenated Sons of Jove" was organized in Texas in 1899 and since that date its membership has spread to every state in the Union and into Canada and Mexico. From year to year various electrical men of Schenectady and Pittsfield have joined.

Very recently these members met and determined to unite in a permanent co-operative organization, designed to be the largest in the country, celebrating the occasion with the initiation of the largest class in the history of the order. This movement is now well under way and from the number of applications received by the committee, there is every reason to believe that it will be successful.

The Sons of Jove is not alone a social organization, although this pleasant feature is by no means neglected. Its worth has been recognized by the electrical societies and a movement is now on foot whereby, as a co-operative feature, it will work in connection with the National Electric Light Association. The object of the order, as stated in the by-laws, is the cultivation of the spirit of fraternity and good fellowship, from which may be evolved practical plans of commercial co-operation for the promotion and popularization of electricity in the world's work.

It is the intent of the Jovians of the twin electrical cities, Schenectady and Pittsfield, to initiate a large class on February 10th, and to begin activities by establishing a Jovian lunch club which will afford a regular opportunity for the members and guests to get better acquainted.

Several of the officials of the General Electric Company are already members of the organization and are keenly interested in its success and development.

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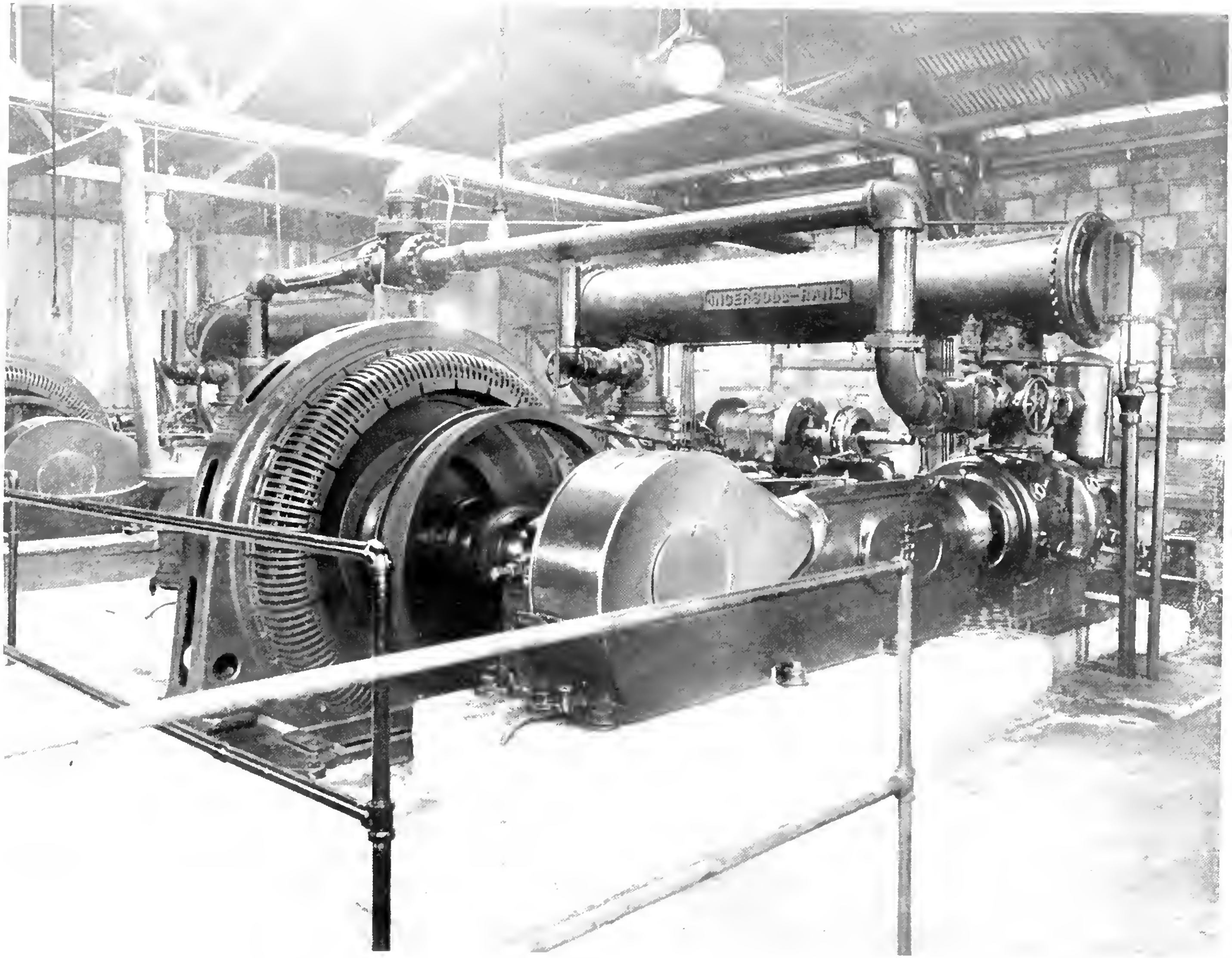


Two 137 Kv-a. Synchronous Motors Direct Connected to Two-Stage Air Compressors. Temporary Installation for Construction Work on Catskill Aqueduct, New York City

(See Page 149)

GENERAL ELECTRIC REVIEW

THE ABUSE OF ESTABLISHMENT CONVENIENCES

The following incident may be made the text of a sermon. After rather more than the usual amount of hard work, a solicitor attached to a local sales office in the middle western field, succeeded in closing the sale of a certain motor, involving probably some few hundred dollars. The order was, as usual, forwarded through the district office of the manufacturing company to the factory. Whether it was through justifiable elation or from motives of philanthropy towards the telephone company, we do not know; but we learn that the individual who handled the transfer, in his endeavor to secure further particulars regarding the sale, succeeded in sinking in a long-distance telephone call some 75 per cent. of the total estimated profits on the order. Nothing has transpired to show that there was any *special* urgency about the execution of the order, and in hardly conceivable circumstances can such extravagance have been justified.

It was purely accidental that these particulars should have become known to parties not immediately interested in the transaction. Cases quite as glaring as the one we have cited are being brought to light every day by those who are making a study of these matters of economy. Pressed for his views upon the degree of his crime and as to whether there was any justification, the offender in the present instance would probably have confessed that he gave the matter at the time practically no consideration — that he telephoned almost as a matter of course. It is easy to see that faults like this will become increasingly common; since they arise, not from any lack of integrity in certain individuals, but as the result of a universal state of mind which has been brought about by the lavish use of modern business conveniences. It is an era of street cars and telephones. It is easier to ride than walk, and easier to talk than write; and, along with this, perhaps resulting from it, it has also become an era of the abuse of our business conveniences.

Solicitors in the field are not the only offenders, nor is the abuse of the telephone the only respect in which they offend. The evil may be traced up through the entire *personnel* of the modern business organization, practised by the rank-and-file, office managers, department heads, presidents, and those occupying positions of the highest authority and responsibility. Lack of all discrimination in the use of the long-distance telephone is certainly a striking example of this spirit; but the same may be observed in nearly all those other business transactions, where money is being spent without the question of the price of the service or of the commodity being prominently in evidence at the time of the transaction. The more one looks into the matter, the more obvious some of these extravagances become, and the more one sees how difficult it must be to place a check on all these expenditures.

There is no need to dilate here upon the value of the telegram in modern business life, which is probably incalculable. It is indispensable; and men have come so to rely upon it, as upon their daily bread, that they have long ceased to wonder at the results which are possible through its use. The *Night Letter* is the latest departure for widening the field of its usefulness, and gives the business man still further facilities for the transaction of urgent business with parties separated by great distances. Let him remember that the urgency is a factor which he should consider with discrimination. The cable is such an excellent specific for emergency cases that the business man, already overworked, may be tempted to defer writing a letter, with the comforting reflection that at the last moment he can always use the wire; in other words, may withhold his attention from a matter which could be covered by a letter in a few moments, and continue to defer until the point of emergency is reached. And apart from that there is also the fact that familiarity (at the receiving end) breeds contempt, and that the telegram as an emergency stand-by often loses its value in correspondence proportionately as its use becomes more common.

A great deal could be written on the subject of the conservation of words in business correspondence. From figures compiled haphazard by men who have examined a number of typical business letters, it would appear that the average man uses in his daily correspondence 100 words where 30 or 40 would suffice; and that he clothes his ideas in such an ambiguity of phrase that the recipient too often has to request a further letter, or several further letters, in order to come at the whole truth of a case. Probably instruction in the art of business letter writing would help matters here; and certainly close self-examination would in the majority of cases cut down the bulk of the correspondence. But, as it is, probably any average business concern is carrying from 10 per cent. to 25 per cent. of stenographic help which is essentially unproductive. If the extent of the waste could be calculated and the annual loss put down on paper in thousands of dollars, it would probably be decided that it was worth while to work out a scheme for its reduction.

We have only touched on the fringe of the subject. Traveling, where often the traveling itself is unnecessary, and where the accounts are usually inflated (not necessarily with bad intent); entertainment, too often indulged in, rarely justified, often unseemly; stationery and other establishment supplies, pilfered and squandered; these and many other outlets for expenditure are saddling the big business concern with an annual liability which sometimes represents quite an alarming percentage of the turnover. As we have said, the waste is due usually to a condition of mind which has been gradually reached by all the *personnel*, from which there are few exceptions. It is quite general among the big organizations, where responsibility is divided and where personal supervision of such matters becomes well-nigh impossible. But it means that the man who has drifted to the extent that his mind ceases to place any check on such habits has ceased to be an efficient business unit. Such a state of affairs in the company may be called a physical disease of the business body, which is awaiting the physician's attention.

The position of the physician in cases of this kind is not an enviable one, since he must forever be pointing out to otherwise thrifty individuals how wasteful they are in their business capacity. If he is to perform his duty thoroughly he must be prepared to take his president to task, if need be; while he must constantly be on the look-out lest he, himself, be accused of using superfluous words in his correspondence, or of incurring other unnecessary expense. It is certainly not our intention to pose as the physician; since we fear that we could not declare, after searching our inmost heart, that this paper was produced on lines of economy which admitted of no possible tightening. We are merely calling attention to the complaint, because we are firmly convinced that there are a great number of people to whom the idea of its existence has never occurred.

SERIALS COMMENCING THIS MONTH

As announced in our February issue, we are commencing this month a series of papers by Dr. E. J. Berg, Professor of Electrical Engineering in the University of Illinois. This series is entitled "An Advanced Course in Electrical Engineering," and really constitutes a summary of the lectures which Dr. Berg is giving to his students of the graduate year. The papers will run through probably ten or twelve issues of the REVIEW; and are devoted chiefly to a study of transient phenomena, in which the mathematical treatment is essentially modified.

Dr. Louis Loewenstein's paper on Centrifugal Compressors also commences in this issue. The design data and the sections on the various applications of the compressor may be taken as an authoritative pronouncement upon the latest practice in this class of apparatus. The articles by Mr. A. Schein in the March and April REVIEW, on "Graphical Methods in the Design of Shafts," have been prepared principally for the service of draftsmen engaged in the layout of electrical machines. They will be found quite elementary in character, and will give to the inexperienced reader all the instruction he requires to enable him readily to apply the graphical method to the layout of a shaft for any kind of electrical machine.

THE NATURE OF TRANSIENTS IN ELECTRICAL ENGINEERING*

Part II

By Charles P. Steinmetz

This paper gives a complete mathematical analysis of transient phenomena in transmission circuits. An electrical transient is defined as the phenomena by which, at a change of circuit conditions, the stored magnetic and dielectric energy of an electric system readjust themselves to the changed conditions. Such transients may be divided into two classes. The first part of this paper (February Review) dealt with single energy transients which exist in circuits storing energy in only one form, usually magnetic, and in which the transients can only consist in a change in the amount of energy stored. The paper proceeds this month to deal with double-energy transients, i.e., transients in circuits storing both magnetic and dielectric energy, and in which there is a change of energy from one form to another, as well as a change in the amount stored. —Editors.

7.—In overhead electric circuits of 30,000 volts and over, and in underground cable circuits of 10,000 volts and over, the dielectric energy $\frac{Ce^2}{2}$ is of the same magnitude as the magnetic energy $\frac{Li^2}{2}$, and such circuits cannot be treated any more as circuits storing energy in one form only. The total stored energy of such high voltage electric circuits thus is:

$$w = \frac{Li^2}{2} + \frac{Ce^2}{2}. \tag{16}$$

With two different forms of energy storage, not only an increase or decrease of stored energy is possible, but also a transformation of energy from one form to the other. This transformation may be in one direction only, or it may be periodic. The former occurs if the power dissipation is very rapid, and in this case the transient is of so short duration and limited energy as to be rarely of serious moment, and therefore will not be considered here; only the second case will be discussed, when the energy transformation is periodic and the gradual decrease of energy fairly slow, that is, the duration of the transient relatively long.

Considering first the periodic part, or factor of the phenomenon:

The magnetic energy is a maximum $\frac{Li_0^2}{2}$, that is, the current i a maximum i_0, when all the energy is magnetic energy, and the dielectric energy is zero, that is $e=0$. The dielectric energy becomes a maximum $\frac{Ce_0^2}{2}$, and the voltage e thus a maximum e_0, when the magnetic energy is zero, that is, $i=0$.

Hence maximum current corresponds with zero voltage, and maximum voltage with zero current. That is, if we represent the current by the cosine function:

$$i = i_0 \cos(\Phi - \gamma) \tag{17}$$

the voltage is represented by the sine function:

$$e = e_0 \sin(\Phi - \gamma) \tag{18}$$

where:

$$\Phi = 2\pi f t \tag{19}$$

and f is the—still unknown—frequency, and γ the phase angle at the moment of the start of the transient.

At the current maximum i_0, all the energy is magnetic:

$$\frac{Li_0^2}{2};$$

at the voltage maximum e_0, all the energy is dielectric:

$$\frac{Ce_0^2}{2}.$$

It is, however, the same amount of energy (neglecting the gradual energy dissipation, as stated above); hence it is:

$$\frac{Li_0^2}{2} = \frac{Ce_0^2}{2} \tag{20}$$

and therefrom follows:

$$\frac{e_0}{i_0} = \sqrt{\frac{L}{C}} \tag{21}$$

where the quantity:

$$z_0 = \sqrt{\frac{L}{C}} \tag{22}$$

is a *constant of the circuit*, of the nature of an impedance, which in overhead transmission lines usually is between 200 and 600 ohms, but is much smaller in underground cables, and much larger in coiled circuits, such as the high potential winding of a transformer. z_0 is called the *natural impedance* of the circuit.

This equation (21) is extremely important. It applies to all double energy transients of the electric circuit, and thereby permits calculation of the voltage of an oscillation, surge, impulse or traveling wave from its current, and inversely.

* A paper prepared for the International Congress on Applied Electricity, Turin, September 10-17, 1911.

For instance, when considering the problem of lightning protection of a transmission line, from the maximum voltage which lightning may produce on the line, equation (21) gives the maximum discharge current, and thereby the maximum resistance which is permissible in the lightning arrester, without backing up the voltage by the resistance of discharge path. Thus, in a 30,000 volt line the insulators may be expected to stand 60,000 volts, and momentarily probably 120,000 volts, and this is the maximum voltage to which a lightning stroke could momentarily raise the line: a higher voltage would spill over the insulators, or puncture them. Assuming $z_0=400$, $e_0(=120{,}000$ volts), gives a maximum discharge current of $i_0=\frac{e_0}{z_0}=300$ amperes, and in such a line, no lightning stroke could produce a higher discharge current than 300 amperes, and if the maximum voltage rise in the station shall be limited to 50% above full voltage, that is 15,000 volts excess, the impedance of the discharge path of the lightning arrester must be limited to a maximum of $\frac{15{,}000}{300}=50$ ohms (inclusive of ground connection).

Or, if in this line the full load current is 200 amperes, the impedance voltage of the line 20% at full load, then the maximum current which could flow in the line at short circuit (if the generators maintain full voltage), is 5 times full load current, or 1000 amperes effective, that is, $i_0=1410$ amperes maximum, about. If then the short circuit current is suddenly broken—as a flaring arc is liable to do—the maximum voltage of the transient oscillation would be $e_0=i_0z_0=560{,}000$ volts: that is, far beyond the disruptive strength of the line. Hence while the oscillation produced by lightning may be relatively harmless, the short circuit oscillation of the system, if it occurs, is certain to be destructive. If full load current of 200 amperes effective were opened at the maximum point of the wave, $i_0=283$ amperes, an oscillation could result of a maximum voltage of $e_0=i_0z_0=113{,}000$ volts. Thus in the control of high voltage transmission lines, safety requires the use of circuit breakers which are certain to open at zero current, and flaring arcs, by their possibility of rupturing at maximum current, are the most dangerous disturbances of high voltage transmission circuits. This has led to the universal adoption of the oil circuit breaker in high power systems, as it has the characteristic of opening at zero current.

In underground cables, z_0 is low, and cable oscillations therefore have a low ratio $\frac{e_0}{i_0}$, that is, large oscillating currents flow with moderate voltages. If, however, such a large oscillating current enters from a cable into an overhead line, in which z_0 is much higher, the voltage e_0 also becomes higher. That is, a high current oscillation, which is relatively harmless in the cable in which it originates, may become destructive by its high voltage when entering an overhead line, and more so still when entering the high potential coil of the transformer in which z_0 is still much higher. Inversely, an oscillation originating in overhead line or transformer may become harmless when entering a cable by greatly dropping in voltage.

The same relation exists between overhead line and transformer: an oscillation originating in the line endangers the transformer which it enters by increasing the voltage due to the higher z_0 of the transformer; inversely, the connection of an overhead line to the transformer protects the transformer to some extent against oscillations originating in the transformer, since these oscillations decrease in voltage by entering the line, due to the lower z_0 of the latter, as will be seen later in the discussion of traveling waves.

The study of the values of the natural impedance

$$z_0=\sqrt{\frac{L}{C}},$$

and especially of the relative values of the z_0 of the various circuit sections which are connected with each other, is thus of great industrial importance in indicating the action which the different circuit sections exert upon each other, in either protecting or endangering each other, and also indicates the relative danger of the oscillations originating in the various circuit sections.

8.—Oscillating current i and voltage e of the double energy transient are in quadrature with each other. During each half wave of current the voltage reverses, that is, changes from $-e_0$ to $+e_0$ (or inversely), hence changes by $2e_0$, and as C is the capacity, the charge of the capacity during the half wave of current thus is:

$$2e_0C$$

This, however, equals the product of the current flowing into the condenser, and the time during which the current flows. The time is one half cycle, or $\frac{1}{2f}$, and the current has the maximum i_0, and thus the mean value $\frac{2}{\pi} i_0$.

Thus the charge of the condenser is:

$\frac{1}{2f} \times \frac{2}{\pi} i_0 = \frac{i_0}{2\pi f}$, for:

$$2e_0 C = \frac{i_0}{2\pi f}; \tag{23}$$

Substituting herein from equation (21):

$$e_0 = i_0 \sqrt{\frac{L}{C}}$$

we get:

$$f = \frac{1}{2\pi \sqrt{LC}} \tag{24}$$

as the expression of the *frequency of oscillation* of the circuit.

This expression (24) of the frequency of oscillation directly applies only to a circuit in which capacity C and inductance L are separately massed. If they are distributed, as in a transmission line or cable, and

L_0 = inductance per unit length of circuit
C_0 = capacity per unit length of circuit
l_1 = length of circuit

the inductances or capacities of the successive circuit elements do not add, as the current and the voltage of the successive line elements are not in phase with each other, but differ by the angle corresponding to the velocity of propagation. That is, if v = velocity of propagation (in overhead circuits about equal to the velocity of light 3×10^{10}), at two points of the line, distant from each other by the length l, the current and voltage differ in phase by the time $\frac{l}{v}$, that is, the phase angle

$$\omega = 2\pi f \frac{l}{v}. \tag{25}$$

Thus, the inductances and capacities of successive line elements must not be added, but combined, and the total effective inductance of the circuit is not $l_1 L_0$, but is $\frac{2}{\pi} l_1 L_0$, and in the same way the effective capacity is $\frac{2}{\pi} l_1 C_0$.

Substituting this in equation (24), gives as the *frequency of oscillation of a transmission line* or cable of length l_1 the value:

$$f_1 = \frac{1}{4 l_1 \sqrt{L_0 C_0}} \tag{26}$$

or, if the oscillation involves only $1/n$ of the line, that is, the line oscillates in n sections, substituting $\frac{l_1}{n}$ for l_1 in (26), gives the frequency:

$$f = \frac{n}{4 l_1 \sqrt{L_0 C_0}} \tag{27}$$

and in general, a line oscillation may consist of any combination of waves of various frequencies f_n, which are multiples of a fundamental frequency f_1.

9.—In the preceding, we have considered only the periodic part of the transient. In addition to the periodic transformation of energy between magnetic and dielectric, a gradual dissipation occurs, that is, to the equations (17) and (18) the transient factor $\epsilon^{-\frac{t}{T}}$ has to be added, where T is the duration of the transient, as discussed in the preceding. This gives the equations:

$$\left.\begin{aligned} i &= i_0 \epsilon^{-\frac{t}{T}} \cos (\Phi - \gamma) \\ e &= e_0 \epsilon^{-\frac{t}{T}} \sin (\Phi - \gamma) \end{aligned}\right\} \tag{28}$$

If all the energy were magnetic energy and remained as such, the duration of the transient would be:

$$T_1 = \frac{L}{r} \tag{29}$$

and the transient factor would be:

$$\epsilon^{-\frac{t}{T_1}}.$$

The energy is, however, magnetic energy only as an average half of the time, that is, the dissipation of magnetic energy occurs only during half of the time, and if there were no other energy dissipation, the transient would last the time $2T_1$. That is, the factor representing the dissipation of magnetic energy is:

$$\epsilon^{-\frac{t}{2T_1}}$$

Half of the time, however, the energy is dielectric energy. If it always were dielectric energy, it would be dissipated in the time:

$$T_2 = \frac{C}{g} \tag{30}$$

As it is dielectric energy only half the time, its dissipation is only half as fast, that is, the factor representing the dissipation of dielectric energy is:

$$\epsilon^{-\frac{t}{2T_2}}$$

and the total transient factor thus is:

$$\epsilon^{-\frac{t}{T}} = \epsilon^{-\frac{t}{2T_1}} \epsilon^{-\frac{t}{2T_2}}$$

$$= \epsilon^{-\frac{t}{2}\left(\frac{1}{T_1}+\frac{1}{T_2}\right)} \qquad (31)$$

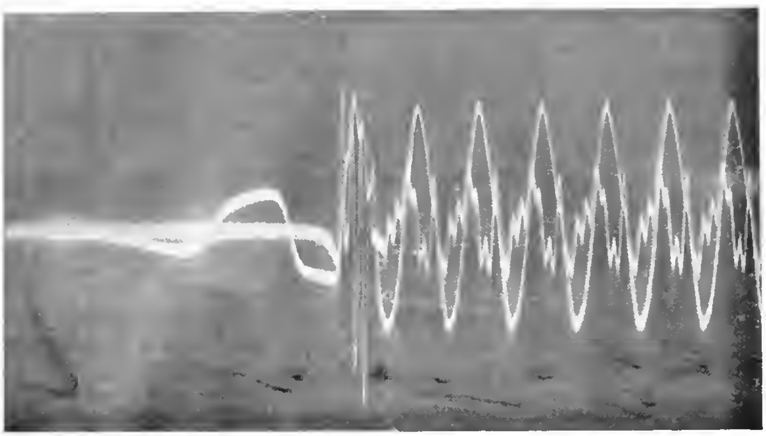


Fig. 10

That is, the duration of the double energy transient, T, is the harmonic mean of the duration of the magnetic transient,

$$T_1 = \frac{L}{r},$$

and the duration of the dielectric transient, $T_2 = \frac{C}{g}$:

$$\frac{1}{T} = \frac{1}{2}\left(\frac{1}{T_1} + \frac{1}{T_2}\right)$$

$$= \frac{1}{2}\left(\frac{r}{L} + \frac{g}{C}\right). \qquad (32)$$

This quantity is usually represented by

$$u = \frac{1}{T}. \qquad (33)$$

As in the circuit with distributed inductance and capacity, such as a transmission line, cable, transformer high potential coil, etc. the phase of current and voltage changes from point to point by the distance phase angle ω, which represents the velocity of propagation, and the transient equations of the circuit are:

$$\left.\begin{aligned} i &= i_0\epsilon^{-ut}\cos(\Phi-\gamma\mp\omega) \\ e &= e_0\epsilon^{-ut}\sin(\Phi-\gamma\mp\omega) \end{aligned}\right\} \qquad (34)$$

Hence, by resolving angle Φ and distance angle ω, into trigonometric functions of time we get terms of the forms:

$$\left.\begin{aligned} i &= i_0\epsilon^{-ut}\cos(\Phi-\gamma)\cos\omega \\ e &= e_0\epsilon^{-ut}\sin(\Phi-\gamma)\sin\omega \end{aligned}\right\} \qquad (35)$$

where:

$$\left.\begin{aligned} \Phi &= 2\pi ft && = \text{time angle} \\ \omega &= 2\pi f\frac{l}{v} && = \text{distance angle} \\ f &= \frac{n}{4l_1\sqrt{L_0C_0}} && = \text{frequency} \\ u &= \frac{1}{T} = \frac{1}{2}\left(\frac{r_0}{L_0}+\frac{g_0}{C_0}\right) && \end{aligned}\right\} \qquad (36)$$

and e_0 and i_0 are related by the equation:

$$\frac{e_0}{i_0} = \sqrt{\frac{L_0}{C_0}} = z_0. \qquad (37)$$

These are the equations of the double energy transient of the circuit with distributed capacity and inductance, that is, of the oscillations and surges of transmission lines, etc.

10.—In equations (35), i and e are in quadrature, that is, the power

$$p = ei$$

is *reactive*, that is, surges or flows first one way, then the other way through any point of the circuit, but the average flow of power at any point of the circuit is zero. That is, the phenomenon is a *stationary oscillation*, or *standing wave*.

If, however, e and i are not in quadrature, but in phase with each other, that is, follow the equations:

$$\left.\begin{aligned} i &= i_0\epsilon^{-ut}\cos(\Phi-\gamma\mp\omega) \\ e &= e_0\epsilon^{-ut}\cos(\Phi-\gamma\mp\omega) \end{aligned}\right\} \qquad (38)$$

we get a transient, in which the average power at any point of the circuit is not zero, and in which power thus flows along the circuit.

Such a transient is a *traveling* wave, or an *impulse*. It carries or transfers energy along the circuit.

Traveling waves frequently precede stationary oscillation and change into them.

Lightning discharges usually are traveling waves.

Traveling waves may have frequencies from a few hundred cycles to many millions of cycles, and in the latter case are very local in extent. If of moderate frequency, they may be observed by oscillograph, and Fig. 10 shows the oscillogram of a traveling wave in a compound circuit consisting of a step-down transformer and 28 miles of 100,000 volt transmission line. This traveling wave represents the readjustment of stored energy between the two circuit sections, the transformer winding and the transmission line, which precedes the (very low frequency) stationary oscillation, by which the compound circuit dies down after opening the high tension oil circuit breaker. If of very high frequency, such traveling waves may be indicated by a spark gap across a small reactance in series with the circuit. In the circuit of Fig. 10, a traveling wave of about two million cycles is produced by closing the high tension oil circuit breaker, the wave starting from the circuit breaker, but dying out within a very short distance.

In circuits comprising sections of different character, as transmission line, transformer, load, etc., that is, in most industrially important circuits, the energy surge is a combination of standing wave and traveling wave. It obviously must die down simultaneously in all circuit sections. In some circuit sections, however, such as the transmission line, energy dissipation occurs at a greater rate than in other circuit sections, such as transformer coils, and the surge would therefore die down more rapidly in the former than in the latter, if the two circuit sections were separate. As they are connected together, energy must therefore be supplied to the line from the stored energy of the transformer, by a traveling wave, so as to give the same rate of decay.

Thus, if u_1 is the transient constant, that is, $\epsilon^{-u_1 t}$ the transient factor of one circuit section, such as the transformer, and u_2 the transient constant of the second circuit section, such as the line, and $\epsilon^{-u_2 t}$ its transient factor, when both are connected together they must have the same transient factor, $\epsilon^{-u_0 t}$, where the resultant transient constant of the compound circuit, u_0, is a weighted average of the individual transient constants u_1, u_2 of the circuit section. If then:

$$u_0 = u_1 + s_1$$
$$u_0 = u_2 - s_2, \text{ etc.,}$$

the common transient factor $\epsilon^{-u_0 t}$ of each section consists of the energy dissipation factors $\epsilon^{-u_1 t}$, $\epsilon^{-u_2 t}$ etc., and the energy transfer factors $\epsilon^{-s_1 t}$, $\epsilon^{-s_2 t}$ etc., the latter representing the transfer of energy along the circuit, by a traveling wave. Such energy transfer means a withdrawal of stored energy from the circuit, if $u_0 > u_1$, or a supply of energy (from other circuit sections), if $u_0 < u_2$. In the former case, the traveling wave increases in intensity along its path, that is, an exponential function of the distance of travel l appears, with positive exponent:

$$\epsilon^{+\frac{s_1 l}{v}}$$

and in the latter case, the traveling wave decreases along its path, that is, the exponential function of distance appears:

$$\epsilon^{-\frac{s_2 l}{v}}$$

where:

v = velocity of propagation, approximately $= 3 \times 10^{10}$

The equation of the traveling wave thus appears in the form:

$$\left.\begin{aligned} i &= i_0 \epsilon^{-(u \pm s)t} \epsilon^{\pm s \frac{l}{v}} \cos(\Phi - \omega - \gamma) \\ e &= e_0 \epsilon^{-(u \pm s)t} \epsilon^{\pm s \frac{l}{v}} \cos(\Phi - \omega - \gamma) \end{aligned}\right\} \quad (39)$$

where:

$$\left.\begin{aligned} &u = \text{transient constant of the respective circuit sections,} \\ &u \pm s = u_0 = \text{resultant transient constant of the entire circuit.} \end{aligned}\right\} \quad (40)$$

Thus a stationary oscillation of a compound circuit consists of traveling waves which transfer energy between successive circuit sections, feeding energy from the section of lower dissipation constant, into the section of higher dissipation constant, by equation (39). The calculated potential distribution of a stationary oscillation of a closed compound circuit is illustrated diagrammatically in Fig. 11, and also separately the two component waves, which traverse the circuit in opposite direction.

In the same manner, if in a uniform circuit, a local piling up and scattering of stored energy occurs, as in a lightning discharge, the transient factor of distance appears, that is, the traveling waves have the form:

$$i = i_1 \epsilon^{-u \ldots t} \epsilon^{-s \frac{l}{v}} \cos(\Phi - \omega - \gamma_1)$$
$$+ i_2 \epsilon^{-u \ldots t} \epsilon^{-\frac{l}{v}} \cos(\Phi - \omega - \gamma_2) \text{ etc.} \quad (40)$$

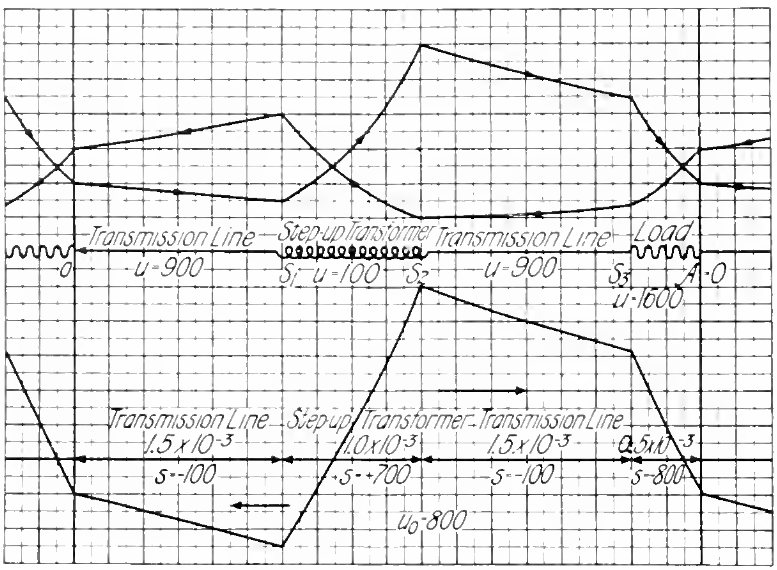


Fig. 11

11.—In the energy surge or transient of a compound circuit, a flow of oscillating power thus occurs between the circuit sections. This results in a transformation of voltage and current at the transition points between the successive circuit sections.

For instance, if a traveling wave passes from a transmission line into the high potential winding of a step-down transformer, and e_1 is the maximum voltage, i_1 the maximum current (hence $p_1 = \frac{e_1 i_1}{2}$ the mean power of the wave in the transmission line), e_2 the maximum voltage, i_2 the maximum current, (hence $p_2 = \frac{e_2 i_2}{2}$ the mean power of the wave in the transformer), the same power must leave the line that enters the transformer; that is, it must be:

$$e_1 i_1 = e_2 i_2$$

e and i are, however, related by the natural impedance of the circuit section, that is:

$$\left. \begin{aligned} i_1 &= \frac{e_1}{z_1} \\ i_2 &= \frac{e_2}{z_2} \end{aligned} \right\} \quad (42)$$

where:

$z_1 = \sqrt{\frac{L_1}{C_1}}$ is the natural impedance of the line,

$z_2 = \sqrt{\frac{L_2}{C_2}}$ the natural impedance of the transformer winding.

Substituting (42) into (41) gives:

$$\frac{e_2}{e_1} = \sqrt{\frac{z_2}{z_1}} = \frac{i_1}{i_2} \quad (43)$$

That is:

At the transition point between two circuit sections, a transformation of voltage occurs, with a transformation ratio which is the square root of the ratio of the natural impedances of the two circuit sections, and a transformation of current by the inverse ratio.

This relation between the oscillating voltages and currents of different circuit sections is of fundamental importance in tracing the origin and determining the destructiveness of disturbances.

A traveling wave, coming from one circuit section into a circuit section of higher natural

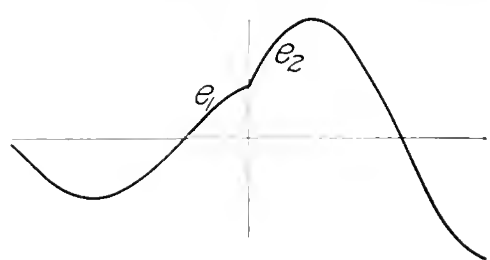


Fig. 12

impedance thus increases in voltage and thereby in destructiveness; and inversely, when entering a section of lower natural impedance, it decreases in voltage.

This explains why electric disturbances, which originate in one circuit section, frequently develop their destructiveness in adjoining circuit sections, in which, due to the higher natural impedance of the latter section, they have increased to destructive voltages. Indication of a transmission line disturbance is thus often the breaking down of the transformers connected to the line; not because the transformers are weaker in insulation, but because the disturbance, while of harmless voltage in the line, has increased in voltage in the transformer.

This voltage transformation at a transition point means that the wave crests of the voltage distribution in the one circuit section are higher than in the other circuit section; at the transition point itself, obviously both circuit sections have the same voltage, and the potential distribution of the traveling wave is thus somewhat like that shown in Fig. 12. At the transition point a change of phase angle occurs, and in the circuit section of higher voltage maximum, this maximum occurs nearly a quarter wave length distant from the transition point. How far this distance is depends on the frequency: with a very high frequency traveling wave, the wave crest may occur within the end turn of the transformer which the wave enters, while with a moderate frequency wave, it may be near the center of the transformer. The location of a breakdown in a transformer, whether in the end turns or in the middle of the winding, thus does not indicate whether the disturbance entered from the outside, or originated in the transformer, but a transformer may be broken down in the middle of its winding, by a moderate frequency traveling wave, which entered it from the transmission line.

SOME SPECIAL APPLICATIONS OF GASOLENE-ELECTRIC AND STORAGE BATTERY AUTOMOBILE EQUIPMENTS

By H. S. Baldwin

Engineer, Automobile Motor Department, General Electric Company

The article forms a review of some of the most recent applications of electric generators and motors to the propulsion of special conveyances which, for the most part, are employed for public service purposes. Those selected for discussion are of widely different character and include a fire-ladder truck, a street sweeper, an omnibus and a commercial truck, all of the gasolene-electric type; the storage battery type being represented by an omnibus, a street car, a snow sweeper and an industrial car. No attempt is made to describe the progress that marks the development of the electric pleasure vehicle or commercial vehicle of the usual kind.—Editors.

The wonderful growth of the automobile industry in all its branches, witnessed during the past few years, has been accompanied by great activity in the adaptation of electrical apparatus to new purposes in this field. It is not intended to here describe the progress of the regular vehicles for either pleasure or commerce, but to point out several comparatively new uses to which such apparatus as motors, generators, controllers, and the like, have been put. Most of these are directly connected with public utility service in one way or another.

The specially designed generator of light weight and high overload capacity has been successfully employed in conjunction with electric motors, to replace the regular change gear box on vehicles for passenger and mercantile service. A number of examples descriptive of this development are herewith briefly cited. While this form of drive and control is as yet not widely known and appreciated, it has been proven entirely practicable, and the possibilities of the system in the near future are exceedingly attractive.

Another line of advance is found in the storage battery railway passenger cars installed on several lines in New York City where it was not permitted nor practicable to use the underground trolley system. To accomplish the change-over, the standard car and equipment designs were attacked from the automobile standpoint; the car body was made as light as possible, and a battery of the automobile type was used to supply current to automobile motors slightly modified for street railway service. The cars referred to have now been run many months and are considered highly successful, both from an engineering and financial point of view. In this rational treatment of the storage battery problem for railways, a new field of great promise to the manufacturer and railway company has undoubtedly been opened up.

The trackless trolley and the storage battery omnibus will also play important parts in handling passenger traffic and freight in places where, for logical reasons, it may not be advisable to use the standard railway and trolley cars. In other words, there are many special applications which will be worked out in accordance with local conditions.

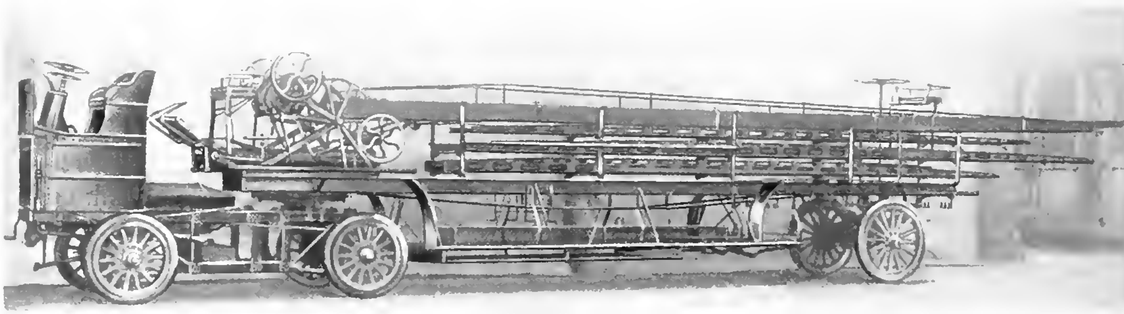


Fig. 1
Gasolene-Electric Aerial Truck. Tractor made by the Commercial Truck Company of America, Philadelphia

The battery truck crane* should also be mentioned as a new and important form of motor vehicle. This has been recently much written about and is an interesting addition to the specialized uses of the electric automobile motor and of the electric hoist. This truck has already attracted wide attention and many are now in active use.

The gasolene-electric street sweeper is electrically controlled throughout and has two generators, three automobile motors, an exhaust fan motor and the necessary controllers. The storage battery baggage truck for railway stations is becoming a more and more frequent sight and greatly increases the speed of handling baggage. The operator stands on a step or small platform at either end and controls the manœuvres of steering, starting and stopping, and sounding an alarm bell. A new motor rated at 24 volts, 40 amperes and 1500 r.p.m. has been developed for this service.

These are only a part of the things that have been accomplished, but it must be conceded that the automobile, even with its marvelous progress, is as yet a comparatively new development, and the future offers great opportunities for further use of electricity in this work.

Not only are there problems of propulsion and motion, but of lighting, ignition, signaling, and innumerable other auxiliaries that are now receiving much attention from the automobile public. No attempt is made in this article to give much technical detail; it is aimed to point out the salient features of a few more recent electrical developments. The list is not complete but is illustrative of what is being done.

The motive and control equipments on all the vehicles mentioned are of General Electric manufacture.

Fig. 2
12 Kw. Generator for Aerial Truck

Gasolene-Electric Tractor

The gasolene-electric tractor shown in Fig. 1 was designed and built by the Commercial Truck Company of America for use with an American La France Fire Engine Company's 75 foot aerial ladder truck. The gasolene engine, made by the latter company,

* For a description of this truck, see General Electric Review for November, 1911.

has four cylinders of $5\frac{1}{2}$ in. bore and 6 in. stroke, and is direct connected by means of an Oldham coupling of special construction to a 6 pole, 12 kw., 125 volt generator. This is the latest addition to the line of generators which has been brought out during the past two or three years to meet the requirements of the gasolene-electric road vehicle. The generator is compound wound and has slotted poles; it is designed for a somewhat drooping characteristic, high overload capacity, and good commutation under the severest conditions.

Each of the four tractor wheels is driven by a motor rated at 125 volts and 24 amperes, which is mounted and geared according to the standard practice of the Commercial Truck Company, all gearing being encased and running in oil. The speed of the tractor is ordinarily controlled by the throttle and spark of the engine, as in the case of the gasolene truck with mechanical transmission. Here the peculiar flexibility of the electric drive with series motors gives in effect an almost automatic change of torque to meet the requirements of the road. A four-motor controller is provided and forms part of the steering column, and is so designed as to connect the motor in series-parallel or parallel, either forward or reverse. Both front wheels are pivoted for steering, the rear wheels being fixed with relation to the axle.

Fig. 4. 7½ Kw. Generator for Street Sweeper

An interesting detail is found in the provision for starting the engine. The generator is used as a motor, current being supplied from an external source through a standard charging plug. To effect the necessary changes, a double-pole double-throw switch is used to connect the generator either to the line or to the control circuit of the tractor. When connected to the line, a permanent resistance is used in the circuit and the series field cut out.

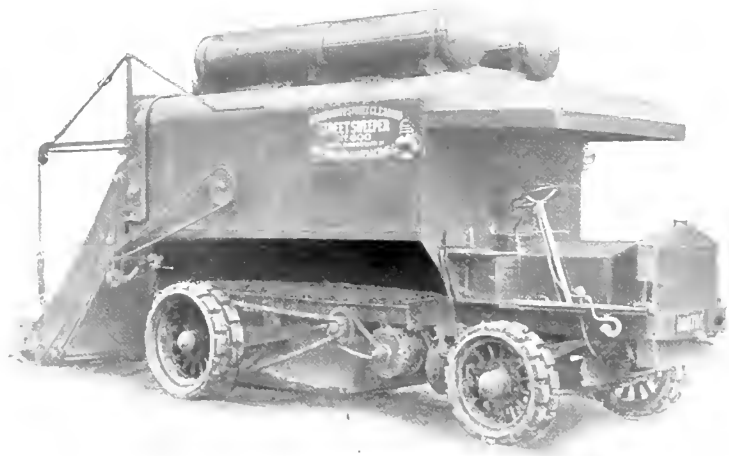


Fig. 3. Gasolene-Electric Street Sweeper. Made by the Emerson Contracting Co. New Brunswick, N. J.

On the occasion of a recent test at Elmira, N. Y., this outfit, including the ladder truck, was run over roads rough with ice and snow at 24 miles per hour on the level, while a 17 per cent. grade was ascended with comparative ease.

The gasolene-electric system of drive seems particularly suited to four-wheel traction, and it is safe to say that this type of road vehicle will play an important part in the solution of many transportation problems.

Gasolene-Electric Street Sweeper

The gasolene-electric street sweeper of the Emerson Contracting Company (Fig. 3) represents one of the latest developments in street cleaning apparatus, made possible by the introduction of the automobile. The new street sweeper is in fact a large motor truck of highly specialized design, with provision for taking up refuse and dust from city pavements.

The prime mover is a gasolene engine of four cylinders. Coupled to the shaft by means of silent chains are two 6 pole, $7\frac{1}{2}$ kw. generators of the type previously described. These generators are connected in multiple with an equalizer and supply current for propelling the sweeper, and for operating the broom, conveyor belt, and exhaust fan. The two driving motors are rated 125 volts and 30 amperes, and are suspended on each side of the car as shown in Fig. 3. Silent chains connect the motors to an intermediate shaft which in turn is connected by roller chains to the rear wheels. A controller serves in conjunction with the engine throttle to give the desired changes in speed.

The cleaning apparatus consists of a revolving steel brush six feet in width, made up in sections, with a conveyor belt of about the same width. The brush and conveyor belt are located in a steel chute which can be raised or lowered by the operator, who is seated at the rear of the sweeper. There is a separator at the top of the conveyor to prevent clogging of heavy material; the entire system being driven through roller chains by a motor rated at 125 volts and 30 amperes. A controller provides the necessary change of speed.

The brush loosens the dirt on the street surface and throws it onto the belt, which carries it into the large tank body. The body, when filled, can be dumped through the bottom at suitable stations. In order to prevent dust from being stirred up by the broom, an exhaust fan, driven by a small motor, is used; the set being placed in a small compartment at the forward end of the body and provided with a suitable screen to prevent the escape of dust. A 9 foot broom has been used on occasions.

The entire body is made of sheet steel and is supported by a chassis, all substantially and well built and specially adapted to the use intended. The driving wheels are of 42 in. diameter and are fitted with triple 4 in. solid tires. The sweeper, without load, has a weight of about eight tons, and from four to seven tons of refuse, according as the material is wet or dry, can be carried. It is driven at from three to five miles per hour on level roads, and can climb any ordinary city grade.

Four of the machines have been in successful operation in New York City, and two others will shortly be sent to Boston.

Fifth Avenue Gasolene-Electric Omnibuses

Over three years ago ten gasolene-electric omnibuses, equipped with the General Electric system of drive, were placed in commission on Fifth Avenue, New York City, and with the exception of a short interval, have been in regular operation since that time. Records show that they have covered to date an aggregate of 350,000 miles. They are run daily over the same route with other gasolene vehicles of practically the same design, capacity, weight, engine and constructional details, but having the regular sliding gear drive and clutch. It will readily be seen that an unusual opportunity has been afforded for a comparison between the two systems of drive, under identical conditions of service and when operated by the same company.*

For years, numerous gasolene-electric systems have been devised and tried out, both in this country and abroad, but as a rule they have been too complicated to last. The Fifth Avenue record is without doubt unique as to duration, and probably stands as the first instance of an engineering and commercial success of the gasolene-electric road vehicle on any considerable scale.

One of the greatest difficulties found with mechanical drive omnibuses, is the rapid wear of change gears and clutch rigging, entailing high expense for maintenance, and what is almost as bad, noisy operation. The frequent change of gear accompanied by the use of the clutch, not always in skillful or careful hands, racks both transmission and engine. As a result, acceleration is uneven, with excessive back-lash, in spite of constant attention. It was to overcome these objections that the electric drive was suggested and tried, and it is generally admitted as a result of observation and experience that the claims of simple and easy control, relatively low cost of maintenance, reduction of wear and tear of transmission and engine, and smooth acceleration and quietness, have been substantiated. Omnibuses of both types operate under the same conditions of headway, although the later models with mechanical drive have somewhat larger engines and are therefore more powerful. The mechanical system has a slight advantage in fuel consumption, as was anticipated, but this is practically negligible as compared with the factors already referred to.

The electrically driven omnibuses, as originally designed, were equipped with two 125 volt, 30 ampere double reduction motors and

* A description of the gasolene-electric busses will be found in the GENERAL ELECTRIC REVIEW for November, 1908, Pages 214-220.

a $7\frac{1}{2}$ kw. generator which was specially designed for gasolene-electric work, being provided with split poles and possessing exceptional overload capacity for its weight.

Fig. 5. Gasolene-Electric Omnibus, Fifth Avenue Coach Company, New York City

During the past year a single motor equipment has been developed using a 125 volt, 60 ampere motor with a special gear housing on its pinion end head to receive the bevel gear and differential of the mechanical omnibus. This motor is interchangeable with the gear box and can therefore be used to replace it. Omnibus No. 15, shown in Fig. 5, is so equipped, and also has the modified generator with double bearings. This omnibus is in regular service on Fifth Avenue.

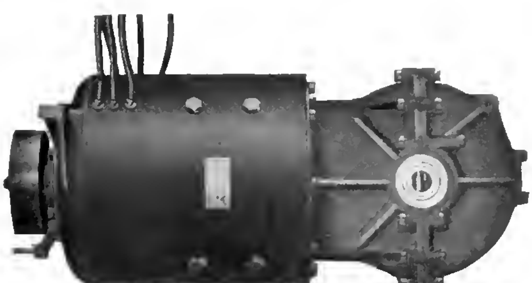


Fig. 6. Motor for Fifth Avenue Omnibus, Showing Special Gear Housing

Gasolene-Electric Truck

The Tate Gas-Electric Motor Vehicle Company was one of the first manufacturers to exploit the electric drive for commercial trucks. One of this company's earliest vehicles was a light delivery wagon having an air cooled gasolene engine, a small generator, and a motor, all mounted as a unit on a sub-frame made after the style of the storage battery truck. This development led to larger and more powerful machines, and for several years the Tate Company has put out gasolene-electric trucks of capacities of 1, 2, 3, and 5 tons, with noteworthy results. An interesting power unit has been evolved by mounting a four-cylinder two-cycle engine and a $7\frac{1}{2}$ kw. generator on a common frame, and connecting them by a suitable coupling. Reference to Fig. 7 will show the method of hanging the motor; also the silent chain first reduction to the counter-shaft, with roller chain drive to each rear wheel. The latest trucks are being equipped with double motor drive, which has some advantages for gasolene-electric transmission. The claims already made of relatively low cost of maintenance, reduced wear and tear on transmission and engine, and flexibility of control, apply equally well to these trucks.

Fig. 7. Gasolene-Electric Express Truck. Made by The Tate Gas-Electric Motor Vehicle Company, New York City

Fig. 8. Electric Vehicle Chassis. Made by the Electric Omnibus Corporation, New York City

The United States Express Company has operated many Tate trucks in Chicago and other cities, with great success, and the writer has seen reports of service under the most trying winter conditions that are highly creditable. Figures are not available for publication at this time, but it may be truly said that the persistent efforts of this Company in designing and exploiting the gasolene-electric truck have been of great value, and very promising progress is being made along this comparatively new line of activity.

In addition to doing local delivery work at Chicago, these trucks complete the line of the United States Express Company between Milwaukee and Chicago, meeting the Chicago and Milwaukee Electric Line at Evanston. Their capacity is $3\frac{1}{2}$ tons and the cars were designed to run $8\frac{1}{2}$ miles per hour on 85 volts and 50 amperes. This speed was not sufficiently high to meet the requirements of the express business, and it became necessary to schedule them as high as 20 miles per hour. This was acquired by increasing the voltage, and the operation of the cars, now in their third year, has proved so satisfactory that the advisability of adopting a number of them for local delivery service in New York City is being considered.

Electric Omnibus

Figures 8 and 9 give an idea of the latest chassis and omnibus designed and built by the Electric Omnibus Corporation of New York City, at their works in Troy, N. Y. A number of these vehicles have recently been put into service

Fig. 9. Passenger Omnibus Fitted on Chassis of Fig. 8

by Carson Pirie Scott Company, of Chicago, Ill., to run between their large department store and the railroad station for the accommodation of customers.

It will be seen that the omnibus body is designed for the comfort and convenience of passengers, and also combines good lines and an attractive appearance. There is a vestibule at the front end, and as the passengers enter they drop the fare in a box near the driver. Seats are arranged lengthwise on the sides, with a cross seat at the rear, giving room for 18 passengers. The omnibuses are equipped with Edison batteries placed under the seats and in the bonnet in front. The battery will give a daily mileage from 70 to 90 miles on a single charge, and boosting charges may be given as required. The chassis is of modern design throughout and is propelled by a motor rated at 60 volts and 60 amperes, 1100 r.p.m., which is mounted lengthwise in the frame and connected by a short propeller shaft fitted with two universal couplings to a counter-shaft, which in turn drives the rear wheels by means of chains. A controller is mounted below a cross-member just forward of the motor and is operated by a lever on the steering column.

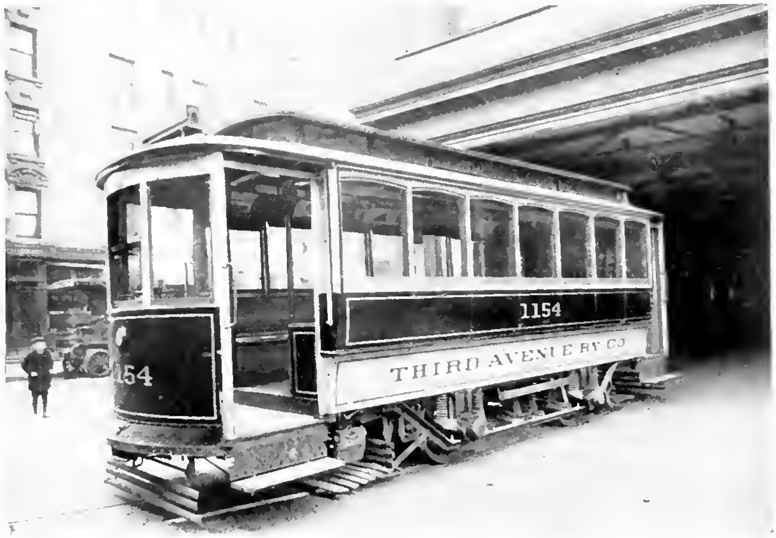


Fig. 10. Storage Battery Passenger Car, New York City


Fig. 11. Automobile Motor Converted into Railway Type for Storage Battery Car

Complete tests of the omnibuses made by the manufacturers show a low wattage per ton mile. The Edison batteries are guaranteed for service on these omnibuses for four years when used at their full rated capacity.

It is believed that there is a large field for storage battery omnibuses as feeders for electric railways, on boulevards, and on avenues where rails are not permitted; also between small towns and especially for suburban traffic of large towns and cities.

The Electric Omnibus Corporation is building other omnibuses with bodies of various styles and of different capacity.

Storage Battery Street Car

The Third Avenue Railway Co., New York City, is entitled to much credit for the successful development of a practical storage battery street car for certain of its lines where the trolley cannot be used. A few years ago it was decided to replace the old horse cars on crosstown lines with self-contained motor cars, either gasolene-electric or storage battery. After interesting investigations, the latter was chosen as best suited to the local operating conditions. Instead of the regulation car body and motive equipment, the body of the first car was adapted from a horse-car, two automobile motors, each rated at 85 volts and 40 amperes, with 50 per cent. overwound fields, being mounted on a truck provided with roller bearing axle journals. The car wheels were connected to the motors by silent chains, each 3 in. wide and over 10 ft. long, made by the Link Belt Engineering Company. The car seated twenty-six passengers and weighed about six tons and was so light that it could be pushed

Fig. 12. Storage Battery Snow Sweeper, Third Avenue Railway Company, New York City

along by one man. The battery was supplied by the Gould Storage Battery Company and consisted of 44 cells of high capacity, each cell containing 29 plates; the battery having a rating of 420 ampere-hours at 84 volts.

Here was a new conception of the storage battery railway car, quite different from the old, which, on account of its light weight and the light weight of its equipment, was fairly certain to be a success. As a result of favorable tests, thirty cars were next built and equipped with motors rated at 85 volts and 30 amperes, 700 r.p.m.

After these cars had been in operation for some months, it was decided to change to gear drive, and this alteration is now being made. The motors were also re-designed mechanically for mounting on the axle, as in railway practice, and the gears were encased in a sheet steel housing. A good idea of the motor can be had by referring to Fig. 11.

The latest cars, Fig. 10, which have only recently been put into service, weigh about seven tons, carry twenty-six passengers, and are equipped with a 58-cell Exide battery of 420 ampere-hours capacity at a 6 hour rate of discharge. These cars operate at about 6 miles per hour, with eight stops per mile, on about 480 to 500 watts per car mile at the motors. The motors are 50 per cent. overwound. The cars have no difficulty in obtaining 100 miles per charge and have gone as high as 119 miles.

The Third Avenue Railway has recently added to its equipment, and is now operating about fifteen cars on the 110th Street and St. Nicholas Avenue line, which runs from the Hudson River, through Manhattan Street, St. Nicholas Avenue and 110th Street, to East River. There are about twenty cars on the 28th and 29th Street crosstown lines running between the ferries on the Hudson River side to the 34th Street ferry on the East River side. The third line is the Dry Dock, East Broadway and Battery, which operates twenty-one cars, running down First Avenue, through 14th Street, and down Avenue B and East Broadway to City Hall.

In all, the Company now has about eighty cars in active service, those not mentioned above being used on its various lines, as required.

Snow Sweepers

The Third Avenue snow sweeper (of which there are four) represents another interesting

Fig. 13. Motor for Snow Sweeper, Converted Automobile Type

development. (Fig. 12.) This sweeper weighs approximately 14 tons, completely equipped with two sets of batteries, each set consisting of 58 cells similar to those used on the passenger cars. The motive equipment includes two railway type motors rated at 85 volts and 60 amperes, 700 r.p.m. Fig. 13 shows the general design of the motor, excepting the gear and gear case, which are omitted. Both driving axles are chained together to prevent slipping and to insure maximum traction. There are also two motors rated 85 volts, 30 amperes, 700 r.p.m., which are duplicates of those used on the passenger cars, and are used to revolve the brooms.

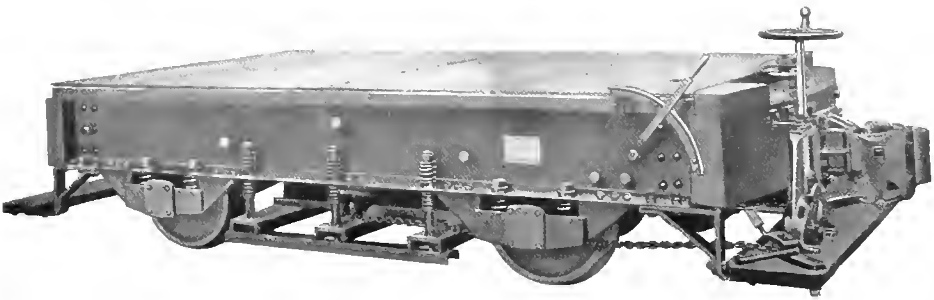


Fig. 14. Storage Battery Industrial Car. Made by General Electric Company

The new sweepers were called out early this winter and operated in a highly satisfactory manner, removing the snow without difficulty as regarded traction, and otherwise. Many of the remarks already made about the storage battery passenger car apply to the snow sweeper as well. These machines are well worked out and are in every way practical.

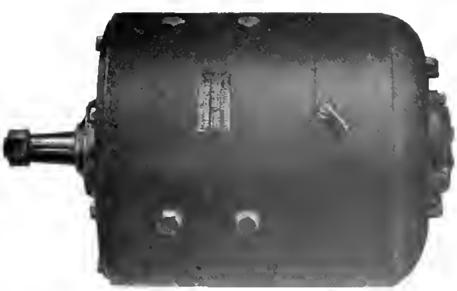


Fig. 15. Motor for Industrial Car

Storage Battery Industrial Car

The storage battery industrial car illustrated in Fig. 14 is one of two built by the General Electric Company for its works at Erie, Pa. It is equipped with two motors (Fig. 15) rated at 85 volts and 22 amperes, 1200 r.p.m., which are mounted in cast steel suspension brackets and connected to the driving axles by double reduction gearing with a ratio of about 20 to 1. The gauge is 56½ in., the driving wheels are 20 in. in diameter, and the journal boxes are provided with roller bearings.

Besides this design, three single-motor cars with 36 in. gauge have been built, two for the Schenectady Works and one for the Pittsfield Works. These cars are equipped with the same motor as that employed on the Erie car. Three more cars are now on order for the Schenectady Works, two single-motor 36 in. gauge and one two-motor, 56½ in. gauge. All the cars are equipped with 44-cell batteries, supplying current to the motors at a potential of 85 volts. The battery for the two-motor car has an ampere-hour capacity of 216, while the single-motor car has an output of 162 ampere-hours. The car speeds vary between 1½ and 4 miles per hour, depending upon the load. A circuit-breaker or fuses are provided to protect the motor. Powerful brakes are operated by a hand wheel having a threaded spindle on which is fitted a nut carrying an equalizing bar.

These cars have been thoroughly tried out and are built for severe service. It is believed that there is a large field for such equipments in the various manufacturing plants of the country.

CENTRIFUGAL COMPRESSORS

Part I

By Louis C. Loewenstein

Engineer, Turbine Department, General Electric Company

This article will be published in three instalments, the first of which considers the subject theoretically, the principle of the centrifugal compressor and the several factors that influence efficient operation receiving considerable attention. Ample data in the form of curves and relatively simple equations are included to enable the reader to calculate the performance of a centrifugal compressor under various conditions of operation. The second instalment will describe the application of centrifugal compressors to blast furnaces, foundry cupolas, bessemer converters, the manufacture of water and coke oven gases, oil burning and forge work, pneumatic cash and mail carrying systems, removal of refuse, etc., etc. The third instalment will deal with the rating of centrifugal compressors and the amount of power required for their operation. A number of problems typical of those usually encountered in practice are worked out by means of the formulæ and table given in the present instalment.—Editors.

The rapid substitution of rotating for reciprocating machinery has been one of the most striking engineering developments of recent years. The marked success of the steam turbine no doubt stimulated the development and introduction of the centrifugal pump and, more recently, the centrifugal compressor. The centrifugal compressor today stands in the same relation to other compressors as the steam turbine stood fifteen years ago to the reciprocating engine, or as the centrifugal pump stood five years ago to other pumping apparatus. Although the initial development of the centrifugal compressor was first begun in Europe, the General Electric Company started about three or four years ago to develop and introduce it in this country; and the marked success attained is well substantiated by the large number of successful units in commercial operation.

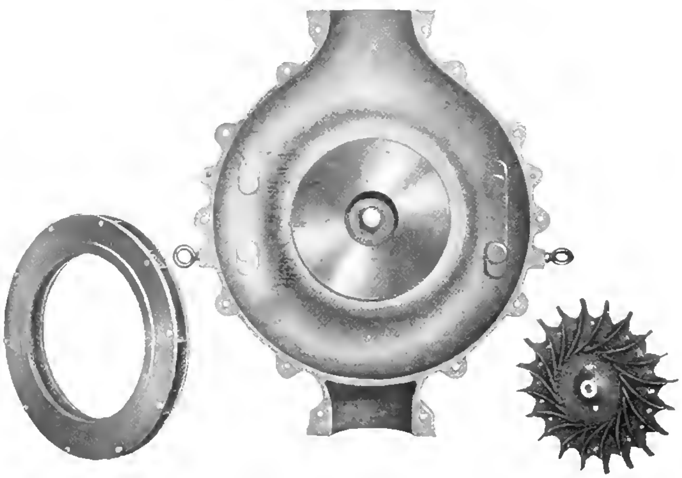


Fig. 1. Impeller, Discharge Vanes, and Half Casing of Single Stage Compressor

A centrifugal compressor resembles a centrifugal pump, except that in the former elastic fluids are compressed and in the latter fluids comparatively inelastic are pumped. A centrifugal compressor consists of a revolving impeller mounted on a shaft supported in suitable bearings and surrounded by a stationary set of discharge vanes supported in a suitable casing. If the desired amount of compression is small, a single impeller suffices and the apparatus is known as a single stage compressor: if the compression desired is larger a multi-stage compressor is used, which consists of two or more single stage units mounted on the same shaft and operating in series within a common casing. Fig. 1 is a photographic view of an impeller, a set of discharge vanes, and a half casing of a single stage compressor.

As the name centrifugal compressor indicates, centrifugal force plays an important part in its operation. When set revolving, the impeller will, by centrifugal force, entrain a fluid, say air, at its inner circumference and will discharge it at its outer circumference at an increased pressure. This pressure can be called centrifugal pressure. Besides this the impeller has set the air into motion; and at its outer circumference, or discharge end of the impeller, the air is moving at practically the same velocity as the peripheral speed of impeller. Hence the work delivered by the driver to the impeller of the centrifugal compressor appears in the air discharged from the impeller in two forms of energy, pressure energy and velocity energy. It is the function of the stationary set of discharge vanes to convert the velocity energy into pressure energy. The discharge vanes are so designed that the air in flowing through the passages between the vanes is gradually reduced in speed and the velocity energy recovered in the form of an increase of pressure energy. Roughly speaking, about 95 per cent. of the energy supplied by the driver to the compressor appears as pressure energy and velocity energy in the air leaving the rotating impeller. About one-half of the available energy is in the form of centrifugal pressure, while the other half is in the form of velocity. In an ordinary fan or blower this high velocity of the air is allowed to dissipate itself chiefly into eddy currents, and finally exists in the air in the form of heat. In the centrifugal compressor this velocity energy is largely recovered in the form of increased pressure. Hence the vital difference between an ordinary fan or blower and a centrifugal compressor lies in the fact that the former does not recover any of the velocity energy generated by the rotating impeller, whereas the latter recovers the larger part of the velocity energy so produced. It can be readily seen why the centrifugal compressor is so highly efficient and why this recent type of air compressor is replacing all older types.

Besides its high efficiency there are other advantages which aided in the introduction of the centrifugal compressor. On account of its operating at high speeds this compressor is much smaller in size than any other compressor delivering the same work; and further, because it can run at high speeds it can be direct connected to high speed drivers, which are in themselves smaller and more efficient than those which must operate at low speeds. This is especially true of the steam turbine, and a turbine driven centrifugal compressor forms an ideal arrangement. Ample clearances can be provided about the impeller, and if the bearings are properly designed and provided with efficient lubrication, no rubbing parts exist; so that the original efficiency of the unit is maintained after years of service. Compare this to the performance of displacement or positive pressure blowers where frequent renewals are necessary to maintain somewhere near the original efficiency and output; or compare this compressor to the inefficient and large fans or blowers, and it then does not seem strange that the centrifugal compressor has made such great strides

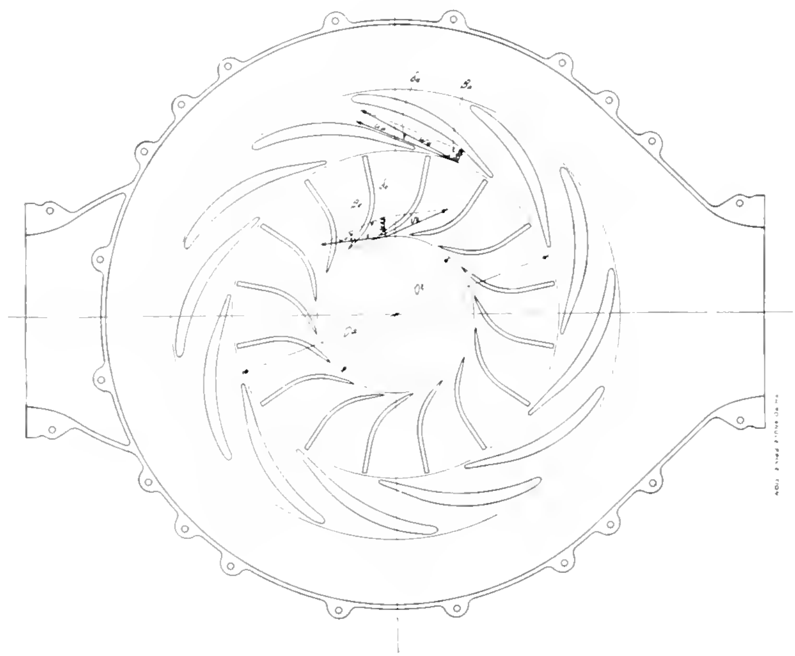


Fig. 2

commercially and is supplanting other forms of compressors in almost all fields of service.

The efficiency of centrifugal compressors will be steadily improved as we gain more theoretical knowledge of the laws governing air flow, but the fundamental principles involved are well understood and are quite simple. Fig. 2 represents diagrammatically a centrifugal compressor. The air particles enter the impeller at a diameter D_e and leave it at a greater diameter D_a. The impeller is rotated by a motor at an angular velocity ω; the air particles are thrown outward by centrifugal force and thus exert a pressure which can be expressed by the equation

$$\frac{\left(\frac{D_a}{2}\right)^2-\left(\frac{D_e}{2}\right)^2}{2g}\omega^2=\frac{u_a{}^2-u_e{}^2}{2g}=\frac{p}{\rho} \qquad (1)$$

in which u_a and u_e, Fig. 2a, represent the peripheral velocities at the diameters D_a and D_e respectively; p the pressure rise; and ρ the density of the air.

The air particles enter the impeller at the diameter D_e with a relative velocity v_e, and leave the impeller at the outer diameter D_a with a relative velocity v_a. The resultant absolute exit velocity w_a of u_a and v_a can

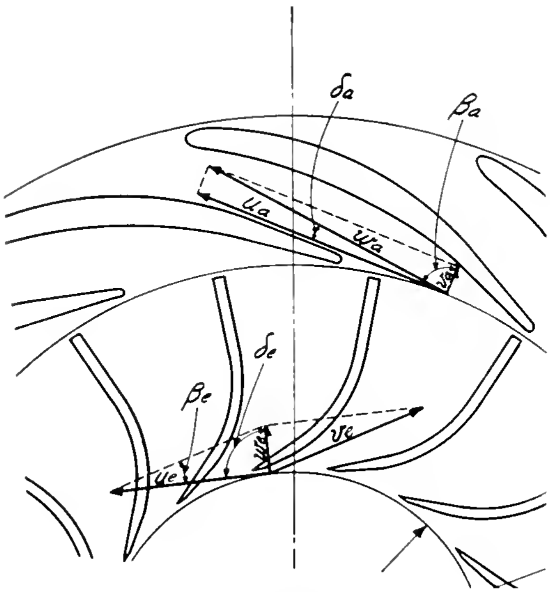


Fig. 2a

be represented by the diagonal of a parallelogram where sides are u_a and v_a. This parallelogram is called the exit velocity diagram. In this diagram u_a and v_a form an angle β_a, which is called the exit angle of the impeller. The angle δ_a, formed by u_a and w_a, is the angle at which the air leaves the impeller, and in order that the air may enter the discharge vanes without shock, their entrance angle must also be δ_a. The object of the discharge vanes is to reduce gradually, with minimum shock losses, the absolute velocity w_a, and thus transform as much as possible of the velocity head $\frac{w_a^2}{2g}$ into pressure.

The entrance velocity diagram of the impeller must be drawn in a manner similar to that of the exit velocity diagram, that is, so that v_e forms the diagonal of a parallelogram whose sides are u_e and w_e. The entrance angle of the impeller will be designated by β_e and the angle between u_e and w_e by δ_e. The entrance and exit velocity diagrams are shown in Fig. 2a.

From the velocity diagrams it will be noted that the air enters the impeller in a radial direction. If the air is not to enter the impeller radially some sort of guide vanes should be provided to properly direct the air; but if the air is to enter radially, only radial ribs are provided to prevent churning of the air before entrance to the impeller. In high speed impellers the blades of the impellers are radial at exit. If they are not radial, great care must be exercised in designing them so that the ensuing centrifugal forces exerted on the blades do not bend or break them. For an impeller with air entering radially the following relation exists between the various velocities:

$$v_e^2 = u_e^2 + w_e^2 \qquad (2)$$

and with impeller blades radial at exit the relation between the various velocities at exit is

$$w_a^2 = u_a^2 + v_a^2. \qquad (3)$$

Hence the air leaves the impeller with an absolute velocity w_a which is somewhat higher than the peripheral velocity of the wheel.

The pressure rise in the impeller alone can be expressed in terms of the impeller and air velocities at exit by the following equation:

$$\frac{u_a^2 - v_a^2}{2g} = \frac{p}{\rho} \qquad (4)$$

in which p is the pressure rise above inlet pressure in pounds per square foot, and ρ is the density of the air in pounds per cubic foot, provided the speeds u_a and v_a are expressed in feet per second.

When there is no flow of air through the impeller, as is the case when the intake to or discharge from the compressor is closed, the resultant centrifugal pressure will be:

$$\frac{u_a^2}{2g} = \frac{p}{\rho} \qquad (5)$$

This equation can also be stated in the following form:

$$\frac{u_a^2}{2g} = h \qquad (6)$$

in which h is the height in feet of a column of the fluid sustained by the impeller. In other words, the centrifugal force generated will support a column of fluid of height h against gravity. This equation also applies to that common form of liquid tachometer in which an impeller is rotated and the ensuing centrifugal force maintains a column of fluid to a height proportional to the square of impeller speed, or number of revolutions.

The discharge vanes receive the air with a velocity of w_a. This high velocity is gradually converted into pressure, provided the vanes are properly shaped. The velocity at the exit end of the discharge vanes is usually very low and if negligible the theoretical rise in pressure above that existing at impeller exit is

$$\frac{w_a^2}{2g} = \frac{p}{\rho} \tag{7}$$

Hence the total theoretical pressure rise obtainable with an impeller having radial blades at exit, and with proper discharge vanes, is the sum of the pressure rise in the impeller, $\frac{u_a^2 - v_a^2}{2g}$, and the pressure rise due to conversion of the absolute velocity at impeller exit $\frac{w_a^2}{2g}$. But as

$$\frac{w_a^2}{2g} = \frac{u_a^2 + v_a^2}{2g} \tag{3}$$

then

$$\frac{u_a^2 - v_a^2}{2g} + \frac{u_a^2 + v_a^2}{2g} = \frac{u_a^2}{g} \tag{8}$$

The total theoretical pressure rise is therefore given by the equation

$$\frac{p}{\rho} = \frac{u_a^2}{g} \tag{9}$$

The actual pressure rise can be expressed by

$$\frac{p}{\rho} = \eta \frac{u_a^2}{g} \tag{10}$$

in which η is the hydraulic efficiency.

It has been assumed in all of the equations that the density ρ is constant. Actually in an air compressor the density varies; but all the equations given are correct for a compressible fluid, provided that the symbol p is taken for the mean effective pressure rise instead of the actual pressure rise, and the density ρ is taken as the initial density. The term "mean effective pressure" is used in the same sense as in reciprocating compressors and it is possible to construct a table giving the values of the mean effective pressure rise corresponding to any actual pressure rise.

In single stage compressors the variation of density is small and therefore for ordinary calculations the density can be taken as constant and the above equations will give the actual pressure rise.

In multistage compressors, if N represents the number of impellers (or stages) in series, the following equation holds for an incompressible fluid:

$$\frac{p}{\rho} = N\frac{u_a^2}{g} \tag{11}$$

For a compressible fluid the same equation holds; only p will then stand for the mean effective pressure rise and not the actual pressure rise, and ρ will be the initial density of the fluid.

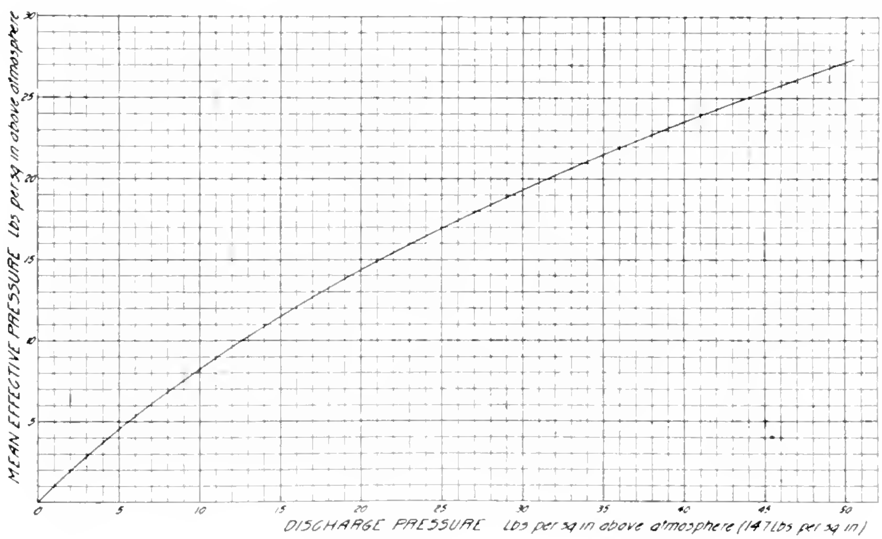


Fig. 3

This equation can also be interpreted to mean the total work done per pound of fluid passing through the compressor exclusive of rotation and short circuit losses.

The theoretical power required for compression when the density remains constant is

$$P = 0.2620\ Qp \text{ (in horse power)} \qquad (12a)$$

or

$$P = 0.1953\ Qp \text{ (in kilowatts)} \qquad (12b)$$

in which Q is the flow of fluid in cubic feet per second and p is the pressure rise in pounds per square inch.

With a compressible fluid the density of course changes, and then p in the above equation again stands for the mean effective pressure. If the compression is adiabatic, then p stands for the mean effective pressure for adiabatic compression; but if the compression is isothermal, p stands for the mean effective pressure for isothermal compression.

Fig. 3 shows a curve from which the final or discharge pressure may be found when the mean effective pressure for adiabatic compression is known, or vice versa.

Fig. 4 gives the theoretical horse power necessary to compress adiabatically 100 cubic feet of air per minute from 14.7 pounds per square inch absolute to various final pressures. If the efficiency of compression is known it is easy to calculate the actual horse power required to compress any volume of air. If it is necessary to refer to isothermal compression, Fig. 5 gives the ratio between the theoretical power required for adiabatic compression and that required for isothermal compression.

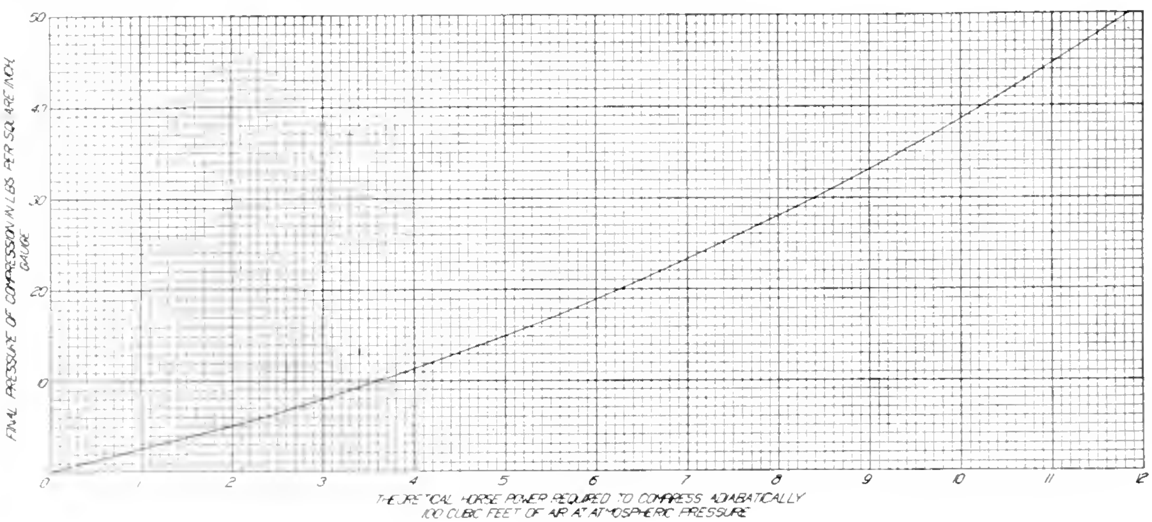


Fig. 4

In practice the efficiency of the compressor is compared to either adiabatic compression or isothermal compression. For cases in which the compression does not exceed 50 pounds per square inch, adiabatic compression is usually referred to, but for higher pressures, isothermal compression is more frequently referred to. The reason for this is that for the lower pressures it is not necessary to cool the air during the process of compression as efficiently or thoroughly as in compressors that compress to higher pressures, and the compressions in practice actually approach more nearly that of adiabatic compression when the compressions are low, and resemble more nearly isothermal compressions when the compression is high. In all problems mentioned in this paper adiabatic compression will be chiefly referred to.

The actual efficiencies of single stage air compressors vary somewhat with the capacity of the unit, but generally speaking the shaft efficiency is over 70 per cent. and the hydraulic efficiency is usually over 75 per cent. The shaft efficiency is the ratio of the theoretical power required to compress a given volume of air to a given pressure to the actual power which must be applied to the shaft of the compressor. The hydraulic efficiency is the ratio of that same theoretical power to the power represented by the fluid input as given by equation 9. The hydraulic efficiency does not include any rotation losses or short circuit losses, but includes losses along impeller blades and along the discharge vanes.

In order not to enter into too much mathematics and still give general and useful formulæ the following equations are simply stated but not derived. They are perfectly general formulæ and apply exactly for all incompressible fluids, such as water, and also for compressible fluids, such as air, if the density is considered constant.

The total pressure rise is

$$p = p_2 - p_1 = \frac{\rho \eta u_a^2}{4631}\left(1 - \frac{v_a}{u_a}\cos\beta_a\right) \quad (13)$$

The theoretical kilowatts corresponding to the total pressure rise above stated is

$$P = 0.1953\ Q\ (p_2 - p_1) \quad (14)$$

p is the rise in pressure in pounds per square inch.

p_1 is the initial pressure of the fluid in pounds per square inch absolute.

p_2 is the final pressure of the fluid in pounds per square inch absolute.

Q is the quantity discharged in cubic feet per second.

ρ is the density of the fluid in pounds per cubic foot (constant) = 62.4 for water and 0.0764 for air at sea level.

u_a is the peripheral velocity of the impeller at exit in feet per second.

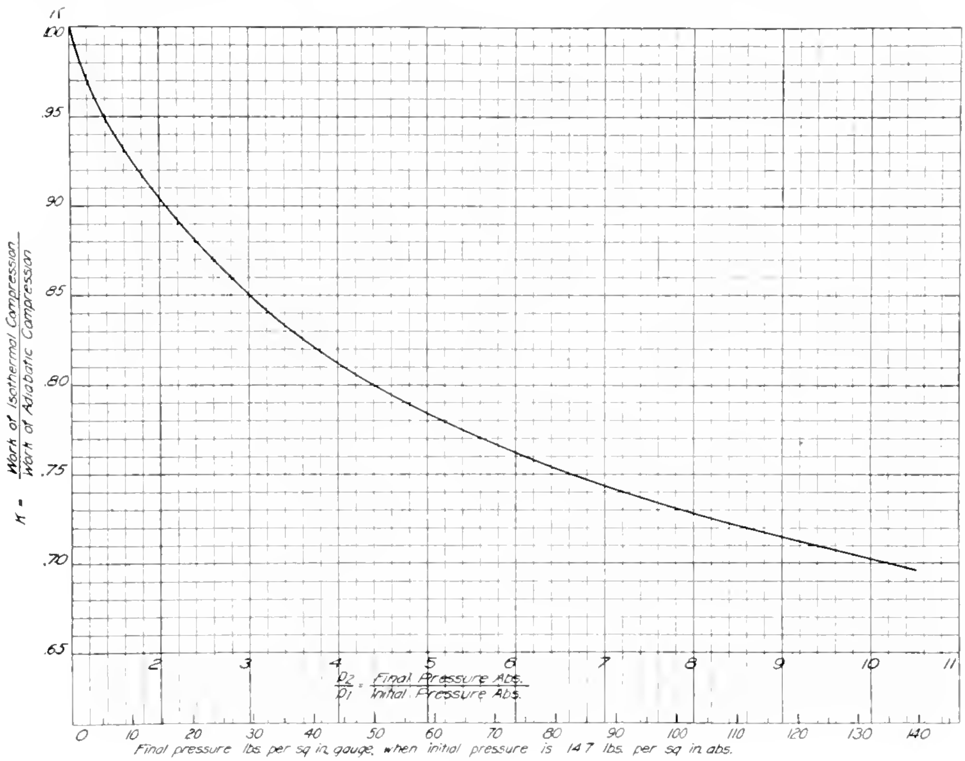


Fig. 5

The fluid input in kilowatts, or the energy put into the fluid per second corresponding to the impressed changes in velocity and pressure, is

$$P_e = \frac{\rho Q u_a^2}{23712}\left(1 - \frac{v_a}{u_a}\cos\beta_a\right) \quad (15)$$

The hydraulic efficiency or ratio of theoretical kilowatt to fluid input is

$$\eta = \frac{4631}{\rho u_a^2}\;\frac{(p_2 - p_1)}{1 - \frac{v_a}{u_a}\cos\beta_a} \quad (16)$$

in which

v_a is the relative exit velocity of the fluid in feet per second.

β_a is the angle between u_a and v_a.

It may be well to give a general formula without introducing the mean effective pressure for cases where the density of the fluid is not constant, as in multistage compressor problems. The following equation is for radial inlet flow to the impeller and for impellers having radial blades at the discharge end (General Electric type), and is based on adiabatic compression.

$$\frac{p_2}{p_1} = \left(1 + \frac{\eta \rho_1 \frac{K-1}{K} u_a^2 N}{4631\ p_1}\right)^{\frac{K}{K-1}} \qquad (17)$$

in which the various letters represent the

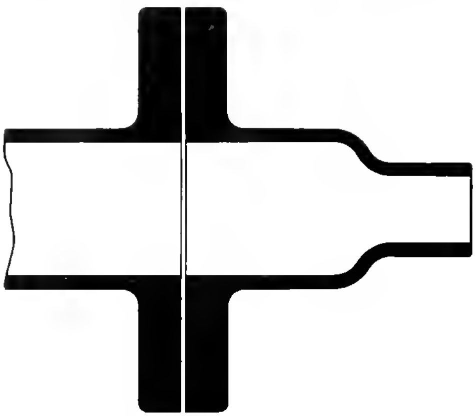


Fig. 6. Standard Orifice

same quantities as heretofore, and in which K equals the ratio of the specific heats at constant pressure and at constant volume. absolute temperature $\rho_1 = 0.0764$ and $K = 1.41$, so that $\frac{K}{K-1} = 3.44$. Assuming a hydraulic efficiency of 72 per cent. and substituting these values in the last equation, we have

$$p_2 = 14.7\left(1 + \frac{N u_a^2}{4300000}\right)^{3.44} \qquad (18)$$

For a given impeller having a fixed exit area, the relative exit velocity v_a is evidently proportional to the quantity of fluid Q passing through the impeller per second. The peripheral wheel speed u_a is also proportional to the revolutions per minute. For any given impeller, therefore, the ratio $\frac{v_a}{u_a}$ will be proportional to $\frac{Q}{R.p.m.}$ and may therefore be represented by it. Consequently if the compressor is designed to give its best efficiency when delivering say Q cubic feet per second at a certain value of revolutions per minute it will deliver at increased or decreased speed proportionately the same ratio of increased or decreased quantity of discharge Q.

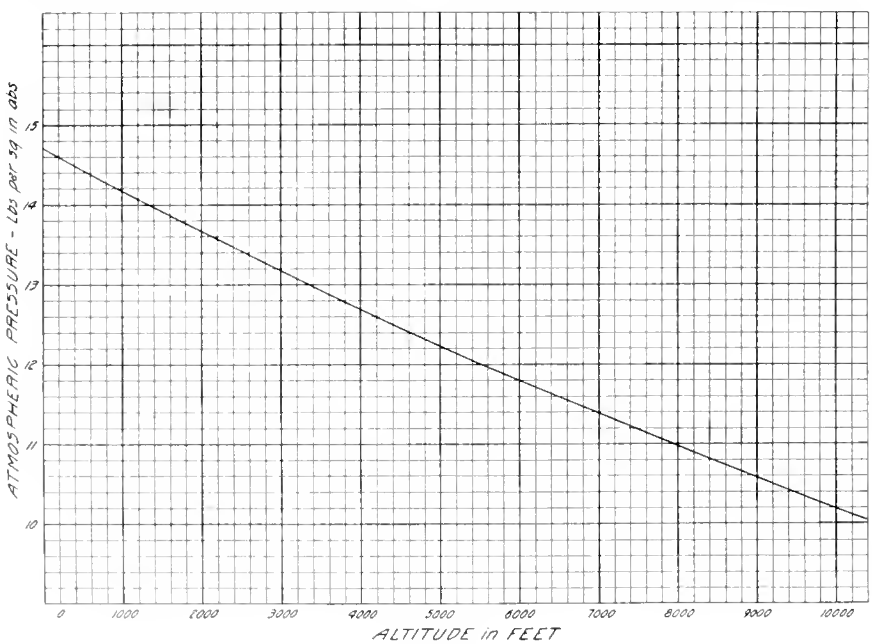


Fig. 7

For air $K = \frac{0.2375}{0.1685} = 1.41$. The subscript 1 stands for initial conditions and the subscript 2 for final conditions. For air initially at 14.7 pounds per square inch pressure and at 520° F.

It is sometimes necessary to determine the flow of air or gases through pipes and orifices. The following formulæ may be useful.

For the flow of any gas through an orifice when the final pressure is greater than the critical value of $\frac{p_2}{p_1}$, (the critical value for air and for most gases $\frac{p_2}{p_1}=0.5272$), the theoretical quantity of discharge in cubic feet per second of free gas (at 60° F. and 14.7 pounds per square inch absolute pressure) is

$$Q=f\frac{3.97a}{\sqrt{T_1\rho_0}}\sqrt{p_2\left(p_1-p_2\right)-\left(\frac{3}{2K}-1\right)\left(p_1-p_2\right)^2}$$

in which (19)

- a = area of orifice in square inches.
- T_1 = initial temperature in F° absolute.
- p_1 = initial pressure in pounds per square inch absolute.
- p_2 = final pressure in pounds per square inch absolute.
- K = ratio of specific heat at constant pressure to specific heat at constant volume.
- ρ_0 = density of gas in pounds per square foot (at 60° F. and 14.7 pounds per square inch absolute pressure).
- f = orifice coefficient (for an orifice shown in Fig. 6 coefficient = 0.99).

For air, after substituting values for ρ_0 and for K, this equation becomes

$$Q=\frac{14.38a}{\sqrt{T_1}}\sqrt{p_2(p_1-p_2)-0.0665(p_1-p_2)^2} \qquad (19a)$$

When any gas flows through an orifice where the final pressure is less than the critical value of $\frac{p_2}{p_1}$ then

$$Q=f\frac{3.972a}{\sqrt{T_1\rho_0}}p_1\sqrt{\frac{K}{K+1}\left(\frac{2}{K+1}\right)^{\frac{2}{K-1}}} \qquad (20)$$

For air, after substituting values for ρ_0 and for K, this equation becomes

$$Q=f\frac{6.98a}{\sqrt{T_1}}p_1 \qquad (20a)$$

For the flow of air in pipes we are indebted to the excellent experiments of Mr. D. W. Taylor. The summary of his experiments is that the coefficient of friction has a value of 0.00008 for pipes of first-class workmanship and in very best condition. If, however, the pipes have some slight internal roughness, error of shape, or alignment, this coefficient of friction should be increased to 0.0001. Mr. Taylor recommends the latter coefficient for general working purposes.

TABLE I

DENSITY AND SPECIFIC GRAVITY OF VARIOUS GASES.

Pressure 14.7 pounds per square inch absolute. Temperature 520° F. absolute.

AVERAGE VOLUMETRIC ANALYSIS

	Coal Gas	Coke Oven Gas	Actual Air Gas (Siemen's Producer)	Actual Water Gas	Water Gas Carburetted	Producer Gas Anthracite	Producer Gas Bituminous	Natural Gas	Blast Furnace Gas	Taylor Anthracite (average)	Density in Lbs. per Cu. Ft. at 60° F. and 14.7 Lbs.
CO_2	.02	.02	.04	.03	.04	.07	.04		.10	.084	.11683
N_2	.03	.18	.62	.04	.04	.47	.50	.08	.58	.527	.07424
CO	.05	.03	.23	.44	.25	.27	.22		30	.183	.07396
H_2	.45	.57	.08	.49	.35	.18	.20	.02	.02	.174	.00531
CH_4	.40	.19			.18			.90		.026	.0426
C_3H_6	.05	.01	.03		.14	.01	.04				.11445
Density in pounds per cubic foot											
	.03341	.03015	.07172	.04157	.05166	.06502	.06365	.04424	.07695	.06449	
Specific Gravity (Air at .0764 taken as unity)											
	.4379	.3935	.939	.5438	.6741	.852	.8325	.578	1.007	.844	

If

f is the coefficient of friction (0.0001),
l the length of pipe in feet,
v the velocity of the gas in feet per second,
d the weight of the gas in pounds per cubic foot;

then the friction loss (in pounds per square inch) can be expressed by the following equation

$$L = \frac{flv^2}{3d} \qquad (21)$$

Inserting for f its value 0.0001 and taking the density of air as 0.07465 the friction loss in pounds per square inch for the flow of air is

$$L = \frac{lv^2}{400000d} \qquad (21a)$$

Fig. 7 gives the atmospheric pressure in pounds per square inch absolute for various altitudes above sea level. This curve is useful in calculating the performance of centrifugal compressors if installed at high altitudes. The use of this curve will be more fully explained later.

Table I gives the densities and specific gravities of various gases sometimes compressed by centrifugal compressors. The use of this table of densities for centrifugal compressor work will be explained later when some practical problems are solved.

(To be Continued)

ALTERNATING CURRENT APPARATUS TROUBLES

Part VII

By W. Brooke

British Thomson Houston Co. Ltd., Rugby, England

SYNCHRONOUS CONVERTERS (Continued)

Part V (February Review) of this series commenced an analysis of synchronous converter troubles, and dealt with: first, overheating; second, accidental grounding; third, excessive voltage drop on a-c. end; fourth, regulation of d-c. voltage. This month the sub-headings are sparking, starting, synchronizing and parallel operation. It must be pointed out that the author is more familiar with British practice than American; and that none of his statements may be taken in any way as official utterances of the General Electric Company.—Editors.

SECTION 5. SPARKING TROUBLES

Sparking at the commutator of a converter may be due to a number of causes, some of which have been described in connection with other faults. The principal other causes are as follows:

Cause 1. Distortion of field may be responsible for this trouble, due to incorrect position of brushes on the direct current side, or to the fact that the machine is being run on a low power-factor under a fairly heavy load. The adjustment of the brushes is a matter which can best be seen to when the machine is running. It may be determined whether the distortion is produced by the machine working under a fairly heavy load on low power-factor by moving the main shunt field rheostat, in order to see if the setting is such as to give minimum input. When this has been done it will be noted whether the commutation has changed for the better. If not the brushes should be shifted.

Cause 2. Short-circuited coil in armature. This has already been treated upon in connection with over-heating troubles (see Section 1, Cause 5).

Cause 3. Open-circuit in armature. An open-circuit in the armature of the converter evidences itself in the same way as in the case of a continuous current machine, by the appearance of a ring of fire around the commutator. The machine should be shut down; and it will usually be an easy matter to locate the open coil, owing to the fact that the open-circuit generally takes place at the soldered joint between the commutator lug and the end winding, or between the commutator lug and the commutator; and is therefore obvious on inspection.

Cause 4. Incorrect brush spacing. If the brush-rigging is ever moved for any reason care should always be taken that the brush-holders are replaced in such a position that the leading edges of all the brushes are pitched equally around the commutator. This is best checked up by means of a strip of cartridge paper about 1 in. or so in width. This is held round the commutator under the brushes and cut off so that both ends exactly meet. It should then be taken off, and the distance divided up into as many parts as there are brush spindles. The strip can then be put back on the commutator and the brushes all made to touch the line with their leading edges. It is essential for good operation that this is done exactly.

Cause 5. Commutating poles not in correct adjustment. Commutating poles are fitted to machines for the purpose of compensating for armature reaction set up by heavy overloads. As the armature reaction in converters is, to a certain extent, balanced, the commutating field is not required to be so heavy as for continuous current generators. Trouble from this cause will be manifested by the brushes sparking as the load comes on, that is to say, the commutation may be fairly good on normal loads, and objectionable at overloads. Whether this is due to a reduction in the power-factor by momentary overloads may be investigated by giving the brushes a forward lead. This would tend to correct the condition, although it might be found that the commutation at no-load would then be interfered with. The amount of diverter resistance across the commutating poles should then be decreased by cutting out some of the strip, so as to allow more current to circulate around the commutating poles, and thus check distortion at the high loads. A good way of obtaining adjustment is to mark the brush position for sparkless commutation on low loads; shift the brush position to obtain sparkless commutation on the high loads; alter the diverter resistance by a small amount temporarily; and then move the brushes nearer to the low load neutral. From this it can be judged how much more of the diverter strip should be cut out in order to obtain the neutral point at high loads at the same place as the low load neutral, thereby enabling the machine to run with fixed brush position.*

Cause 6. High bars in commutator. It sometimes happens, when a commutator becomes heated up to some considerable extent, as may be the case when dealing with heavy loads, that a commutator bar may become loosened and project a very small amount above its neighbors. Such a condition manifests itself by a chattering noise at the brushes. It can sometimes be remedied by shutting down the machine, and tightening up the commutator bolts while the commutator is hot. If the same trouble shows up again, it will probably be due to defective material in the mica end cone. In this case the only remedy is to take the commutator down and put in a new mica cone. (See Review, July, 1911, p. 332.)

Cause 7. Eccentricity of commutator. If the commutator becomes eccentric from any cause the brushes chatter and sparking is caused, particularly on machines of fairly high speed; this can be remedied by removing the brush gear and grinding the commutator until true.

Cause 8. Uneven air gaps. This defect has been already dealt with (Section 4, Division 6).

Cause 9. Grooving of commutator. Most machines are provided with end-play devices, either of the mechanical or magnetic type. If there is any tendency for grooves to wear on the commutator, it is probably due to the end-play device not being in proper working order, or not working at all. It should therefore be carefully adjusted so that the armature has a swing of about 3/8 in. to and fro.

Cause 10. Reversed armature coil. This condition may be met when an armature is repaired and a new coil may be accidentally connected up the wrong way. It does not usually manifest itself very plainly. In some cases it causes a spark at the particular commutator segment to which it is connected, which can be noted by a black edge on that segment when the machine is at rest. The defective point can best be found by passing a small current through the armature of the machine through one pair of brush spindles with the other brushes raised from the commutator and slip rings. Voltage drop readings should be taken with a milli-voltmeter or other low reading instrument between each pair of commutator segments. It will be noted that reverse readings (which will recur at regular intervals) are obtained, corresponding to the number of poles of the machine, or the number of armature circuits in its winding. If an intermittent reverse reading is obtained whose distance from the starting point is not a multiple of the number of poles, then this

* Manufacturers have various methods of their own which may be applied in the test room or on site for adjusting the commutating poles, which are considerably superior to this method as regards general accuracy. This "cut-and-try" method has the advantage of requiring no special testing appliances, and may be quickly performed.—Editors.

represents a reversed coil. The coil should be unsoldered from the commutator lugs and the leads reversed and soldered up again. This error is only likely to occur on machines with armatures having wound coils, as in bar wound machines it is practically impossible to connect the coils in the reverse direction.* The effect of such a condition is to lower the voltage of the particular section which is being commuted, by the fact that the reversed coil opposes and neutralizes another coil having the same number of turns as itself. The effect is then equivalent to leaving out two of the armature coils between certain positive and negative points which are being commuted, with a resulting voltage drop over that particular section. A circulating current is then set up, which flows either from the other brushes, or through the equalizing rings so as to make the potentials balanced.

Cause 11. Reversed field coil. When reconnecting the field of a converter it may sometimes happen that a field spool is reversed; and this will manifest itself by the fact that the induced voltage of the converter will be reduced across a certain pair of brushes, since the poles, being of incorrect polarity, will have an effect somewhat like that of a booster, by opposing some of the circuits. This will be attended by bad sparking; and a circulating current, due to this difference of potential, will flow through the brushes or the equalizer rings, in order to restore the balance of potential between each pair of brushes; some paths in the armature will be operating at full voltage, since the polarity of certain poles is correct, while in others there will be a reversed direct current potential due to the reversal of the polarity of a certain pole. When for any reason the field spools have once been disconnected and pulled down, it is a good plan to avoid the possibility of a reversed coil by testing out the polarity before the machine is again set to work. This may be done in the usual way, by passing a direct current through the field spools and testing with a bar of iron.

Sparking at Starting

In commutating pole machines objectionable sparking is sometimes experienced when the converter is started up from the alternating current side by means of a compensator or transformer tappings; and although sometimes a temporary improvement may be effected by adjustment of the brush position before starting and again when the converter is up to synchronism, it is generally necessary to use a separate starting motor, or to employ a brush lifting device for starting. Care should be taken that the field circuit is always disconnected from the direct current side when starting. It is also necessary to make sure that the direct current side is open, and not connected to any of the apparatus which usually works from it; as the potential across the direct current brushes is an alternating one until the armature is up to synchronism, and the frequency of reversal is equal to that of the slip.

* Practically all of the converters now manufactured by the General Electric Company have bar-wound armatures.—EDITORS.

SECTION 6. DIFFICULTIES WITH STARTING

Div. 1. Failure of Machine to Start from A-C. Side

In the case of machines being started with compensators it may happen that the compensator winding is open-circuited on one phase; the machine will fail to start as it is on single-phase. This will be indicated by two of the ammeters on the supply side of the machine reading zero. The same trouble is possible where machines are started from transformers, in which case the lead may become accidentally disconnected while the machine has been standing. Where the converter is started by external means, failure to start may be traceable to the fact that one of the stator phases of the starting motor has become disconnected or otherwise open-circuited, the machine being left on single-phase. This applies to machines started with both squirrel cage and slip ring motors. The trouble may be investigated as described in the previous article on induction motors. (See G.E. REVIEW, Nov. 1911.)

Div. 2. Short-Circuit at Starting

Where converters are used on the Edison 3-wire system on the direct current side, the neutral is made to return at the neutral point of the transformers; and in 4-phase machines running from 2-phase circuits, or in 6-phase machines running from 3-phase circuits having diametrical or double-star connected secondaries, the neutral point must be opened up while starting. That is to say, the middle points of all the windings should be broken up or otherwise a short-circuit will result; since, during the starting period when the machine is not moving synchronously with the supply current, certain portions of the winding of the armature constituting certain phases may be supplied with maximum phase voltage when they are in a position generating minimum back e.m.f., i.e., when a phase is between a pair of poles. When running of course the phase voltage is always minimum when in this position under synchronous conditions. A 2-pole switch is generally used for breaking up the two diameters of connections in 4-phase machines; a 3-pole switch for breaking up the three diametrical phases of a 6-phase machine; and a 2-pole switch for breaking up the connections between the two star points in double star machines. The hinges of the switch are all joined together so as to form a connection for the neutral direct current lead.

Div. 3. Heavy Current at Starting When Machines are Started from the A-C. Side from Transformers

In starting 6-phase machines it may happen that a large current is taken from the line in one particular phase. This may be due to the phase rotation of the supply not coinciding with that of the machine itself, in which case one phase of the machine would be 180 deg. out of phase with one of the line phases, and would hence be on short-circuit. This would be indicated on the ammeters, and the phase in which the heavy current is taken should be reversed and another start made. This applies more particularly in connection with 6-phase diametrically connected machines.

SECTION 7. DIFFICULTIES WITH SYNCHRONIZING

Div. I.

Machines started up *by external means* need to be synchronized as in the case of alternators. The frequency of the back e.m.f. is only equal to the line frequency when the converter is up to speed; whereas in machines self-started from the alternating current side the poles are magnetized by a revolving field of a frequency equal to that of the slip, and hence the back e.m.f. has a frequency equal to the line at all speeds. If machines are synchronized by the dull lamp method with lamps arranged in each phase, and there is a flashing in the lamps in and about one another (i.e., when the lamps are never all bright or all dull together), it is evident that the phase rotation is incorrect with respect to the line. It is then necessary to shut down the machine and correct the phase rotation. On a 2-phase machine one pair of leads should be changed over, belonging to one phase. On a 3-phase converter any pair should be interchanged; while for a 6-phase machine both ends of a pair of phases should be changed, i.e., four leads belonging to two different phases.

Div. 2. Erratic Synchronizing When Using Dull Lamp Method

Unless a synchronizing transformer is used the dull lamp method is the only lamp method that can be adopted for synchronizing; and on some machines, with a tendency towards instability, synchronizing with lamps at all may be found rather difficult under normal conditions. The use of metallic filament lamps instead of carbon lamps may assist matters, as with the latter there may be quite an appreciable voltage across the lamp with no apparent illumination; that is to say, the machine may be out of phase to a considerable extent when the lamps indicate no apparent phase displacement. Synchronizing on machines that have a tendency to be unstable may be further assisted by synchronizing at a less power-factor than unity; that is, by closing the switch when the lamps are dull, but with a voltage on the converter slip rings of less or more than line voltage. This should not exceed 15 or 20 per cent., i.e., 85 or 80 per cent. power-factor.

Div. 3. Erratic Synchronizing When Using Synchroscope or Bright Lamp Method

When putting to work a synchroscope or synchronizing transformer provided with bright lamps, it may be found that the converter does not parallel properly, but that it blows the circuit breakers when the paralleling switch is closed. The connections should be checked up by means of an alternating current voltmeter. It is best to do this before attempting to synchronize. With one of the switch blades of the paralleling switch connected to its corresponding hinge, the voltage should be taken between one of the other switch blades and the corresponding hinge when the converter is up to speed, and the synchronizing lamp bright, or the pointer of the synchroscope indicating synchronism. The voltage measured across the points mentioned should then be zero. If it is not zero, or nearly zero, the connections of the field coil in the synchroscope should be reversed; or, where lamps are used, the secondary of the synchronizing transformer should be reversed.

Div. 4. Difficulty of Obtaining Adjustment when Synchronizing on Externally Started Machines

Machines started by squirrel cage motors are provided with a loading resistance which is temporarily connected across the slip rings of the converter. This resistance receives power from the converter which operates for the time being as an alternator; and thus prevents the squirrel cage motor (which has a pair of poles less than the converter) carrying the speed very far beyond the synchronizing speed of the latter. Small adjustments to speed are made by altering the field excitation, which changes the load; and if difficulty is found in getting the speed to settle, more of the loading resistance should be switched in, so as to enable the field of the converter to be worked at a higher density, giving more positive adjustment. This also applies to machines started by a slip ring induction motor, the speed of which is primarily adjusted by rotor resistance, and afterwards by field adjustment. It will here be noted that the machine must be synchronized at the voltage which exists on the converter, as it is adjusted into phase by the shunt field, which, in most cases, is at a power-factor something below unity. The excitation should afterwards be correctly adjusted when the machine is paralleled. With the slip ring machine no loading resistance is provided, but speed adjustment is obtained by field adjustment or hysteresis drag.

SECTION 8. DIFFICULTIES OF PARALLEL OPERATION

Div. 1. Effect of Wave Shape on Parallel Operation of Converters

Bad parallel operation and kindred faults are sometimes put down to difference of wave shape of the converter from that of the supply generator. Broadly speaking, however, no serious difficulties in ordinary commercial operation have been traceable to this cause. One respect in which difference of wave forms affects a converter is in preventing a power-factor of unity being obtained on the converter. When minimum alternating current input amperes is obtained the alternating current volt amperes are not found to be equal to the direct current watts *plus* losses. That is to say, owing to the fact that the wave of back e.m.f. does not coincide with the impressed wave, the current that flows, due to the potential existing in one wave and not appearing in the other, is a magnetizing current; this current sets up flux which cannot be overlapped by field flux in the converter, since the distribution is different from the supply wave. The minimum input alternating current amperes then determines the maximum power-factor, which is not necessarily unity.

Div. 2. Polarity of Converters Wrong when Starting from A-C. Side

This trouble sometimes happens where machines are working in parallel and are started from the alternating current side. It is observed that the paralleling voltmeter reads double volts instead of zero. The field-split switch on the converter should be withdrawn and placed in the bottom position, which reverses the field of the converter. This should be done while the machine is running on the tappings of the transformer or compensator, and not when running from full supply voltage; as otherwise a large magnetizing current will be taken which will perhaps affect other apparatus on the line by causing the voltage of the system to drop. As soon as the pointer of the paralleling voltmeter crosses the zero mark, the field switch should be withdrawn and put in its top position. The effect of this is to retard the armature to the extent of one pole-pitch, where it then gains its correct polarity; and it will then be opposing the busbar voltage on the direct current side instead of helping. When this has been done the alternating current side can be switched on to full voltage. If the converter is not operating in parallel with others wrong polarity will be indicated by the direct current meters reading the wrong way. It is advisable to have this changed, as it may interfere with the circuit connections.

Div. 3. Series Field of Converter Bucking

If a converter is operating alone this can be found by putting the machine on load, when the direct current volts will drop. If the converter is operating in parallel with others it must not be put on load without first ascertaining if the series field is magnetizing in the proper direction. To do this the equalizer switch and the negative line switch should be closed, and note made as to whether the direct current volts rise across the open armature. If so, the machine may be paralleled; if not, the series field must be changed over. The machine should be shut down to do this unless a series field reversing switch is provided.

ELECTRICITY IN EXCAVATION WORK

By W. C. Lancaster

Assistant Manager, The United Engineering and Contracting Company

The failure of central stations in most cases to offer proper rates, the disinclination of the manufacturer of contractors' machinery to adapt his machines to motor drive, and the reluctance on the part of the contractor to abandon his timeworn friends, steam and compressed air, have been largely responsible for the delayed application of electric power to excavation and construction work. The author shows that as a motive power for most of the operations involved, electricity is much superior to either steam or compressed air, particularly as regards flexibility in transmission, ease and certainty of control, and cost. Several installations with which the author has been connected in a professional capacity and in which the electric motor has been used with pronounced success, both from an operating and economical standpoint, are described and illustrated.—Editors.

Why have general contractors been slower than men engaged in other industries to use electricity for power purposes within its proper field of usefulness? There are few industries to which the electric motor is better suited than to excavation work, yet a few years since, a contractor about to undertake the moving of large masses of material would have received with incredulity the suggestion that his machinery could profitably be driven by such motors.

When the New York subway was built, about 1901, only a small amount of current was used for power purposes. For digging this subway, the contractors erected steam driven compressor plants. These plants were noisy, they ejected steam, smoke and cinders, and in the opinion of the neighborhood constituted a nuisance for which damages could be collected in the law courts.

In the driving of the high pressure water tunnel, and in the building of the new subways now under construction more than 90 per cent. of the machinery is driven by electric motors. These motors do their work so quietly that they do not disturb the neighborhood, and they are housed in sheds so small that they give no indication of the magnitude of the work. This is a complete change in the motive power used in excavation work. To one conversant with electric power, the surprise is not that this change has come, but that it has been so long in the coming.

The delay in introducing electricity into construction work is chargeable to the electric central stations, to the manufacturers of contractors' machinery, and to the contractors themselves. The electric central stations did not allow the contractor minimum rates, because of the temporary nature of his plants. These companies have, with time, learned the effect of these plants, operating usually twenty-four hours a day, on their load curve, and consequently have kept reducing their prices. A contractor can now purchase electric power in many localities cheaper than he can make it.

The manufacturer of contractors' machinery continued for a long time to recommend mechanical drive, for he understood it, and if he happened to use a motor very likely hit upon one unsuited to his machine. But knowledge has come to him with experience, and he now recommends electric drive and selects the right type of motor.

The contractor felt a natural reluctance to abandon the steam and air driven machinery, well understood by him, and to rest the successful completion of a large contract on a form of energy of which he had no practical knowledge. Even when he took the step and used electric motors for driving a hoist, mixer, or air compressor, he did not do as he would have done had he used steam, that is, employ experienced engineers to lay out the work; but gave the installing and care of the motors to men inexperienced in this work. Trouble was the usual result. The mechanics did not know what to do in the emergency, and as its failure was costing money by delaying the progress of the work, the motor was usually pronounced "no good" and replaced by a machine which the contractor's employees knew how to handle. This change was made usually without giving the manufacturer an opportunity to investigate the trouble, because the work could not be delayed.

Some of the more progressive contractors have learned to employ an experienced engineer or electrician to assist in determining whether a given piece of work can be done more cheaply by steam, by air, or by electricity. The question is regarded as a commercial one; that is, the striking of a balance between the first cost, the operating cost, the maintenance, and the salvage of his machines driven by electricity as against the same machines driven by some other form of motive power. As these factors differ in every case, no set rule can be laid down when the one or the other form of power should be used.

The success or failure of a contract may depend on the proper solution of this question, and consequently, it is economy for a contractor to have it passed upon by the most competent authorities.

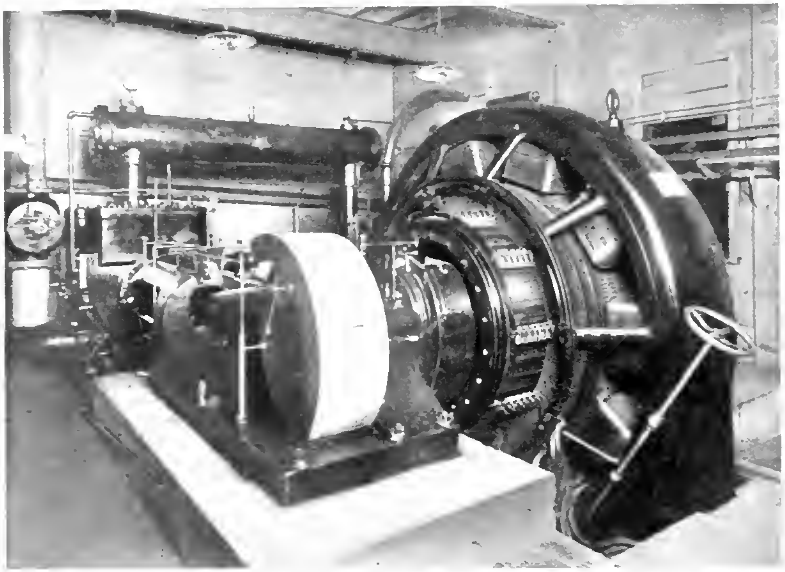


Fig. 1. 480 H.P., 230 Volt D-C. Motor Direct Connected to Laidlaw-Dunn-Gordon Company's 32x20x30 In. Air Compressor

The writer proposes in this paper to give a brief description of some of the electrical installations on large construction work with which he has been connected in a professional capacity. These illustrate a few of the advantages to be gained by adopting electricity as a motive power.

Air Compressors

Fig. 1 shows one of the 2900 cubic foot air compressors used in the construction of the Pennsylvania Railroad crosstown tunnels, New York City. Compressors of this type, direct connected to electric motors, occupy a much smaller floor area than do steam-driven compressors of the same capacity, for they do not require boilers, condensers, auxiliary apparatus, and space for the storage of coal. In this case the plant had to be located in the hotel and theater section of the city, where real estate values were high, and it was important to save every possible square foot of space. It was for this reason that electric compressors were selected. The idea of using electricity for the air compressors worked out so well that it was carried further and electricity used for driving all the machinery.

This saving in space, however, is by no means the only economy that may be effected. Fig. 2 shows a large air compressor plant used for the work of enlarging the Erie Canal near Lockport, New York. In this instance space was unlimited. Coal was cheap and water plentiful. Yet it was found that the installation and the operating cost of a steam plant, with condensers, would have been more than the corresponding costs of an electric plant; and further, as this was a state contract, it was necessary to work eight hour shifts, making the labor unusually high; but

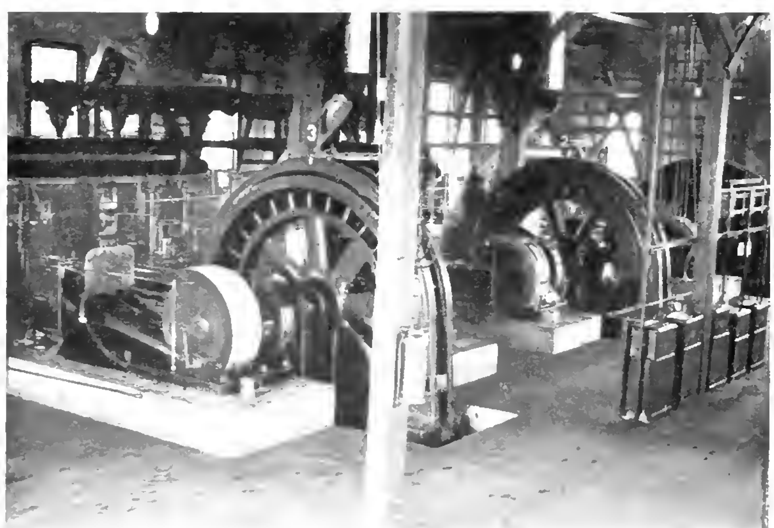


Fig. 2. 500 H.P., 2200 Volt Synchronous Motor Direct Connected to 32x20x30 In. Air Compressors. The United Engineering & Contracting Company, Barge Canal Contract 40, Lockport, N. Y.

by using electric compressors, the whole of the boiler-room pay-roll would be eliminated. It was decided, therefore, to purchase electric current from the Niagara, Lockport & Ontario Power Company, whose transmission line crosses the work. At present only one man to a shift runs the entire compressor plant without the aid of even an oiler. Further saving results from the use of less oil because of the absence of steam cylinders, and from fewer repairs because of fewer wearing parts.

Figs. 1 and 2 show compressor units of high efficiency, designed to use the smallest possible amount of electric energy in proportion to the output of compressed air. These compressors are suitable for work extending over a considerable length of time, the first cost of the machine thus becoming small compared with the total cost of electric energy consumed in running it. On a short job, however, the saving in cost of electric current consumed by a highly efficient and, therefore, high priced compressor over that used by a less efficient machine for the short period it is in operation frequently does not justify the additional outlay. In these cases, when the floor space is ample, a belted compressor can be used to advantage. An air compressor of this description that was used in driving a short water tunnel near Shelburne Falls, Mass., is illustrated in Fig. 3.

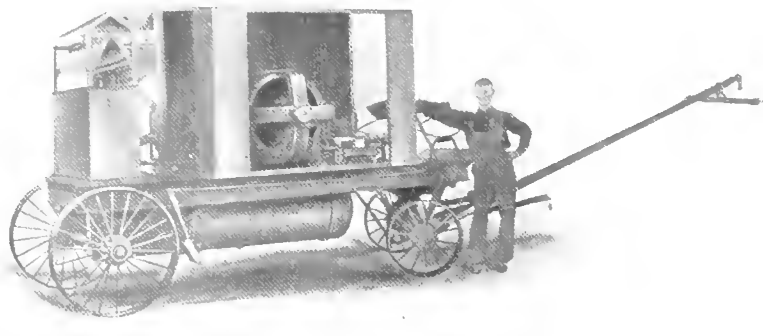


Fig. 4. 35 H.P., 500 Volt D-C. Motor Geared to Ingersoll-Rand 10x10 In. Portable Air Compressor, Havana, Cuba

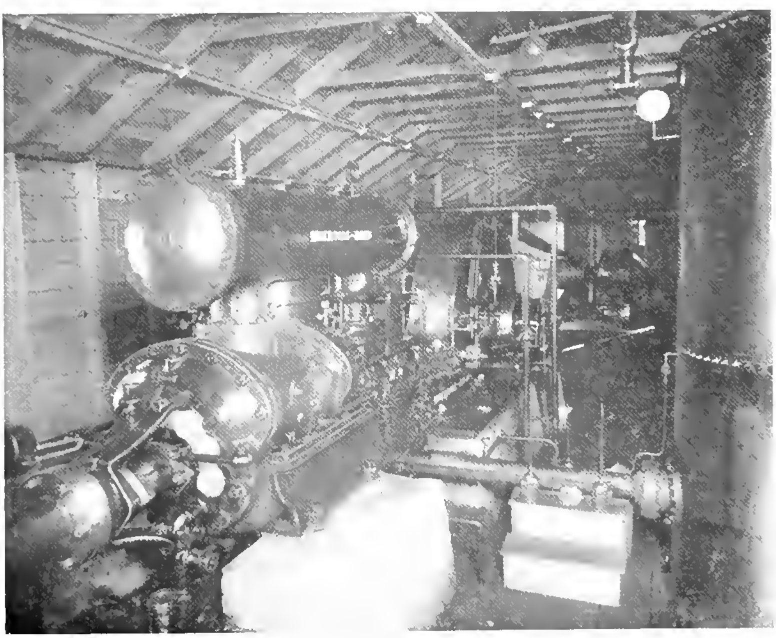


Fig. 3. 200 H.P., 2200 Volt Induction Motor Belted to Ingersoll-Rand 20¼x13¼x18 In. Air Compressor. Frazer Brace & Co., Shelburne Falls, Mass.

In Fig. 4 is shown a portable electric compressor of about 250 cubic feet per minute capacity. This compressor furnishes air for hand rock drills and small pumps used in excavating sewer trenches in the city of Havana, Cuba. It is light and easily moved along as the work progresses. The motor receives current from the nearest overhead trolley wire.

Hoists

The hoist in some form is perhaps more widely used in excavation work than any other class of machinery. Its uses are many and varied, and for practically all of them the electric drive is suitable. In cases where the space available is small there is great advantage in using electricity rather than steam. Fig. 5 shows a dock, at 35th Street and the East River, New York City, where were handled all the rock excavated and concrete material used during the construction of the Pennsylvania Railroad crosstown tun-

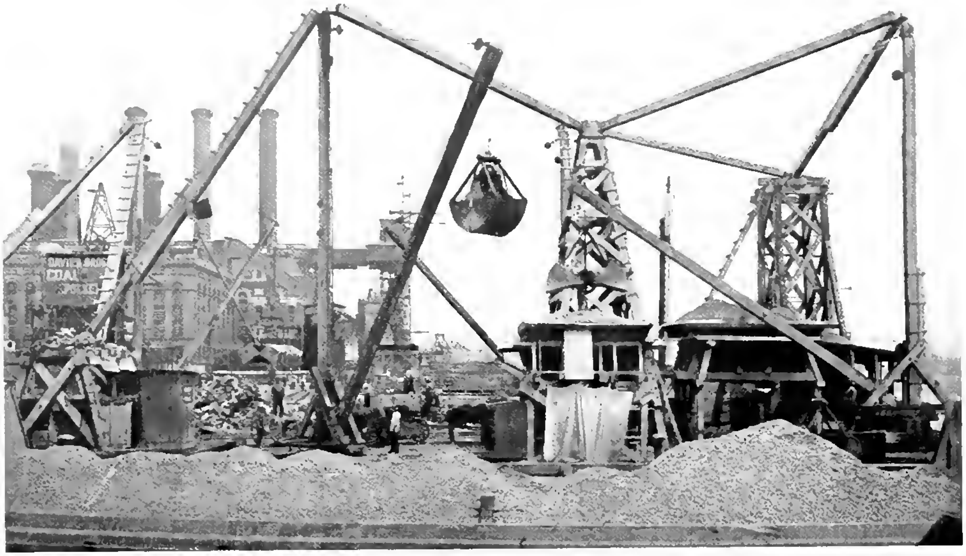


Fig. 5. Electric Derricks, East 35th Street Dock. The United Engineering & Contracting Co.

nels. On the far side may be seen two derricks dumping the excavated rock from the special dump buckets into barges alongside, and in the foreground two derricks with clam-shell buckets unloading a scow of broken stone into an overhead bin. This dock is only 60 by 150 feet. Had these four derricks been steam driven, a much larger space would have been required to accommodate the boilers and leave room for the storage of coal.

Another material saving in the operating cost of nearly all electric hoists is the saving in firemen's wages, the extra labor required to clean the boilers at regular intervals, and to get up steam before the engineer arrives. With the electric hoist, the engineer can give his whole time to keeping his hoist in good shape, since he need not attend to the fires himself nor see that his fireman is attending to them.

The type of boiler used on a contractor's hoist is wasteful of coal and the exposed location where the hoist usually has to be

Fig. 6. 90 H.P., 550-230 Volt D-C. Motor Geared to Lidgerwood Mnfg. Company Mine Hoist. Smith, Hauser, Locher & Co. Catskill Aqueduct Contract 66, New York City

placed does not tend to lessen the coal bills. On the other hand, the efficiency of the electric hoist is not affected by weather conditions.

The time that the hoist is actually lifting its full load is usually small compared with the time that it is idle. This difference is greater than many contractors realize. In the case of steam hoists, steam at full pressure must be always in readiness, a large part of the heat energy of the coal going to waste up the stack. In the case of the electric hoist, current is used only when the motor is hoisting, and then no more than enough consumed to do the work at hand, whether the load be a heavy or light one. Sufficient energy is always in the wires to do the heavy work instantly whenever the occasion demands it. There is no waste. All the current paid for is used to run the hoist.

An electric hoist of the type known as a "mine hoist" is shown in Fig. 6. This hoist is used for operating the cages in a shaft 250 feet deep on the Catskill aqueduct in New York City.

Fig. 7 shows a cantilever bridge for canal work, on which runs an electrically operated carriage from which a drag bucket is suspended. This bucket digs the canal bank, transports the earth up the incline, and dumps it from the upper end, forming a "spoil pile" parallel with the canal. As fast as the excavation is completed, the crane moves forward under its own power.

Fig 7. Cantilever Crane Operating Drag Bucket made by Brown Hoisting Machinery Co. 225 H.P., 400 Volt Induction Motor. The United Engineering & Contracting Company, Barge Canal Contract No. 40, Lockport, N. Y.

Fig. 8. Monorail Hoists Operated by One 75 H.P. and One 15 H.P. Motor. The United Engineering & Contracting Co., New York City

Fig. 8 shows the special monorail hoists, known as "telphers" loading buckets of rock on wagons. These buckets are shown on the dock, Fig. 5. They are hoisted from the tunnel by the telphers, and transported horizontally to the street. By these means the disposal of the excavated material, which is loaded into the buckets at the tunnel headings, is accomplished without re-handling and therefore with minimum labor and minimum noise.

In Fig. 9 is another type of monorail hoist now in use for building sewers in Havana. The A-frames supporting the I-beams along which the hoist travels can be easily moved from the rear and placed in front as the work progresses.

The types of hoists illustrated in Figs. 8 and 9 could not readily be run by any other power than electric.

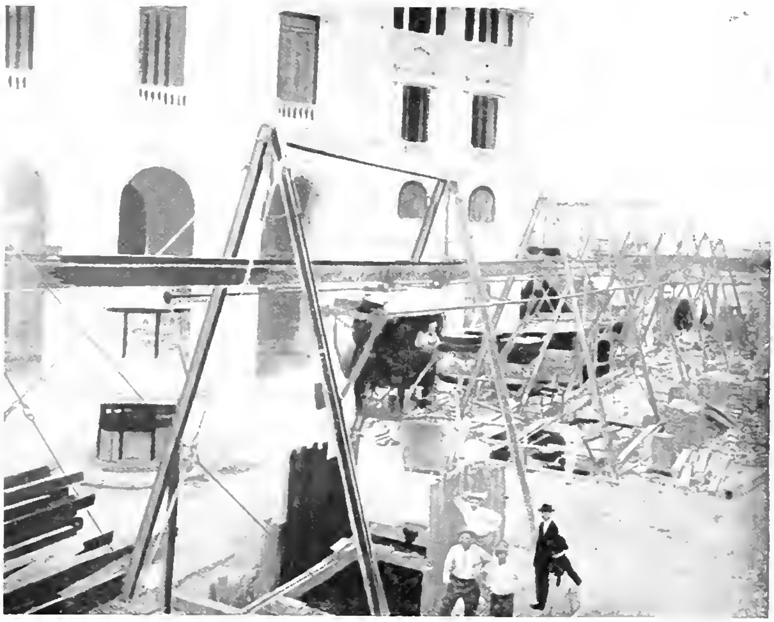


Fig. 9. Portable Monorail Hoist with 10 H.P., 500 Volt Motor. Cuban Engineering & Contracting Company, Havana, Cuba

These are excellent examples of machines designed especially for work of such nature that the standard types of machinery are not suitable. They show the flexibility of electric power.

Pumps

The type of pump particularly suited to motor drive is the centrifugal. On excavation work this type of pump is most successfully operated where a sump can be maintained and the water allowed to drain to it. When choice must be made between centrifugal pumps driven by electric motors and reciprocating pumps operated by compressed air, consideration shows the centrifugal pump to be the more economical. In the former case there are only the losses in the centrifugal pump, motor, and transmission wires, while in the latter case there are the losses in the reciprocating pump, air-pipe line, air compressor and steam engine or electric motor which drives the air compressor. The efficiency of reciprocating pumps, such as are used on contract work, may be taken as about the same as that of the best centrifugal pumps for the same work; but it is undoubtedly less when the pistons are worn and when the packing is leaky. The centrifugal pump with few wearing parts runs at nearly constant efficiency for a long period.

Concrete Mixers

It is often necessary, especially in tunnel work, to install the mixer near the point where the concrete is being placed, in a location that makes the use of steam for driving the mixer either impossible or inconvenient. Fig. 10 shows an electrically driven mixer at the foot of a tunnel shaft, where the use of steam would have been impractical. Compressed air could have been used, but when the concrete work was going on, the drilling had been completed and it would have been very wasteful of power to run the large air compressors for operating a few mixers.

Locomotives

A contractor on tunnel work who has always used mules for hauling out excavation and hauling in concrete little appreciates the advantages of electric locomotives. By taking on one trip a large number of cars at high speed, the rate of progress of the work is

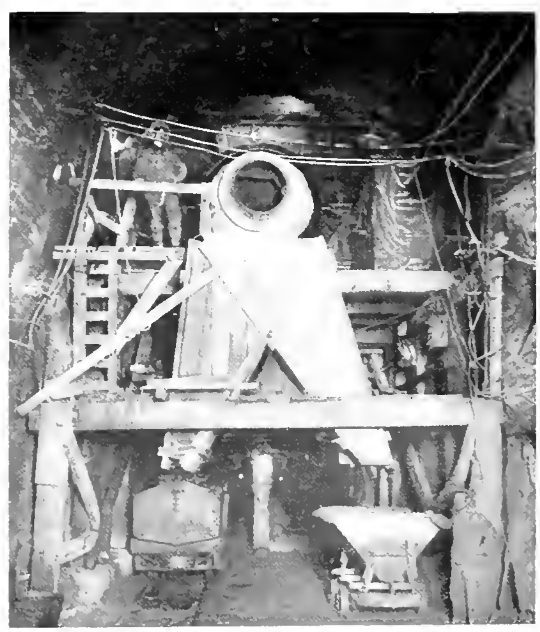


Fig. 10. Motor Driven Concrete Mixer. Engineering & Contracting Company. Pennsylvania Railroad Crosstown Tunnels, New York City

materially increased. A good many mules are required to do the work of one locomotive, and even this number must be doubled, as a mule must rest one shift out of two. Feeding and caring for mules, especially in city work, where space for a stable is expensive, is considerably more costly than the maintenance of locomotives and interest on the investment. Each mule must have a driver, but as one locomotive replaces a good many mules, one man can thus do the work of a large number of "mule-skinners." Accidents to mules are not infrequent and their death rate is high. The depreciation of a locomotive is small and a little overhauling and painting makes it as good at the close of the job as at the beginning. Fig. 11 shows an electric locomotive handling a train of concrete cars during the construction of the Pennsylvania Railroad tunnels already referred to. On top of the locomotive may be seen the cable-reel which permits the locomotive, when necessary, to run beyond the point where the trolley wires must stop.

Fig. 11. 10 Ton Electric Mine Locomotive
The United Engineering and Contracting Co., Pennsylvania Railroad Crosstown Tunnels, New York City

Transformers

Where electricity is purchased at a voltage higher than is safe for the wiring and for the motors, it is usually stepped down by means of transformers. An illustration of such an installation is given in Fig. 12. This shows the interior of the transformer and switchboard room at one of the shafts for the Catskill aqueduct tunnel, New York City. The New York Edison Company delivers the current at high voltage to this point, where it is transformed to a lower voltage and distributed over the work for lighting and power purposes.

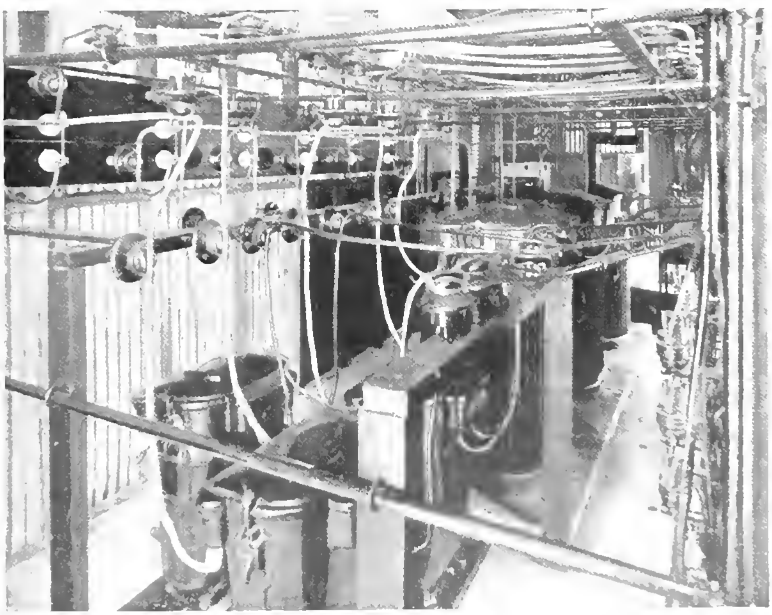


Fig. 12. Three 50 Kv-a., 6600/460 Volt Transformers for Power; Three 10 Kv-a. 6600/130 Volt Transformers for Lights
Smith, Hauser, Locher & Co., Shaft 14, Catskill Aqueduct Contract 66, New York City

Conclusion

In excavation work, the chief expense is the cost of labor, and any machine that cannot be relied on to run continuously and keep that labor employed must be replaced without regard to other advantages that it may possess.

The electric compressor in Fig. 1 was in use three years on the construction of the Pennsylvania Railroad Manhattan tunnels, and the work never lacked air. The electric compressors in Fig. 2 have been in use three years on the construction of the New York barge canal and this work has never lacked air. The dock hoists in Fig. 5 successfully handled all the excavation and all the concrete materials for the Manhattan tunnels of the Pennsylvania Railroad without delaying the work.

Contractors have to their own loss denied to electric power the consideration it deserves, for under certain conditions, the use of electricity may effect sufficient saving to change a losing contract into a profitable one.

ADVANCED COURSE IN ELECTRICAL ENGINEERING

Part I

By Ernst J. Berg

Professor of Electrical Engineering, University of Illinois

Introduction

The following articles are abstracts of a series of lectures, illustrated by problems, given to graduate students in electrical engineering at the University of Illinois, upon methods of determining transient conditions existing in electrical circuits. Such a course is intended to prepare the graduate for understanding and guarding against the dangers that may arise not only from abnormal conditions due to breakdowns of apparatus or lines, but also from normal, though sometimes extreme, conditions that may exist in the regular course of switching at the generating or the receiving station. While applicable especially to alternating currents many of the problems are first studied from so general a standpoint as to apply equally well to direct current, where instantaneous conditions alone are involved.

In a general way the scope of the course is that of Dr. Steinmetz's "*Transient Phenomena*"; but the mathematical treatment is essentially modified so that students with only a fair knowledge of fundamental mathematics can readily follow it, and thus later be in position to enjoy the concise and rapid elegance of Steinmetz's work.

In their undergraduate courses the students have become familiar with the symbolic or complex quantity method of rectilinear analysis of vector quantities. Besides the usual calculus course the students have had a short course in differential equations, imparting greater familiarity with the general processes of differentiation and integration; and some knowledge of series, especially of the application of the Fourier series, so fundamental in the analysis of complex wave forms of alternating currents. Properly taught, the calculus loses its imagined difficulties, and presents so beautiful and really simple a method of treating many problems as to appeal even to students who are not rated as mathematical "sharks". Fortunately the differential equations required for electrical problems are not numerous and their solution may be found in many standard mathematical texts, such as "*A Treatise on Ordinary and Partial Differential Equations*" by Johnson. With sufficient practical experience in the laboratory to recognize the underlying conditions and with that mathematical facility indicated, students solve with certainty and satisfaction many problems ordinarily looked upon as difficult or impossible of exact solution.

In this series of articles intermediate steps are generally omitted, and the result given at once. For convenience the general equations and their solutions will be collected and tabulated in the last of the articles.

The course opens with the study of circuits having resistance and inductance in series and in parallel. This inductance may be either mutual or self-inductance, and is to be distinguished from reactance, a term applicable only to the effect of inductance in a simple sine-wave alternating current circuit. In the more general problems of the application or withdrawal of an instantaneous electromotive force the term reactance is inapplicable either to inductive or capacity circuits. At the beginning many numerical problems are assigned, to make the student thoroughly familiar with the meaning of such terms as work, power, rate of change, etc. Later capacity effects are studied in series and parallel circuits with resistance and with inductance. Numerous problems are again assigned for circuits with resistance and capacity; but when inductance is also present relatively few well-chosen problems seem warranted, owing to the tedious intricacy of the equations and their solution, especially where alternating electro-motive forces are involved.

Problems concerned with the inductance due to turns surrounding iron cores, as distinguished from that due to turns alone, were found of especial interest. Such problems include the important consideration of the initial current upon closing a transformer primary upon the operating circuit. The use of the oscillograph in confirming the calculations is a part of the course; and also a consideration and calculation of the inaccuracies of the oscillograph due to the possible use of a current transformer in indicating the phenomena mentioned. Further problems will be brought out in these papers.

CIRCUIT CONTAINING RESISTANCE AND INDUCTANCE

The solution of problems of this class requires the knowledge of linear differential equations of the first degree.

$$\frac{dy}{dx}+ay=b \qquad (1)$$

where a and b are not functions of y, but may or may not be functions of x. The general solution is:

$$Y=\epsilon^{-\int a\,dx}\left(\int \epsilon^{+\int a\,dx} b\,dx+C\right) \qquad (2)$$

Frequently a is a constant, but b a function of x. In that case

$$Y=\epsilon^{-ax}\left(\int \epsilon^{+ax} b\,dx+C\right) \qquad (3)$$

Often both a and b are constants when

$$y=C\epsilon^{-ax}+\frac{b}{a} \qquad (4)$$

In these equations C is the integration constant which is determined from the nature of the problem.

It is evident that if $b=0$, that is, if the differential equation is:

$$\frac{dy}{ax}\pm ay=0, \qquad (5)$$

then

$$y=C\epsilon^{\mp ax} \qquad (6)$$

Again, if in the last case a were a function of x, the solution of

$$\frac{dy}{dx}-ay=0$$

would be

$$y=C\epsilon^{+\int a\,dx} \qquad (7)$$

which solution is evident from equation (2) when a is negative and b zero.

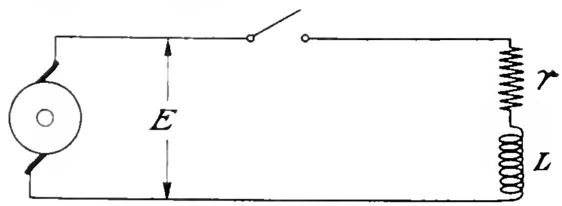


Fig. 1

Consider First the Case of Starting a Current from a Source of Constant Potential E

The following e.m.f's exist:

First, the impressed e.m.f., E

Second, the e.m.f. consumed by resistance $=ir$

Third, the e.m.f. consumed by self-inductance $\frac{N}{10^8}\frac{d\phi}{dt}$, or $L\frac{di}{dt}$

Where E is the constant impressed e.m.f. in volts,

r the resistance in ohms,

N the number of turns of the coil,

L the inductance in henrys,

$\frac{d\phi}{dt}$ the change of flux at a particular instant, and

i the current in amperes at any particular instant.

(The e.m.f. consumed by self-inductance can be expressed as $\frac{N\,d\phi}{10^8dt}$ or $L\frac{di}{dt}$ because the inductance by definition is:

$$L=\frac{N\phi}{10^8i}$$

thus

$$\frac{N\,d\phi}{10^8dt}=L\frac{di}{dt} \qquad (8)$$

We have then at any instant

$$E=ir+\frac{N}{10^8}\frac{d\phi}{dt}, \qquad (9)$$

$$\text{or } E=ir+L\frac{di}{dt} \qquad (10)$$

That is, at any instant the impressed e.m.f. E is numerically equal to the e.m.f. consumed by the resistance and the e.m.f. consumed by the inductance. Note that we deal with e.m.f's *consumed*, not e.m.f's of resistance and self-induction respectively, which would have been $-ir$ and $-L\frac{di}{dt}$.

Equation (10) can be written

$$\frac{di}{dt}+\frac{r}{L}i=\frac{E}{L} \quad (11)$$

Compare this equation with (1) and note that $a=\frac{r}{L}$ and $C=\frac{E}{L}$ are constant and not functions of t. Thus the solution is found in equation (4) and

$$i=C\epsilon^{-\frac{r}{L}t}+\frac{E}{r} \quad (12)$$

The integration constant C is determined from the fact that time is required to produce or alter a magnetic field.

Before the switch is closed there is obviously no field surrounding the turns. Shortly after, however, there is a current and thus a field which appears simultaneously with the current.

Thus since a magnetic field cannot be produced instantaneously no current can pass at the very first instant. Thus for $t=0$ $i=0$. Therefore

$$0=C\epsilon^{-\frac{r}{L}0}+\frac{E}{r} \quad (13)$$

but

$$\epsilon^0=1$$

therefore

$$0=C+\frac{E}{r} \text{ and } C=-\frac{E}{r}$$

and

$$i=\frac{E}{r}\left(1-\epsilon^{-\frac{r}{L}t}\right) \quad (14)$$

This equation shows that as t increases the current increases and finally reaches a value

$$i_f=I=\frac{E}{r} \quad (15)$$

Assume now that after the current has reached this value the circuit is disconnected from the generator and at the same instant short-circuited. What can be expected to happen?

The Dying Away of a Current in an Inductive Circuit

Since the coil is surrounded by a magnetic field and the field cannot be destroyed instantaneously, and since furthermore the magnetic field cannot exist without a current, it is evident that the current cannot disappear instantaneously but must die away gradually.

Referring to equation (10) and Fig. 2, since there is no impressed e.m.f., $E=0$. Thus

$$0=ir+L\frac{di}{dt},$$

or

$$\frac{di}{dt}+\frac{r}{L}i=0. \quad (16)$$

The solution of this equation is given in (5). It is

$$i=C\epsilon^{-\frac{r}{L}t} \quad (17)$$

To determine the integration constant, C, it is remembered that for $t=0$, $i=I$. Thus

$$I=C, \text{ and } i=I\epsilon^{-\frac{r}{L}t} \quad (18)$$

In this equation I is the current in the circuit at the instant of switching.

The rate at which energy is transferred is in engineering called power. It is $P=\frac{dW}{dt}$, where dW is the work done in time dt. The practical unit of power is the watt, which is work done at the rate of one joule per second. At any instant the power is the product of the instantaneous values of e.m.f. and current.

Thus the power equation corresponding to equation (10) is

$$Ei=i\times ir+i\times L\frac{di}{dt}$$
$$=i^2r+Li\frac{di}{dt} \quad (19)$$

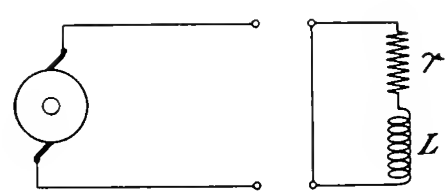


Fig. 2

It is seen from this equation that when the instantaneous value of the current is i, energy is being dissipated at the rate of i^2r joules per second, or watts, in heat, and is being stored in the magnetic field at the rate of $Li\frac{di}{dt}$ watts. The energy that has been supplied to the circuit t seconds after the switch is closed and the current started is:

$$\int_0^t Eidt \quad \text{joules} \qquad (20)$$

The energy dissipated in heat

$$=\int_0^t i^2rdt \qquad (21)$$

and the energy stored in the magnetic field

$$=\int_0^t Li\frac{di}{dt}dt = L\int_0 idi = L\frac{I_0^2}{2} \qquad (22)$$

where I_0 is the particular value of i when the time is t.

In almost all calculations of transient phenomena the expression ϵ^{-ax} is met with. ϵ is the base of the natural logarithm system. It is numerically approximately 2.718. To calculate the numerical value of any particular expression the ordinary logarithms are used. Thus, for instance, to find the numerical value of $y=\epsilon^{-.2}$, the method is as follows:

$$\log y = -.2 \log \epsilon = -.2\times 0.434 = -.0868 = .9132-1$$

therefore

$$y=.819$$

therefore

$$\epsilon^{-.2}=.819$$

Fig. 3 gives the values of this function for a large number of values of the exponents. Since this curve is plotted on rectangular co-ordinate paper, it is rather unsatisfactory for small values of the exponent, and the table below has therefore been worked out.

Numerical Example No. 1.

A coil having 1000 turns and 5 ohms resistance is connected to a source of constant potential of 100 volts.

(a) Show at what rate energy is being delivered to the entire circuit and to the resistance. Show at what rate it is being stored in the magnetic field as the current is increasing after the circuit is closed.

(b) What is the rate of change of the flux when the current is 10 amps?

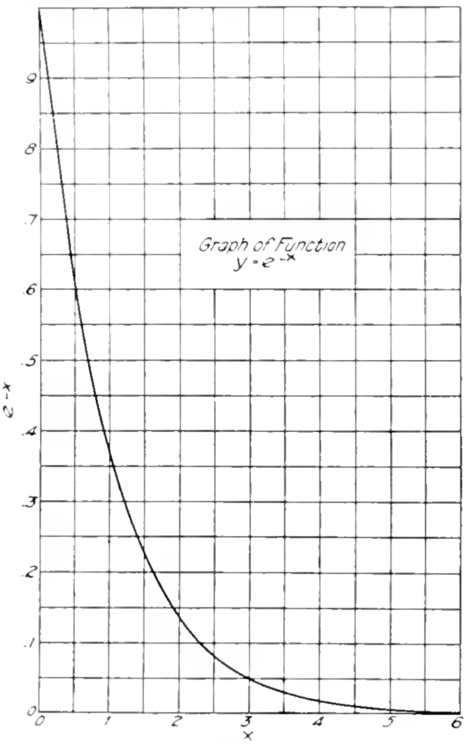


Fig. 3

Referring to equation (9)

$$E=ir+\frac{N}{10^8}\frac{d\phi}{dt} \qquad (23)$$

therefore the rate of energy supply to the entire system is Ei watts

and

$$Ei=i^2r+\frac{Ni}{10^8}\frac{d\phi}{dt} \qquad (24)$$

The current will begin at zero value and finally reach a value of

$$i=I=\frac{E}{r}=20 \text{ amp.}$$

x	e^{-x}	x	e^{-x}	x	e^{-x}	x	e^{-x}
.00	1.	.25	.78	.80	.449	1.8	.165
.02	.98	.30	.741	.85	.427	2	.135
.04	.96	.35	.705	.90	.407	2.5	.084
.06	.942	.40	.67	.95	.387	3	.05
.08	.923	.45	.638	1.0	.368	4	.018
.10	.905	.50	.607	1.1	.333	5	.0067
.12	.887	.55	.577	1.2	.301	6	.0025
.14	.870	.60	.549	1.3	.273	7	.0009
.16	.852	.65	.522	1.4	.247	8	.00034
.18	.835	.70	.497	1.5	.202	9	.00012
.20	.819	.75	.472	1.8	.165	10	.00004

At any particular value of the current i the rate of change of the flux $\frac{d\phi}{dt}$ is $\frac{E-ir}{N\times10^{-8}}$. Therefore the rate of energy supplied by the generator is Ei watts.

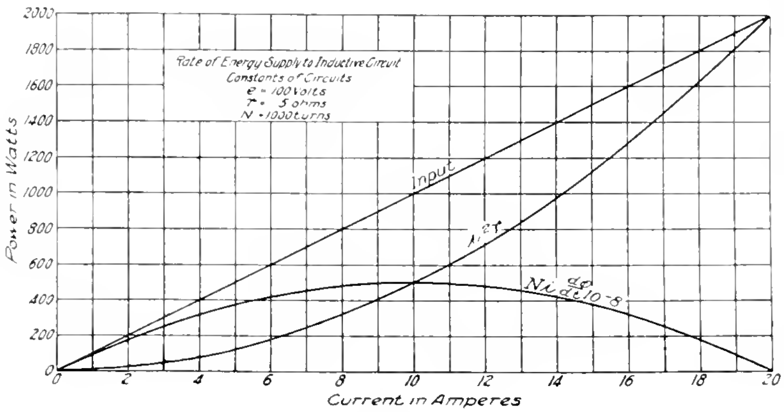


Fig. 4

The rate of energy dissipated in heat is i^2r and the rate at which energy is stored in the magnetic field is

$$\frac{Ni}{10^8}+\frac{E-ir}{N\times10^{-8}}=i(E-ir)=Ei-i^2r \quad (25)$$

The three curves in Fig. 4 show these rates.

It is interesting to note that energy is being stored at the greatest rate when the current is one-half of the final value. This can readily be proven by differentiation of equation (25)

$$E-2ir=0$$

therefore

$$i=\frac{E}{2r}=\frac{I}{2}$$

The rate of change of the flux as the current changes is obviously $\frac{d\phi}{dt}=\frac{E-ir}{N\times10^{-8}}$. Therefore when the current is 10 amps. the rate of change is 5,000,000 lines per second. The rate of change is greatest at first and becomes zero when the current reaches its final value.

The determination by calculation of the inductance L of a circuit is usually very difficult, in fact almost impossible except in the very simplest cases, such as parallel long circular conductors. Approximations of one nature or another have almost always to be resorted to. Usually the inductive circuit contains iron, and in that case it is not constant but changes with the degree of magnetization. Later in this series of papers the effect of the changing inductance in iron circuits will be considered, but at present it shall be assumed that L is a constant regardless of the value of the current.

The inductance of the field circuit of a dynamo can readily be determined for any particular field current by experiment. All that is needed is to run the machine at some speed and to read the voltage and field current. These data in connection with the data of the field and armature winding suffice. By definition

$$L=\frac{\text{total flux}\times\text{turns}}{\text{current}\times10^8} \quad (26)$$

The total flux per pole is determined from the voltage, speed and armature winding. Consider a 10 kw. two pole direct current 110 volt generator, having 2.5 megalines of flux per pole, and 1500 field-turns per pole. Assume that at normal voltage its field current is 3 amp. and that the field spools are connected in series.

Thus

$$L=\frac{2.5\times10^6\times1500\times2}{3\times10^8}=25 \text{ henrys.}$$

Let the field resistance be 36.5 ohms.

Example No. 2.

Figs. 5 and 6 represent the direct current generator referred to above. M is the armature and F the field. If a voltmeter of 11,000 ohms resistance is connected as shown and

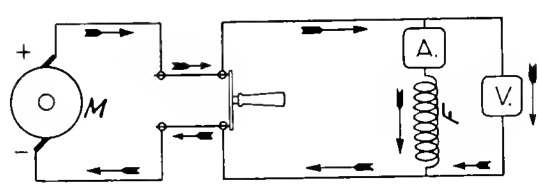


Fig. 5

switch S is opened without arc when the field current in ammeter A is 3 amps., what will be the effect on the voltmeter and will the ammeter and voltmeter read in the same direction as before the switch was opened? Before the switch is opened the current flow is as shown in Fig. 5. As the switch is opened the field flux cannot die away instantaneously. The field current therefore cannot die away instantaneously, but continues to flow through the only available path, which is that of the voltmeter. Since the resistance of the voltmeter is 11,000 ohms it is evident that the voltage across the instrument becomes at the very first instant very high.

It is $ir = 3 \times 11{,}000 = 33{,}000$ volts.

Thus the voltmeter will probably burn out as the needle swings to the opposite side of the scale. The ammeter needle will remain stationary for the first instant and gradually come down to zero.

This problem gives an idea of the nature of the shock that is experienced if the field current of a generator is carelessly interrupted and permitted to pass through a person. Depending upon the nature of the contact the resistance of a body may be from 1000 to 10,000 ohms. If, therefore, a person touches both sides of the field winding when the field circuit is interrupted he will experience a very severe shock. The energy stored is usually quite considerable. In this case it is $\frac{1}{2} LI^2 = \frac{1}{2} \times 25 \times 9 = 113$ joules. Since one joule is 0.74 foot-pounds, the energy available is 84 foot-pounds, i.e., that of a pound weight dropping 84 feet.

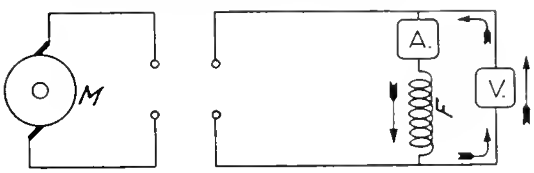


Fig. 6

It may be asked, what would happen if the voltmeter were not connected across the field winding? Where would the initial rush of current, of 3 amperes, flow when the switch was opened?

poles. This phenomenon will be understood later from the investigation of circuits having mutual inductance.

The problem is instructive in that it explains frequent burnout of voltmeters, and in that it teaches that the voltmeter should

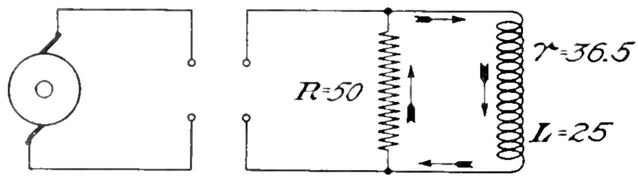


Fig. 7

always be disconnected before the switch is opened, or otherwise be connected on the armature side of the field switch. It teaches also that in opening the field switch a relatively low resistance should be shunted across the field winding to prevent high voltage, and finally that it is well to open the field switch slowly. The importance of shunting the field circuit is best illustrated by a numerical example.

Example No. 3. (Fig. 7)

Assume that the field is shunted by a resistance of 50 ohms, and assume again, for the sake of simplicity, that the field current is 3 amperes and is interrupted without arc and that L is constant and is 25 henrys. The total resistance in the circuit is then $50 + 36.5$ ohms or 86.5 ohms. Determine the current in the field winding and the shunted resistance and the voltage across the field which is the same as the voltage across the resistance after the switch is opened.

Referring to equation (18)

$$i = I\epsilon^{-\frac{rt}{L}} = 3\epsilon^{-3.46t}$$

For t	0	.05	.10	.20	.5	1
$\epsilon^{-3.45t}$	1	.84	.71	.50	.18	.03
i	3	2.32	2.13	1.5	.54	.09
iR	150	116	107	75	27	3

In reality it is impossible to open the field switch without an arc; therefore the current cannot be interrupted instantaneously. Furthermore the circuit is more complex than assumed. The field winding has considerable capacity and therefore acts as if it were shunted by a condenser. A portion of the 3 amperes will therefore flow as condenser current, but a large portion will appear as secondary currents in the iron circuit of the

It is seen that in this case the maximum voltage across the field, which of course occurs at the moment of opening the switch, is 150 volts, as compared with 33,000 when the voltmeter shunted the field. The field current i dies away very rapidly. In one second it has almost disappeared. The energy stored in the field is spent in heating, in i^2r.

(To be Continued)

LINE DROP COMPENSATORS

By E. F. Gehrkens

Transformer Engineering Department, General Electric Company

This article points out the function of the line drop compensator in an alternating current supply system; and, with the aid of vector diagrams, explains the theory upon which they operate. The construction and connections of the two main types of compensator in commercial use are considered. The article concludes with directions as to how these compensators, with their voltmeter or automatic voltage regulator, should be adjusted for service.—Editors.

Construction and Theory of Operation

A line drop compensator consists primarily of a resistance and a reactance, each separately adjustable by means of dial switches. It

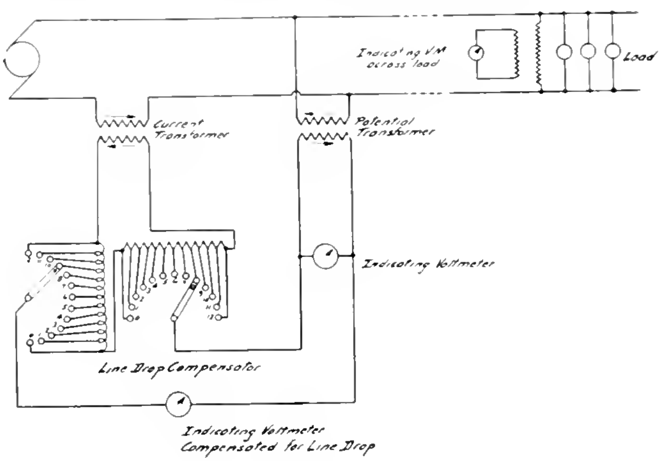


Fig. 1

is designed for use with a voltmeter which, located in the station, will indicate the voltage at the end of the line or at some predetermined point on the line, as, for instance, the center of distribution; regardless of the voltage of the line at the station, the load on the line, the drop in the line, or the power-factor of the load within the limits for which the compensator is designed. Each feeder, whose voltage at the center of distribution is to be indicated or recorded in the station, must be provided with its own compensator, which must be adjusted for the ohmic and reactive drop of that particular feeder. It is also desirable to provide each feeder with its own voltmeter.

The diagrammatical connection of line drop compensator, voltmeter, and current and potential transformers is shown in Fig. 1. The operation is as follows: Assume full load on the line and a line drop of 10 per cent. due to resistance and 10 per cent. due to reactance, with 100 volts across the load. With a unity power-factor load, the vector voltage diagram is as shown in Fig. 2, *AB* being the voltage across the load. With this character of load, the line current is in phase with the voltage, *AB*, so that the line resistance drop, *BC*, is also in phase, and the line reactance drop, *CD*, at right angles. When plotted as given and for the values assumed, this shows that a generator voltage equal to *AD*, the value of which is 110.45, is required to fulfil the conditions, i.e., 100 volts on the load. In Fig. 1 the voltage of the generator must, therefore, be 110.45 to obtain 100 volts on the load, and the voltmeter placed directly across the secondary of the potential transformer will indicate this value.

As shown in Fig. 1 the current transformer has its primary connected in series with the feeder and its secondary in series with the compensator. The voltmeter which is to be compensated for line drop, is connected across the potential transformer, but in such a way that a varying amount of the resistance and the reactance of the compensator is included in series, this connection being made so that the voltage of the current transformer is opposed to that of the potential transformer. By selecting the proper current transformer, i.e., one having a primary capacity equal to full load, full load current, stepped down in the ratio of turns of the current transformer, will be forced through the compensator with full load on the feeder. The compensator

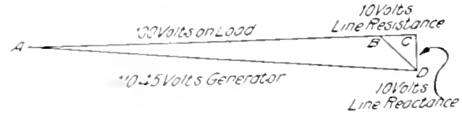


Fig. 2

should have such a resistance and reactance that the voltage drop across each, with full load current flowing, can be adjusted to equal the resistance and the reactance drop in the line, in per cent. of the transformed potential. Under this condition the voltage across the compensated voltmeter will be the same as the voltage indicated by the voltmeter at the load, for the reason that the line conditions have been exactly duplicated in the compensator; i.e., the drop across the resistance is in phase with the voltage and the drop across the reactance at right angles, the total drop across the compensator being proportional to *BD*. *BD* may therefore represent in value and direction the voltage of the secondary of the current transformer. This voltage is deducted from the voltage of the generator, stepped down by the potential transformer, at the angle shown, and the difference is indicated on the compensated voltmeter. The voltmeter at the end of the line, however, indicates the generator voltage less the actual line resistance drop and reactance drop, respectively in phase with and at right angles to the line current, as reproduced in miniature in the compensator. This compensation is correct for all loads; for, as the voltage drop in the line decreases, due to decreasing load, the voltage drop in the compensator decreases proportionally.

Again assume the same line but with an 80 per cent. power-factor load. With this change in the condition of load the vector voltage diagram is as shown in Fig. 3, *AB* again being the voltage across the load. With the power-factor assumed, however, the current lags behind the voltage at an angle whose *cosine* is 0.8, shown as angle *BAE* in Fig. 3. Plot the line resistance drop, *BC*, in phase with the current, which is in the

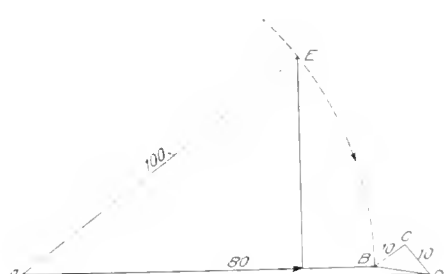


Fig. 3

direction *AE*, and the line reactance *CD* at right angles to *AE*. Then the vector *AD*(=114) represents the value and the direction of the generator voltage required to give 100 volts on the load. As in the previous case the line conditions are exactly reproduced in the line drop compensator, the current producing the drop, *BD*, across the compensator, lagging behind the voltage across the potential transformer by the angle *BAE*. *BD* represents in direction and value the voltage of the secondary of the current

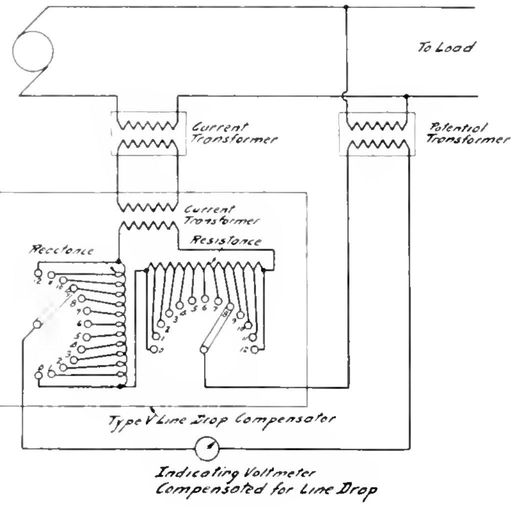


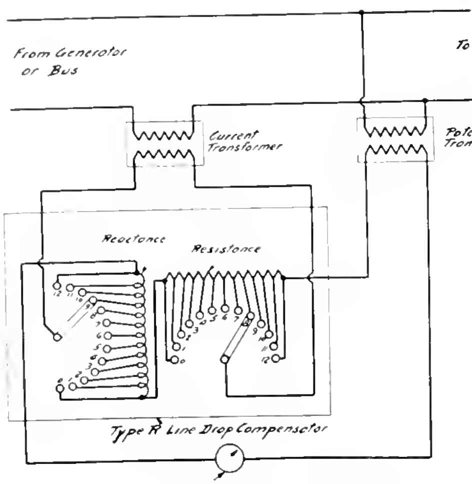
Fig. 4

transformer which is deducted from the generator voltage represented by *AD*; so that the compensated voltmeter again indicates the same voltage as the indicating voltmeter at the end of the line. As will be noted, the value of *BD* is constant for a given line and load, and its angular relation to the generator voltage *AD* varies with the power-factor of the load. This variation, as previously explained, must be proportionally the same at the compensated voltmeter as across the load at the end of the line; so that after the compensator is once adjusted for a given point of distribution on the line, the indicating voltmeter in the station, which has been compensated for line drop, will indicate the voltage at the center of distribution, for all conditions of load within the limits of range of the compensator.

Types and Connections

Two types of line drop compensators, *viz.*, type V and type R, are built each in several sizes, the former for use with indicating voltmeters; and the latter for use with compensated recording voltmeters, compensated automatic voltage regulators, and contact-making voltmeters used to control automatically-operated feeder voltage regulators arranged for line drop compensation.

The internal and external connections of the type V compensator, together with current and potential transformer and voltmeter, are shown in Fig. 4. This diagram is identical with Fig. 1 except that the compensator itself contains a small current transformer, which



Voltage Coil of Automatic Regulator or Contact Making Voltmeter

Fig. 5

reduces the current obtained from the main current transformer in the ratio of 5 to 0.7, thereby reducing the loss in the compensator. This arrangement also insulates the potential transformer secondary from the main current transformer, allowing the grounding of both current and potential transformer secondaries.

The internal and external connections of the type R compensator, with auxiliary apparatus, are shown in Fig. 5. In this the resistance and reactance are designed to carry the full secondary current of the current transformer, and they are connected to the secondary of this transformer through the dial switches, instead of directly as in the type V. It is preferable to connect the secondary of the current transformer permanently, as in the type V, so as to insure a good and uniform connection. This arrangement is impractical in the type R compensator, for the reason that the resistance of the potential coil of the recording voltmeter, contact-making voltmeter or automatic voltage regulator is small compared to the resistance of the indicating voltmeter; i.e., the resistance of the compensator is a very much greater percentage of the combined resistance of compensator and potential coil, than the resistance of the type V compensator is to the total resistance of compensator and indicating voltmeter. If the type R were connected as the type V, then changing the amount of resistance or reactance, or both, of the compensator, would affect the calibration of the instrument with which it is used, i.e., the current in the potential coils of these instruments would change appreciably in value for different adjustments of the compensator dials. Changing the resistance and reactance by the dial switches is of course only necessary when adjusting the compensator for the circuit on which it is to be used; but, in view of the difficulty of obtaining a proper adjustment, as explained in the following section, the additional difficulties which would be introduced by the type V connection are eliminated, as explained above, by connecting all of the resistance and reactance permanently in series with the potential coil of the instrument, so that its calibration is in no way affected by the adjusting of the dials.

The necessity of using a type V compensator with an indicating voltmeter for which compensation is desired on a circuit containing a type R compensator, is frequently questioned, as it might seem that a single compensator on a given feeder would be sufficient to take care of both instruments. The current taken by the instruments using the type R compensator is nearly one ampere. Considering the circuit with no load on the feeder, the voltage at the station is 100 per cent., the same as at the end of the line. The voltage across the potential coil of the instrument is not, however, 100 per cent.; but is this amount, *minus* the drop across the compensator due to the current flowing in it. An indicating voltmeter, therefore, connected in parallel with a compensated recording voltmeter, regulator or contact-making voltmeter, would not indicate the line voltage. The direction of currents in transformers and compensator with load on the line is such that the current from the current transformer is always added to that of the potential transformer, as illustrated in Fig. 1. The difference in voltage across the potential coils of the instruments and the voltage across the voltmeter at the end of the feeder, is constant for all loads, the voltage across the former being decreased by the drop across the compensator, owing to the current in the secondary of the potential transformer. It is, therefore, only possible to dispense with the type V compensator, in this case, by the use of some specially arranged indicating voltmeter connected across the potential coil of the recording voltmeter, automatic voltage regulator, or contact-making voltmeter, which would be correct only when calibrated after installation and connected as specified.

There are, of course, a number of ways in which a voltmeter may be designed to meet the above condition. The method so far used has been to provide a standard indicating voltmeter with a blank scale. This scale must be calibrated after installation, as stated, and requires recalibration when the voltmeter is to be used for any other purpose.

Adjustment of Compensator

Type V compensator. By referring to Fig. 2 it will be noted that with a 100 per cent. power-factor load the line drop is due almost entirely to the line resistance, and is practically independent of its reactance. From Fig. 3 it will be noted that as the power-factor of the line decreases, the effective voltage drop produced by the resistance decreases, and that produced by the reactance increases; until, at an imaginary zero power-factor load the drop is due almost entirely to the reactance, and is practically independent of resistance.

A compensator used on a feeder carrying a high power-factor load will therefore compensate the voltmeter approximately if the resistance dial is properly adjusted, with any setting of the reactance dial. In the same manner the line drop due to a low power-factor load may be approximately compensated for by adjusting the reactance dial of the compensator. Such adjustments will, however, be incorrect for any other power-factor; and this possibility of improper adjustment has frequently caused considerable confusion. It is therefore essential that the compensator have both its resistance and reactance adjusted in proper proportion to the line resistance and reactance, so as to compensate the voltmeter properly for all conditions of load.

The plugs of the compensator dial switches are numbered; and the drop in volts across that part of the compensator resistance and reactance which is in series with the instrument compensated, with 100 per cent. current in the current transformer, is equal to the numbers of the plugs on which the blades of the dials rest. If the line resistance and reactance to the center of distribution are known, it is, therefore, only necessary to calculate the voltage drops at full load, divide by the ratio of the potential transformer used with the compensator, and adjust the compensator by setting both the resistance and reactance dials at the corresponding numbers.

In view, however, of the difficulty of determining the rectance of a commercial circuit with any degree of accuracy, it is recommended that, after the point on the line at which it is desired to maintain constant voltage has been decided upon, the resistance of the line to this point be calculated as nearly as possible, and both resistance and reactance dials set for this amount. A recording voltmeter should then be installed at the center of distribution; and, to obtain the final adjustment of the compensator, a series of readings should be taken on the compensated voltmeter at the station, noting the power-factor of the load at each reading. The compensated voltmeter readings should then be compared with the recording voltmeter chart, and the compensator re-adjusted if necessary; taking into consideration, however, the power-factor of the load at the various points, and adjusting the resistance dial for high power-factor loads, and the reactance dial for loads of low power-factor. As it is essential that the voltages agree throughout the entire cycle of load and power-factor, it may be necessary to make several readjustments; but after once being properly adjusted the compensator will require no further attention, and the compensated voltmeter will indicate the correct voltage at the particular point on the feeder for which the compensator was adjusted, for all conditions of load and power-factor.

Type R compensator. Before adjusting the compensator, the contact-making voltmeter or automatic voltage regulator for which the compensator is required, should be adjusted so that the armature will float in the neutral position when connected in series with its accompanying resistance only, and the combination connected across a line whose voltage is equal to that which it is desired to maintain at the center of distribution. The approximate adjustment is made by changing the amount of the series resistance, by means of the plugs on the resistance box: and the final adjustment by means of the adjusting spring, which partly counter-balances the armature of the automatic voltage regulator or contact-making voltmeter. If it is inconvenient to obtain the proper voltage independently, the voltage regulator or contact-making voltmeter, compensator, and current and potential transformers may be connected in circuit, as shown in the diagram of connections; and, with both dials of the compensator on zero, the voltage of the feeder should be adjusted by means of the field rheostat of the generator or the feeder regulator, so that the bus voltage, or that across the feeder in the station, is equal to the voltage desired at the point of distribution. The adjustments on the automatic voltage regulator or contact-making voltmeter should then be made as outlined, after which the compensator should be adjusted as explained. To obtain the final adjustment of the compensator it is only necessary to compare the chart of the recording voltmeter at the center of distribution with the power-factor at various loads and make the final adjustment of the compensator as already described. With the final adjustment, the voltage chart at the center of distribution should be a straight line.

An approximate adjustment of both types of compensator can usually be obtained in less time by establishing telephonic communications between the station and the center of distribution, using an indicating voltmeter at the latter point; but the final adjustments can only be made by comparing the voltages over an extended period of time as already explained.

SYNCHRONOUS MOTORS IN PREFERENCE TO INDUCTION MOTORS FOR LOW SPEED WORK

By Henry M. Hobart, M. Inst. C. E.

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The beneficial effect which a synchronous motor may have on the power-factor of a system, rendering it in many cases preferable to the induction motor, is well known. It is not so generally realized that the synchronous machine also possesses certain attributes which render feasible the acquirement of starting characteristics distinctly superior to those of a squirrel cage induction motor of equal efficiency. This article shows how advantage may be taken of these possibilities by providing the synchronous motor with a starting winding having magnetic end rings, of which the impedance automatically decreases as the motor comes up to speed. The wide field which may thereby become opened for the synchronous motor is indicated. —Editors.

It has long been recognized that the inherent simplicity and robustness of the squirrel cage induction motor constitute features of very great importance and justify the wide use of such motors. Induction motors show up to better advantage, however, the higher the rated speed. The chief disadvantage of a low-speed induction motor is its low power-factor.

Thus take the case of a 100 h.p., 60 cycle motor. The design for a rated speed of 1800 r.p.m. will have a power-factor of 93 per cent., whereas the design for a 100 h.p., 60 cycle motor for one-tenth of this speed, i.e., for a speed of only 180 r.p.m., will have a power-factor of only some 80 per cent. The power-factors given above correspond to rated load. For light loads, the inferiority of the low-speed motor as regards low power-factor is much greater, and this circumstance further increases the objection to the use of such a motor.

For a long time there has existed a general impression that a synchronous motor could not be so constructed as to provide much starting torque. Otherwise it would probably have been realized that, for low speeds, it would often be desirable to give the preference to the synchronous type. For with the synchronous type, the field excitation can be so adjusted that the power-factor shall be unity; indeed there is no objection to running with over-excitation and reducing the power-factor again below unity, thus occasioning a consumption of leading current by the synchronous motor.

By the judicious admixture (on a single supply system) of high-speed induction motors consuming a slightly-lagging current and low-speed synchronous motors consuming a slightly leading current, it is readily feasible to operate the system at practically unity power-factor; and to thereby obtain, in the generating station and in the transmission line, the advantages usually accruing to operation under this condition.

Now the point which is beginning to be realized,* and which it is important at this juncture to emphasize, is that the synchronous motor, instead of being of inferior capacity as regards the provision of good starting torque, has, on the contrary, certain inherent attributes rendering it entirely feasible to equip it for much more liberal starting torque than can be provided by *efficient*

* Mr. H. H. Dewey has drawn attention to this point in a paper, entitled "Special Applications of Synchronous Motors," read at the 1911 Engineers' Meeting of the General Electric Company.

squirrel cage induction motors. The word "efficient" has been emphasized in the preceding statement and for the following reason: by supplying an induction motor with a squirrel cage system composed of conductors of sufficiently small cross-section, and consequently sufficiently high resistance, any amount of starting torque which is likely to be required can be provided. Unfortunately, however, the high resistance squirrel cage is inherently associated with a high I^2R loss in the rotor when the motor is carrying its load. This high I^2R loss not only occasions great "slip" but also occasions very low efficiency. Furthermore, owing to this very low efficiency, the heating of the motor would be very great were it not that such a motor is rated down to a capacity far below the capacity at which it could be rated were it supplied with a low resistance (i.e., low starting torque) squirrel cage system.

But when we turn to the consideration of the synchronous motor, we note the fundamental difference, that the squirrel cage winding with which we provide the rotor is only active during starting and during running up toward synchronous speed. When the motor has run up as far toward synchronous speed as can be brought about by the torque supplied by its squirrel cage, excitation is applied to the field windings and the rotor pulls in to synchronous speed. So soon as synchronism has been brought about, the squirrel cage system is relieved of all further duty; and it is consequently immaterial whether it is designed for high resistance or for low resistance.

Consequently with the synchronous motor we are completely free from the limitations which embarrass us in designing high-torque induction motors. In the case of the synchronous motor, we can provide any reasonable amount of torque by making the squirrel-cage system of sufficiently high resistance. One difficulty, however, presents itself: while, at the instant of starting, we may desire very high torque and may provide it by a high resistance squirrel cage, the higher the resistance the more will the speed, up to which the rotor will be brought by the torque of the squirrel cage, fall short of synchronous speed. In fact as the rotor acquires speed, it would be desirable that the squirrel cage should gradually be transformed from one of high resistance to one of low resistance. If we could accomplish the result that the squirrel cage should, at the moment the motor starts from rest, have a high resistance, and if it could be arranged that this resistance should gradually die away to an exceedingly low resistance as the motor speeds up, then the motor would gradually run up to practically synchronous speed and would furnish ample torque throughout the range from zero to synchronous speed.

We can provide precisely this arrangement if, instead of making the end rings of the squirrel cage of copper or brass or other non-magnetic material, we employ instead, end rings of magnetic material, such as wrought iron, mild steel, cast iron or some magnetic alloy.

Let us now consider the reason why this arrangement should produce the result indicated. Just before the motor starts, the currents induced in the squirrel cage system are of the full periodicity of the supply. In the end rings, these currents will, with usual proportions, be very large in amount; and since the currents are alternating and since the material of the end rings is magnetic, there will be a very strong tendency, in virtue of the well-known phenomenon generally described as "skin effect," to confine the current to the immediate neighborhood of the surface of the end rings. The current will be unable to make use of the full cross-section of the end rings; and consequently, even though the end rings may be proportioned with very liberal cross-section, the net result will, at starting, be the same as if the end rings were of high resistance. But as the motor speeds up, the periodicity of the currents in the squirrel cage decreases, until, at synchronism, the periodicity would be zero and there would be no "skin effect." In view of these explanations, it is obvious that the impedance of the end rings will gradually decrease from a high value at starting to a low value at synchronism.

Now we are more free to make use of this phenomenon in the case of synchronous motors than in the case of induction motors, for as already stated, when the synchronous motor is run at full speed, the squirrel cage is utterly inactive (except in serving to minimize "surging" and to decrease "ripple" losses); whereas the induction motor's squirrel cage is always carrying alternating current (even though of low periodicity); and this alternating current flowing through end rings of magnetic material, occasions a lower power-factor than would be the case with the equivalent squirrel cage motor with end rings of non-magnetic material.

Even in the case of induction motors, excellent use can be made of constructions

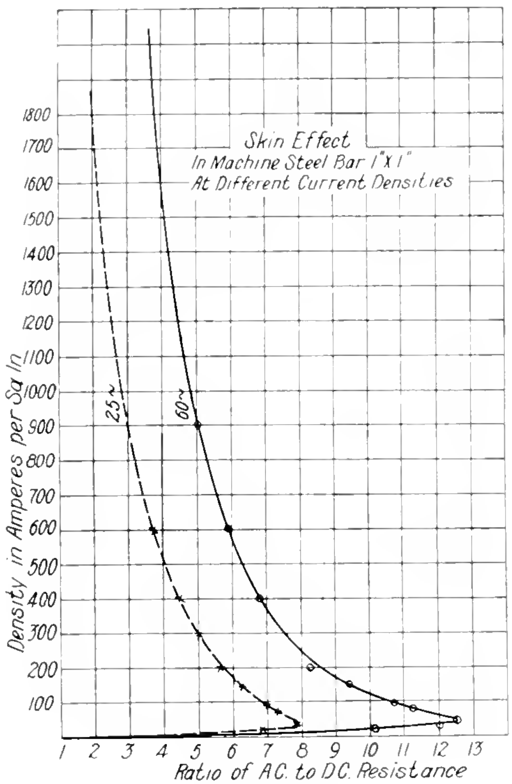

Fig. 1

starting torque than can be provided with induction motors, without impairing other desirable characteristics such as low heating and high efficiency.

Of course there always remains the disadvantage of requiring a supply of continuous electricity for the excitation of the field magnets. Cases will arise where this disadvantage is sufficient to render it preferable, even for slow-speed work, to employ induction motors, but in the majority of cases where polyphase motors must operate at very low speeds, it would appear that synchronous motors are preferable.

In the curves in Figs. 1 and 2 are plotted results of some interesting tests which have recently been made by Mr. L. T. Robinson, on "skin effect" in machine steel bars. By means of these and similar data, and by applying to the design of the synchronous motor the ample experience which has been acquired in the design of induction motors, the preparation of a design for a synchronous motor for stipulated characteristics as regards torque, presents no difficulties. The smooth-core type of field with distributed excitation is to be preferred to the salient-pole type.

I have dwelt upon the relative inappropriateness of the induction motor for low speed applications. Conversely it is a particularly excellent machine for high speeds. Its power-factor is higher the higher the rated speed; and when we come to very high speeds we obtain, in motors of large capacity, full load power-factors in excess of 95 per cent.

with end rings of magnetic material, in improving the starting torque, but there is unavoidably at least a little sacrifice in power-factor during normal running.

It should now be clear that there is a legitimate and wide field for low-speed synchronous motors and that these motors will be superior to low-speed induction motors, in that, while the former can be operated at unity power-factor, or even with leading current if desired, the latter will unavoidably have very low power-factors. Furthermore these low-speed synchronous motors, instead of being in any way inferior to induction motors with respect to starting torque, have attributes permitting of providing them with higher

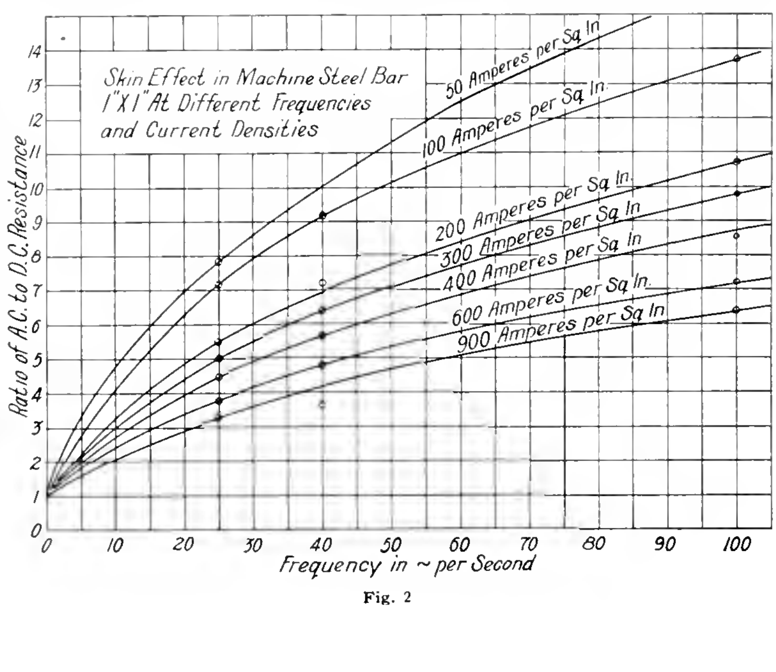

Fig. 2

In such instances the simplicity of induction motors should frequently lead to their use in preference to synchronous machines.

Reasoning along similar lines, in the case of generators, the induction type offers advantages over the synchronous type in many instances. It cannot, however, *replace* the synchronous generator even at high speeds, for it requires to be run in parallel with synchronous generators, the latter supplying the magnetization for the induction generators and also supplying the lagging component of the external load when the latter's power-factor is less than unity. Notwithstanding these limitations, there is a wide field for the induction generator; and the above indications may be useful for guidance in showing its appropriateness for any specific instance.

GRAPHICAL METHODS IN THE DESIGN OF SHAFTS

PART I

By A. Schein

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SHAFTS FOR TWO-BEARING SETS

This is the first of two papers which we are publishing on this subject. Two-bearing machines are here considered; three-bearing sets will be dealt with next month. The principle on which these methods are based is not new, and may be found in many text-books on applied mechanics, in the chapters on bending of beams. It is now extensively applied to the design of electrical machines; and it is the purpose of these two articles to present the subject in a form which will be useful to draftsmen and students engaged actually on the shaft layout of various typical electrical machines.—Editors.

In describing the application of graphical methods to the design of shafts for electrical machines, it must be pointed out that all possible cases can not be considered in detail; but a clear exposition of the method applied to a few fundamental cases will enable anyone with a slight knowledge of geometry and mechanics to apply the graphical method to the solution of any possible combination.

In making a layout of the shaft design for a two-bearing machine (such as a generator, motor, etc.), the weight of the revolving parts is known. Knowing the load on the shaft, the permissible bearing pressure per square inch, and the ratio of bearing length to diameter, an approximate bearing length may be obtained; whence, from a knowledge also of the overall length of the armature—or armature and commutator, as the case may be—a value of the span between bearing centers may be arrived at. It is usual to assume that all the weight is supported at the center line of the two bearings. In employing the graphical method, it is necessary to make a preliminary calculation (approximate) of the shaft diameter; and then, by means of the bending moment diagram and the deflection diagram, to determine what the fiber stress and the actual shaft deflection will be under the given conditions and with a shaft of this diameter. If either of these exceeds the maximum permissible, then the shaft must be thickened up and the method worked through again for the new diameter. Sometimes two or three sets of diagrams must be drawn out before the correct solution is obtained; sometimes one calculation will suffice. As a general rule, it depends on the experience and judgment of the designer who is using the method. After some practice, it is a simple matter to plot the diagram, and at the worst it will probably be found considerably shorter than any other known method.

Commencing, then, only with a knowledge of the weight of the revolving parts and of the distance between bearing centers, we proceed to place some hypothetical value on the shaft diameter, in order that we may use this value in applying our graphical method to see if the diameter is correct. Assume that the weight of the shaft itself is 25 per cent. of the weight of the revolving parts which it carries.* Then calculate the shaft diameter from the formula:

$$\text{Deflection} = \frac{0.019 \times W \times L^3}{E \times I},$$

where

W = total weight of revolving parts, including shaft;

L = the span in inches between bearing centers;

E = modulus of elasticity = 29,000,000 for steel;

I = moment of inertia of a shaft of uniform section.

*25 per cent. is a fair assumption for large and medium-sized machines. For smaller machines the value may vary between 15 and 25 per cent.

For the deflection a value must be assigned in the equation equal to the maximum permissible deflection. Solving the equation for I, the diameter may be obtained.

In the four following fundamental cases, a diameter is assigned to the shaft in this way, and the graphical method worked through. The actual fiber stress can be calculated from the bending moment diagram, and the actual deflection from the deflection diagram, as described below.

Case 1

The shaft is 40 in. long between bearing centers, and carries two loads of 600 lb. each. Our preliminary calculation has given us a value of 3 in. for the shaft diameter.

Figure 1

Draw the shaft in any convenient scale, in this case 1:4, or $S=4$. Locate the acting loads and reactions. The weight of the shaft which is about 80 lb. should be taken as being an evenly distributed load; but for convenience it is assumed as concentrated in three points only. Heavy shafts have to be divided in as many parts as may be found convenient, and the weight of each part assumed to be acting at the center of gravity of the same.

Figure 2. First Vector Polygon

On the vertical line AA' set down the weights in the same order as they are located in Fig. 1. Select a weight scale, in this case 1 in. = 200 lb., or $W=200$. Then make $ab=28$ lb., $bc=600$ lb., $cd=24$ lb., $de=600$ lb. and $ef=28$ lb.

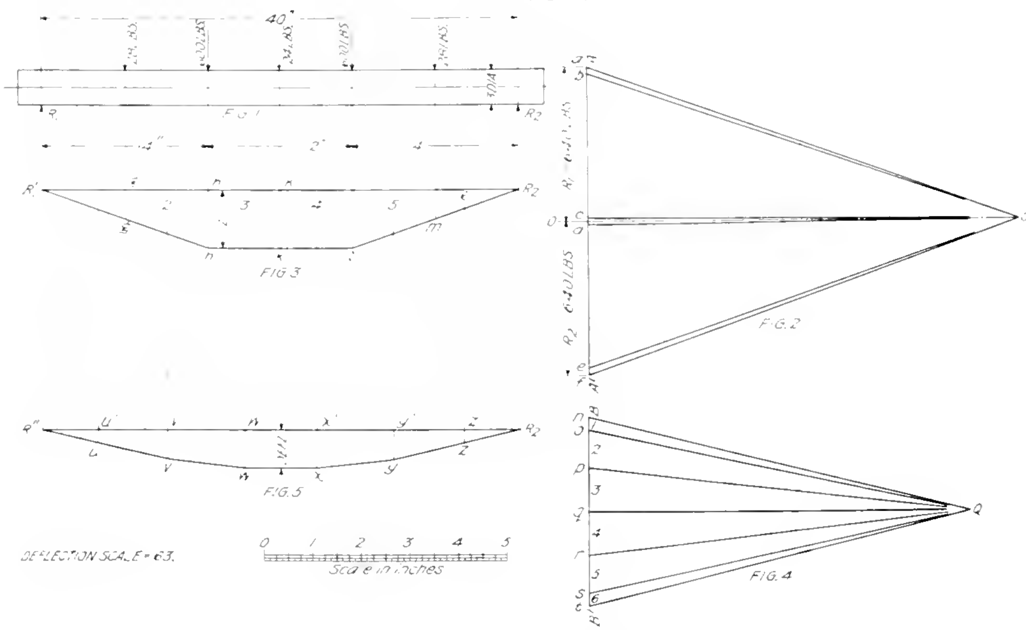
The pole O has a perpendicular distance to AA' of 9 in., or $h=9$ in. (an arbitrary assumption). Connect the points a, b, c, etc., with O.

Figure 3. Bending Moment Diagram

Draw vertical lines from R_1, R_2 and all loads. Make $R_1'g$ parallel to aO, gh parallel to bO, hk parallel to cO, etc. Connect the last point R_2' to R_1'. The enclosed figure is the *bending moment area*.

The bending moment at any point
$$M=L\times S\times W\times h$$

Case I



where L is the vertical ordinate in the bending moment diagram at the point in question. For instance, under the load of 24 lb., the bending moment

$$M=1.23\times4\times200\times9$$
$$=8900 \text{ inch-lb;}$$

and the fiber stress at the same point

$$f=\frac{M}{Z}=\frac{8900}{2.65}$$
$$=3350 \text{ lb. per sq. in.}$$

A line parallel to R_2', R_1' from O divides AA' in two parts, AO' which is equal to R_1 and $A'O'$ which is the reaction R_2. In this case, where the shaft is symmetrically loaded, both reactions are equal.

Treat the bending moment diagram as a load diagram. Split it up into narrow convenient strips, the areas of which are marked 1, 2, 3, 4, etc. Find the area of each strip, the values of which are: 1 = 0.54, = 1.562, 3 = 1.83, 4 = 1.83, 5 = 1.56 and 6 = 0.54 sq. in.

Figure 4. Second Vector Polygon

Choose any scale (here 2 sq. in. = 1 in. in length, or $A = 2$), and set down the calculated values of the areas 1, 2, 3, etc., on the vertical line BB', where $no = 0.54{:}2$, $op = 1.56{:}2$, $pq = 1.83{:}2$, etc. The pole distance for Q should preferably be made in a certain ratio

$$\text{The deflection scale} = \frac{E \times I}{S^3 \times h \times W \times A \times H};$$

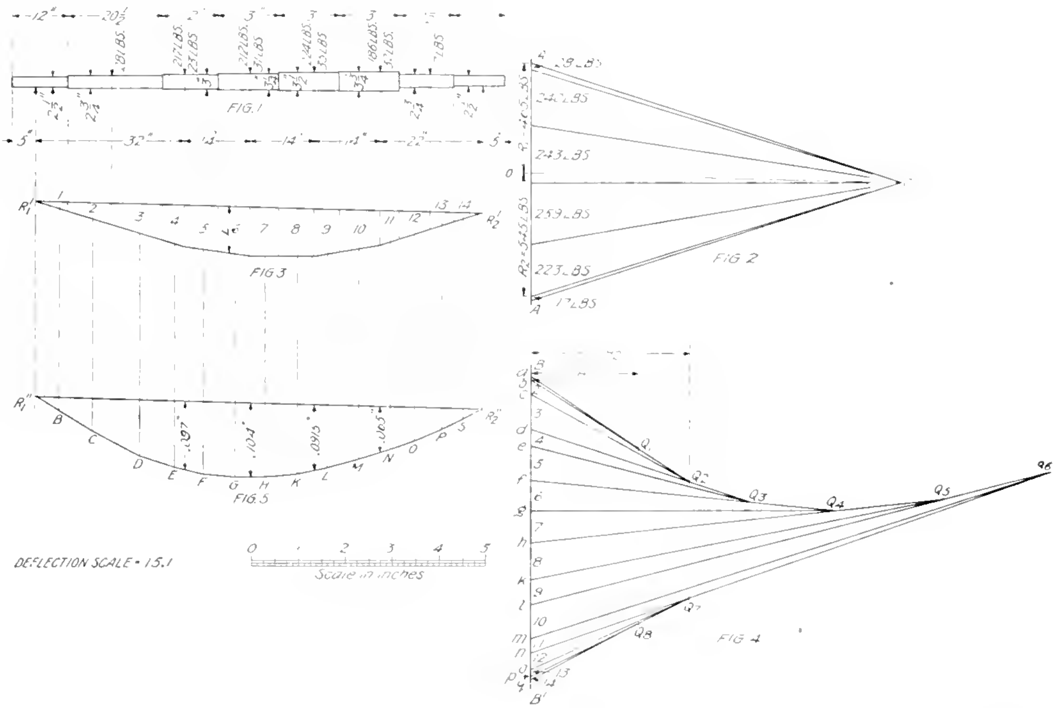
or, for our values from the previous explanation,

$$\text{deflection scale} = \frac{29{,}000{,}000 \times 3.98}{4^3 \times 9 \times 200 \times 2 \times 7.96} = 63$$

To find the actual value of the deflection at any point on the shaft, divide the vertical distance in Fig. 5 at the point in question by 63. The result is the desired answer. For instance the deflection at ww' is

$$D = \frac{0.8}{63} = 0.0127 \text{ in.}$$

Case 2



to the moment of inertia of the shaft. As I of a 3 in. diameter shaft is equal to 3.98, the perpendicular distance from BB' to Q is taken as 7.96 in. Connect n, o, p, q, r, s and t with Q.

Figure 5. Deflection Curve

Find the center of gravity of each element in Fig. 3 and drop vertical lines from them. Make $R''u$ parallel to nQ, uv parallel to oQ, vw parallel to pQ, etc. Connect the last point R'' with R''. The link line $R_1''\ uv\ \ldots\ R_2''$ actually is supposed to represent a curve, to which the straight lines $R_1''u$, uv, etc., are tangents. The vertical distances between $R_1''\ R_2''$, and the curve are the deflections in enlarged scale.

In this manner the actual fiber stress in, and the deflection of, a shaft of 3 in. diameter, loaded in the manner indicated, may be determined graphically. Sometimes the fiber stress may be the limiting feature, while in other cases it may be the deflection. Wherever either of these quantities is found to exceed the value which experience has shown to be the safe limit, a fresh diameter must be assigned for the shaft, and the method and calculations worked through afresh.

Case 2

The shaft of a centrifugal pump is, in this case, of varying diameter and is loaded with four propellers. All the preliminary dimensions and loads are shown in the drawing.

Figure 1.

The shaft is drawn to scale, taking in this case 1:10, or $S=10$. From the located weights and reactions drop vertical lines.

Figure 2.

Plot down the weights on the vertical line AA' to scale (200 lb. = 1 in., or $W=200$) in the order in which they are located on the shaft. Mark each weight on the line AA'. The pole O is taken 8 in. from AA' (perpendicular distance). Complete the polygon by drawing the lines to O. (Obtain the reactions by drawing a line OO' parallel to $R_1'R_2'$, after completing Fig. 3.)

Figure 3.

Draw the link line in the same way as already shown in Case 1. From the enclosed bending moment diagram the values for stresses are figured as before.

Bending moment $= L\times S\times h\times W$.

Fiber stress $=\dfrac{\text{bending moment}}{Z}$

L and Z are taken for the diameter and the point at which the fiber stress is to be calculated. Drop vertical lines from the different points along the shaft at which there is either a change of cross-section or a point of application of a load. Mark each element of the bending moment area, 1, 2, 3, 4 . . . . 14.

Figure 4

Calculate the area of each element of the bending moment diagram. These are respectively: 0.07, 0.315, 0.72, 0.382, 0.7, 0.67, 0.7, 0.77, 0.55, 0.72, 0.295, 0.33, 0.15, 0.06; or a total of 6.43 sq. in. Plot these values on the vertical line BB' to scale (1 sq. in. = 1 in., or $A=1$).

The moment of inertia of the shaft for various diameters may be found from the tables. The values are as follows:

For $2\frac{1}{2}$ in., $I=1.91$
$2\frac{3}{4}$ in., $I=2.81$
3 in., $I=3.97$
$3\frac{1}{4}$ in., $I=5.47$
$3\frac{1}{2}$ in., $I=7.36$
$3\frac{3}{4}$ in., $I=9.7$

Assuming the ratio of $\dfrac{H}{I}=1.2$, we get

$H_1=1.91\times1.2=2.3$ in.
$H_2=2.81\times1.2=3.38$ in.
$H_3=3.97\times1.2=4.75$ in.
$H_4=5.47\times1.2=6.55$ in.
$H_5=7.36\times1.2=8.83$ in.
$H_6=9.7\times1.2=11.64$ in.
$H_7=2.81\times1.2=3.38$ in.
$H_8=1.91\times1.2=2.3$ in.

The area 1 in Fig. 3 is the bending moment area of a shaft element of $2\frac{1}{2}$ in. diameter, and therefore Q_1 is taken at a perpendicular distance from BB' of $H_1=2.3$ in. Connect a and b to Q_1. Extend the line bQ_1. Lay off $H_2=3.38$ in. on this extended line and mark it Q_2. (Note that the pole distance is always measured perpendicular to the BB' line or AA' line.) Connect c and d with Q_2. It is evident that areas 4 and 5 must lie again on the extended line dQ_2, and have a pole distance $H_3=4.75$ in., which is at Q_3.

For areas 6 and 7, Q_4 is at H_4.
For areas 8 and 9, Q_5 is at H_5.
For areas 10 and 11, Q_6 is at H_6.
For areas 12 and 13, Q_7 is at H_7.
For area 14, Q_8 is at H_8.

Figure 5

Deflection curve is drawn as before. $R_1''\ B$ is parallel to aQ_1, BC parallel to bQ_2.

The deflection scale $=\dfrac{E\times I}{S^3\times W\times h\times a\times H}$

or, deflection scale

$$=\frac{29{,}000{,}000\times9.7}{10^3\times200\times8\times1\times11.64}=15.1$$

In the above equation I and H should always be taken for corresponding sections. (The ratio of I to H may be substituted in the equation, as in case 4.)

The deflections under each of the loads by measurement are found to be 1.39 in., 1.57 in., 1.38 in., 0.985 in. Dividing each of these values by 15.1, we get the actual deflections of the shaft in inches. These are 0.097 in., 0.104 in., 0.0915 in. and 0.065 in.

Case 3

Our third typical case relates to a direct current motor, having an overhung pulley 25 in. in diameter. The motor is rated 300 h.p. and runs at a speed of 750 r.p.m. The driven apparatus is vertically above the motor, so that the belt pull is upwards.

Figure 1.

The shaft is drawn to scale, 1:6, or $S=6$. The approximate loads are:

Weight of armature, 2380 lb.

Weight of shaft, 900 lb.

Total belt pull *minus* weight of pulley 3750 lb.

Figure 2.

The weights are plotted on AA' to scale (1000 lb. = 1 in., or $W=1000$). The weights, 930 lb. $=ab$, 2100 lb. $=bc$, and 250 lb. $=cd$, are plotted downward, and 3750 lb. $=dc$ is plotted upwards.

The pole distance is 6 in. from AA', or $h=6$.

Figure 3.

Make $R'f$ parallel to aO, fg parallel to bO, gh parallel to cO, hk parallel to dO and kR'_2 parallel to eO. Connecting R_2' and R_1' we get the bending moment diagram. The fiber stress in the shaft at the middle of the pulley end bearing is found as follows:

$$B_s = \text{bending stress} = \frac{L \times S \times W \times h}{Z}$$

$$= \frac{2.5 \times 6 \times 1000 \times 6}{21.21} = 4250 \text{ lb. per sq. in.}$$

$$T_s = \text{torsion stress} = \frac{321{,}400 \times \text{h.p.}}{d^3 \times \text{r.p.m.}}$$

$$= \frac{321{,}400 \times 300}{6^3 \times 750} = 600 \text{ lb. per sq. in.}$$

Figure 4.

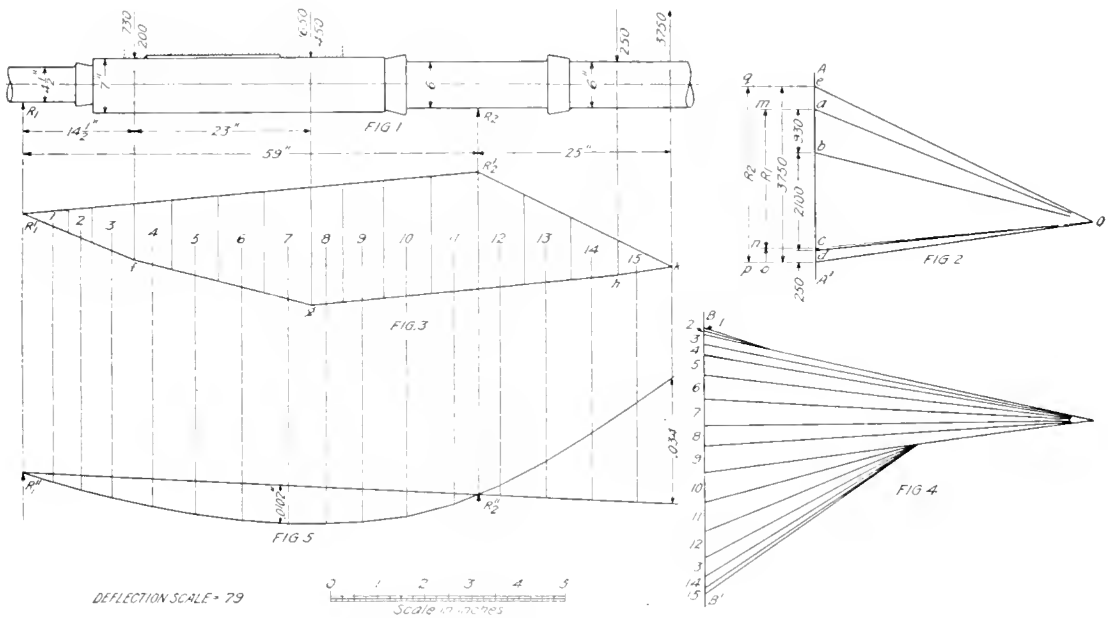
On BB' the areas 1, 2....15 are plotted to scale (4 sq. in. = 1 in., or $a = 4$).

The areas 1 and 2 were taken for $4\frac{1}{2}$ in. diameter. The areas 3 to 9 inclusive were taken for 7 in. diameter. The areas 10 to 15 inclusive were taken for 6 in. diameter.

The ratio $\frac{I}{H} = 14$. The stiffness of the oil deflectors was neglected, since the additional strength imparted thereby is insignificantly small.

The moment of inertia for the different diameters may be found from the tables. The values are:

Case 3



$$\text{Combined stress} = \frac{B}{2} + \sqrt{\left(\frac{B}{2}\right)^2 + T^2}$$

$$= 2125 + \sqrt{2125^2 + 600^2} = 4350 \text{ lb. per sq. in.}$$

Draw from O a line parallel to $R_2'R_1'$. Then the reaction $R_1 = mn = 2980$ lb., and the reaction $R_2 = +no - pq = -3450$ lb.

$$\text{Pressure on bearing } R_1 = \frac{2980}{4\frac{1}{2} \times 13\frac{1}{2}}$$

$$= 49 \text{ lb. per sq. in. (down).}$$

$$\text{Pressure on bearing } R_2 = \frac{-3450}{6 \times 18}$$

$$= 32 \text{ lb. per sq. in. (upwards).}$$

For a $4\frac{1}{2}$ in. diameter shaft, $I = 20.13$
6 in. diameter shaft, $I = 63.62$
7 in. diameter shaft, $I = 117.9$

and

H for $4\frac{1}{2}$ in. diameter $= 20.13{:}14 = 1.43$ in.
H for 6 in. diameter $= 63.62{:}14 = 4.53$ in.
H for 7 in. diameter $= 117.9{:}14 = 8.42$ in.

Figure 5.

The link line is drawn as before. Connect R_1'' and R_2'' and extend this line to the right. The deflection shows a positive deflection between the bearing and a negative deflection outside the pulley end bearing.

$$\text{The deflection scale} = \frac{E \times I}{S^3 \times W \times h \times a \times H}$$

$$= \frac{29{,}000{,}000 \times 117.9}{6^3 \times 1000 \times 6 \times 4 \times 8.42} = 79$$

Maximum deflection under armature

$$= \frac{0.81}{79} = 0.0102 \text{ in.}$$

Maximum deflection under pulley

$$= \frac{2.7}{79} = 0.034 \text{ in.}$$

acting). Pole O is at a distance of 6 in., or $h = 6$ in. Complete the vector polygon.

Figure 3.

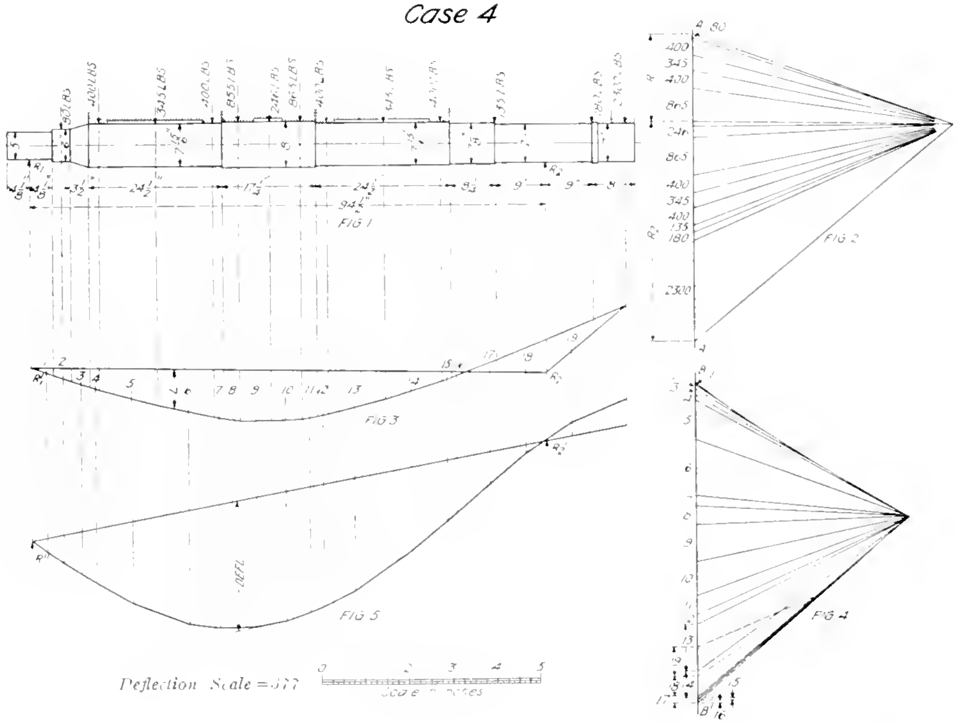
Draw the link line in the same way as in the previous cases. Connecting R_2' and R_1' we get a *positive* bending moment area below the line $R_1'R_2'$ and a *negative* area above $R_1'R_2'$. The reactions R_1 and R_2 are obtained by drawing a parallel line from O to $R_2'R_1'$.

R_1 scales 2000 lb. R_2 scales 4961 lb.

$$\text{Pressure on bearing } R_1 = \frac{2000}{5 \times 8}$$

$$= 50 \text{ lb. per sq. in.}$$

Case 4



Case 4

For the fourth typical case we may consider a turbine-generator shaft with an overhung wheel.

Figure 1.

The weight of the generator is 3330 lb.

The weight of the turbine wheel is 2300 lb.

The weight of the shaft is 1331 lb.

The shaft is drawn to scale (1:8, or $S = 8$). The dimensions and location of loads are all as shown in Fig. 1.

Figure 2.

The weight scale is 1000 lb. = 1 in., or $W = 1000$. Plot all weights on the line AA' down (in the same direction as the loads are

$$\text{Pressure on bearing } R_2 = \frac{4961}{7 \times 17^3{}_4}$$

$$= 40 \text{ lb. per sq. in.}$$

$$\text{Bending stress at } R_2 = \frac{L \times S \times W \times h}{Z}$$

$$= \frac{0.75 \times 8 \times 1000 \times 6}{33.67} = 1060 \text{ lb. per sq. in.}$$

Dropping vertical lines from points along the shaft at which there is either a change of cross-section or a point of application of a load, we get sixteen *positive* and three *negative* areas.

Figure 4.

On the vertical BB' plot the areas from Fig. 3. Areas 1, 2, 3....and 16 are to be plotted down, and 17, 18 and 19 up, as negative areas. The portion of shaft which is tapered (from 6 in. to $7\frac{15}{16}$ in.) is assumed $7\frac{1}{16}$ in. diameter.

The moments of inertia are:

For 5 in. = 30.68
6 in. = 63.62
$7\frac{1}{16}$ in. = 122.5
$7\frac{15}{16}$ in. = 195
8 in. = 201
$7\frac{7}{8}$ in. = 188.8
7 in. = 117.9

Selecting a ratio of $\frac{I}{H} = 40$ we get:

H_1 for area 1 = 0.765
H_2 for area 2 = 1.59
H_3 for area 3 = 3.05
H_4 for areas 4, 5, 6 and 7 = 4.86
H_5 for areas 8, 9, 10 and 11 = 5.02
H_6 for areas 12, 13, 14 and 15 = 4.86
H_7 for areas 16 and 17 = 4.75
H_8 for areas 18 and 19 = 2.94

Complete the figure as in Case 2.

Figure 5.

From the center of gravity of each area 1, 2, 3....19 (in Fig. 3) drop vertical lines and draw the link line. Connect $R_1''R_2''$. The deflection is again measured as a vertical distance between the line $R_1''R_2''$ and the curve.

$$\text{The deflection scale} = \frac{E \times I}{S^3 \times W \times h \times a \times H}$$

$$= \frac{29{,}000{,}000 \times 40}{8^3 \times 1000 \times 6 \times 1} = 377$$

Maximum deflection under armature

$$= \frac{2.95}{377} = 0.0078 \text{ in. positive.}$$

Maximum deflection under wheel

$$= \frac{0.6}{377} = 0.00159 \text{ in. negative.}$$

THE CONSTRUCTION OF CONSTANT CURRENT TRANSFORMERS

By L. Arnold

Engineer, Transformer Department, General Electric Company

This article describes the present standard construction of constant current transformers designed for delivering a constant current to series lighting circuits at varying voltage. The core construction, coil winding, coil insulation and assembly are described, and the general advantages discussed. The "edgewise wound" method of winding the coils results in a great reduction of volts between turns, as well as affording a much more economical design from the heating standpoint.—Editors.

Introduction

The constant current transformer, as its name implies, has the characteristic of delivering a varying voltage to lines which operate incandescent or arc lamps in series; under which condition the lamps are subjected to a constant value of current, while the load on the circuit varies in voltage only.

This type of transformer operates automatically with respect to the load, making it possible to cut out any number of lamps, from full rated load to zero load, while still maintaining a constant current on the line. The self-regulating characteristic is obtained by constructing the transformer in such a manner that either the primary or secondary coil is balanced through a system of levers against a counter-weight, which permits the distance between primary and secondary coils to vary. This automatically increases or decreases the reactance of the circuit in such amount as to hold the current constant irrespective of the load. The construction, therefore, of this type of transformer not only presents the problems met with in constant potential lighting and power transformers, but the further mechanical feature of permitting one of the coils, while carrying a high voltage load, to be free to move vertically over a varying distance, in some cases of several feet. The building of a constant current transformer, therefore, involves special processes and operations, which will be described as closely as possible in the order in which they occur in the course of manufacture.

Core Construction

The core of a constant current transformer is built up of laminations of specially annealed iron, which are sheared to the required length and width. The strips are then treated by coating the surfaces with a species of japan, which serves to reduce materially the eddy loss in the core. This japan is applied by passing the individual sheets between rolls which are constantly kept moist with the japan, in much the same manner as the type in a printing press is kept supplied with ink. After passing the rolls, the pieces of iron are carried along a travelling table, where they are dried by passing nozzles through which air is blown.

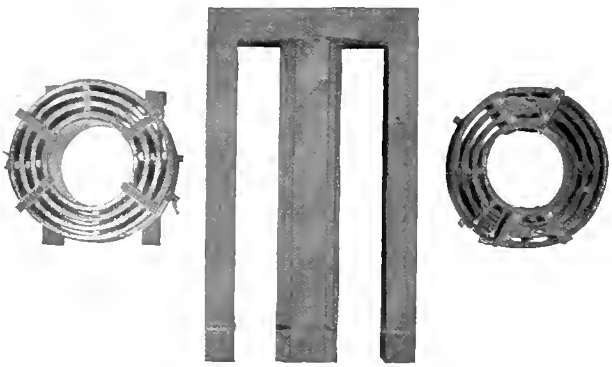


Fig. 1. Core and Coils of Constant Current Transformer

The legs of the cores are then assembled by stacking together the individual laminations, and wrapping them with sheets of .020 in. horn fiber. The legs are then placed in a hydraulic press, under a pressure of several tons and a temperature of 200 deg. to 250 deg. Fahr., which reduces the height of iron to the required dimension. The insulating dowels shown in Fig. 1 are driven in and each core leg is then a solid mass, which may be handled as one piece. The three legs of the core are placed on end and accurately spaced and the end irons put in place. The core is then turned over with the end irons just mentioned forming the bottom, as in Fig. 1. The entire lower end of the core is next clamped in a permanent iron casting, lined with pressboard. This casting is called the "bottom clamp," and, in the case of transformers for alternating current series lighting, also forms the base for the transformer. It would be well, in passing, to call particular attention to the fact that the two side legs are rectangular in cross-section, while the center leg is cruciform and of larger cross-section than the side legs; this is in order to make the middle leg as nearly circular in cross-section as possible, in order that the distance from core to the inside of surrounding coils be as uniform as possible.

Coil Winding

This cruciform construction of the center leg is of very recent design and is used in connection with an entirely new system of constant current transformer coil construction which has recently been developed. This construction is known as the "edgewise wound" construction; and while it has been used for some time back in constant potential power and lighting transformers, it has only recently been adapted to constant current transformers. This system of winding employs wires which are rectangular in cross-section, the width being several times the thickness. Except for the stiffness of the copper, this copper strip, when covered with its several thicknesses of insulation, looks not unlike ordinary cotton tape. In the winding of the coils a specially designed cylinder is rotated in a winding machine similar in construction to an ordinary turning lathe. The full diameter of this cylinder is exactly the same as that of the inside diameter of the finished coil. On this form the wire is wound on edge; but, inasmuch as many hundred turns are frequently wound in one coil, special arrangements are necessary to enable the completely wound coil to be removed from the form. This is accomplished by using a winding form that can be partially collapsed, thereby permitting the form to be withdrawn from the coil without the slightest damage to the coil, and incidentally making the operation of withdrawal very simple.

In the winding, the wire is fed through a friction device to give the required tension, the starting end of the wire being clamped to a flanged collar revolving with the winding form. The wire is pressed firmly against

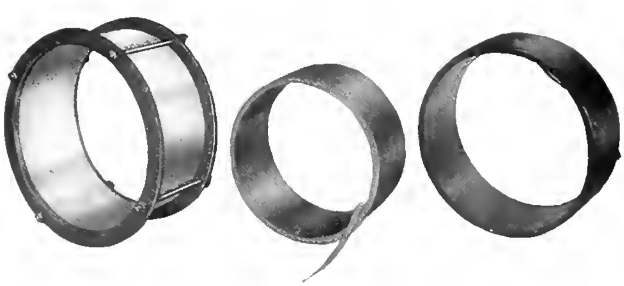


Fig. 2. Coils and Clamping Ring of Constant Current Transformer

the collar by another collar, which loosely fits the winding form and is held stationary; next follows another flanged collar which presses heavily against the stationary collar, thereby forcing the several turns of wire very tightly against one another. The flanged collar, or follower, thus travels slowly along the winding form; so that for one revolution of the machine it travels a distance equal to the insulated thickness of one turn of the conductor. After the required number of turns have been wound four bolts are passed through an iron collar at either end of the winding, as shown in Fig. 2. The winding form is then collapsed and removed, thus leaving a hollow cylinder of wire, whose inside diameter is equal to the original outside diameter of the winding form, and whose outside diameter is greater than the winding form by the insulated *width* of the conductor.

Coil Insulation

The coil thus wound and clamped is then baked at a temperature of approximately 180 deg. Fahr. in a well-ventilated oven, thereby removing every vestige of moisture; and, while still hot, is dipped in a tank containing insulating varnish. This varnish is rapidly taken up by the cotton insulation on the wires, and so thoroughly permeates the coil that moisture cannot enter. The coil is then baked again at the same temperature as before, and receives a second varnish dip, after which it is baked again. These repeated dippings and bakings cement each turn of wire to its neighbor so solidly that the coil becomes self-sustaining, as shown in Fig. 2 (center). The dipping and baking process above mentioned is repeated until the insulation will take up no more varnish.

Following the dipping and baking process, the coil is wound with tape approximately one inch wide, each turn overlapping the preceding turn by one-half to one-third its width. This insures practically uniform strength of insulation over the entire surface of the coil. Various kinds of tape are used in the insulating of coils, such as cotton tape, which is varnished after applying, varnished cambric tape, which is treated before applying, and mica tape. The last mentioned tape is, however, only used on very high voltage coils. Where cotton taping is employed it receives a brushing of the highest quality of insulating varnish, is then baked, revarnished and rebaked; and this process is repeated several times for each tape. It is a fixed rule in the factory that no untreated material must be employed in insulating these coils. The various materials are used in combinations best suited to the particular location on the coil and the insulation strain on this particular part of the coil; for instance certain points on a finished coil may require much more insulation than others, depending on their distance from grounded parts of the apparatus, etc.

Assembling the Transformer

The completed taped coil with lead terminals, as shown in Fig. 2 (right), is now ready

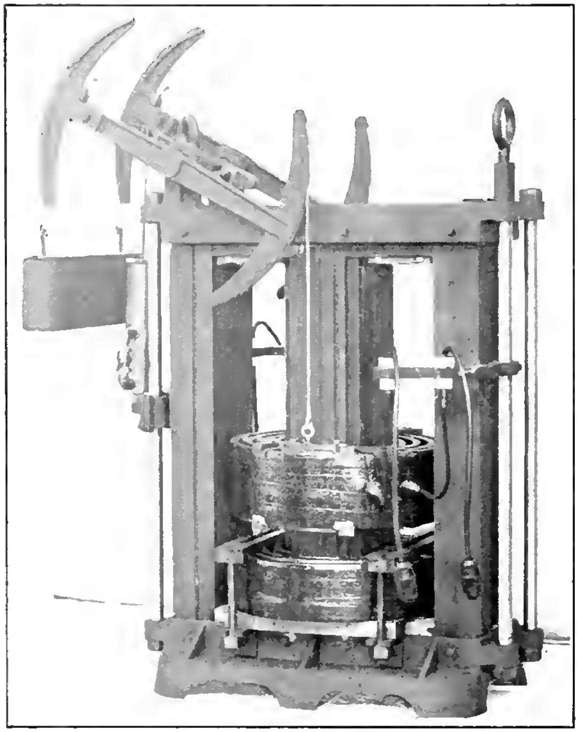


Fig. 3. Constant Current Transformer for Series Lighting

for assembly. Where, as in many cases, the total voltage on each winding is high, the large number of turns required would result in a coil of a length too great to be serviceable, if all these turns were wound in one coil. It is, therefore, the practice to divide each winding into several coils (usually four) connected in series. These four coils are wound on forms of different diameters so that they may be assembled one inside the other, with insulating blocks between, and held in place by clamps at top and bottom securely bolted together. It is customary to make the lowest-voltage coil the movable coil. In the case of transformers for use with mercury arc rectifier outfits, this is always the primary winding. On transformers for series alternating current lighting circuits the secondary coil is usually movable. The coil clamps previously referred to are, in the case of the movable coil, bolted together with insulated metal bolts, as they not only serve to keep the several coils in

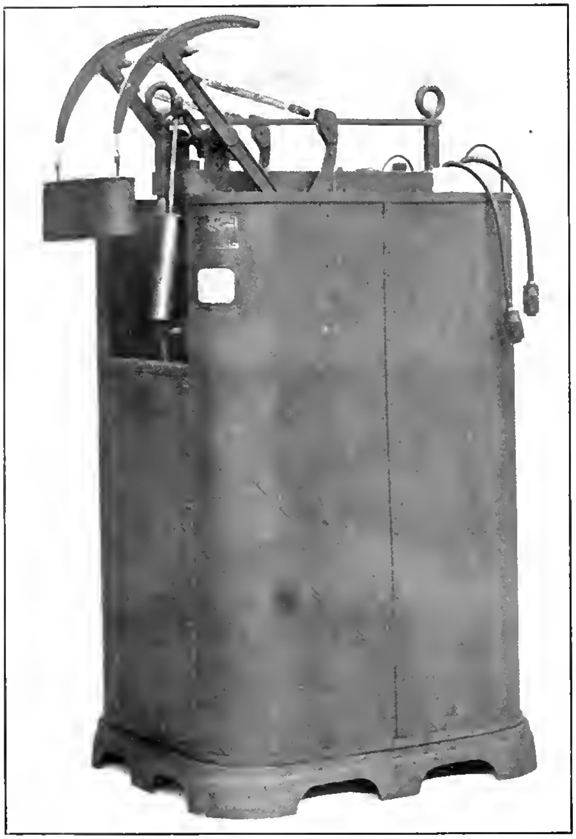


Fig. 4. Constant Current Transformer for Use with Mercury Arc Rectifier

position, but also are required to support their entire weight. In addition they are called upon to withstand the shocks experienced when the coil is violently forced from one position to another along the core. For example, if the transformer is running at full load and the secondary line becomes short-circuited, the coil would travel the full length of the core in a very short period of time.

The stationary coils are clamped by bolts and nuts made entirely of insulating materials. These, however, are not required to do more than hold the coils firmly in position, as the weight of this coil is carried on the bottom clamp. The core shown in Fig. 1 is next placed in the bottom clamp and firmly secured by clamping screws passing through the side of the clamp. The coils are then placed over the core, encircling the center leg, and the top end irons are then carefully put in place. The top clamp is placed in position and the side rods tightened, thus securely holding the top clamp with the completed core to the base. The top clamp casting carries the balancing mechanism. This consists of levers keyed to a steel shaft which turns on carefully made ball bearings, thereby reducing friction to a minimum. The supporting cords are now conducted from the fixed sectors of the balancing mechanism to the movable coil on the one side of the shaft, and from the adjustable sectors of the balancing mechanism to the hanger-weight on the opposite side of the shaft, thereby balancing the coil against the hanger-weight.

The general appearance of the finished transformers varies somewhat according to the service for which they are designed. Fig. 3 shows one of the first constant current transformers of this construction built for series alternating current lighting. This, while differing somewhat in minor details, may be considered typical of the general construction of the whole line. Fig. 4 shows a transformer for use with a mercury arc rectifier outfit. This transformer is shown enclosed in a casing which is deemed necessary in some stations to protect the operators against accidental contact with the high voltage windings.

In closing it might be well to mention two electrical advantages which are particularly noticeable in the form of winding described in this article. Owing to the fact that all the turns in any one coil are in one layer, the voltage between any two adjacent turns is very low (in no case higher than twelve volts). This is in marked contrast to the old style layer-wound coil, where the voltage between turns at the ends of adjacent layers was often as high as 100 or 120 volts. By removing these high differences of potential much space previously used for insulation is saved. From the standpoint of heating the edgewise-wound coil is an ideal construction. The liberal air ducts allow free radiation of heat; while the fact that the two edges of each individual conductor are at the surface of the coil does away with conductors buried in the center of a thick coil, and with the consequent high heating at this point.

BOOK REVIEW

"THE MAGNETIC CIRCUIT"

By V. Karapetoff

McGraw-Hill Book Company (1911)

270 pages. 64 Illustrations Price, $2.00 net

Karapetoff's "Magnetic Circuit" is one of the most *original* contributions to electrical engineering literature which has come under the present reviewer's attention for a long time. A casual glance through its pages might convey precisely the opposite impression, for the text is honeycombed with allusions to the investigations of other workers in this field. Karapetoff has employed his intimate familiarity with the literature of the subject to interweave the results of the researches of these authors with the results of his own investigations and reflections. Indeed, the investigations of his contemporaries are described by the author with a lucidity which in several instances endows the conclusions now for the first time with thoroughly practical usefulness. It might, however, be more decorous for the present reviewer to speak exclusively for himself on this point. From this standpoint, he has no hesitation in stating that in several instances where he has in vain struggled with various of the original publications in question, only to be compelled to admit that he could not make out what the authors were driving at, he has readily followed Karapetoff's version as presented in the present treatise, and has been very much impressed by the important conclusions deduced therefrom. In many such instances, however, one cannot but believe that the conclusions are Karapetoff's own. Under his clear reasoning the wheat has been separated from the chaff; the needle has been extracted from the haystack, the pearl from the oyster; at any rate, thanks to the author, the wheat and the needle and the pearl are now ready at hand for the edification of their possessor.

In the earlier chapters of the book the treatment is confined to those magnetic circuits for which the magnetomotive force is provided in a single electric circuit. In so far as air is a component of the magnetic circuit, the treatment is rendered novel and interesting by the author's plan of assigning to air a permeability of $\frac{4\pi}{10} = 1.257$. By this plan it becomes rational to employ the ampere-turn as the unit of m.m.f. instead of the gilbert, and this is done throughout the book. The advantages of the plan are amply demonstrated. The term "magnetic intensity" is employed to denote the m.m.f. in ampere turns per centimeter of length of the magnetic circuit. The letter H is adopted for denoting the magnetic intensity as thus defined. As usual, B is employed to denote the flux density in lines per square cm. Also, as usual, μ denotes the permeability and we still have:

$$\mu = \frac{B}{H}.$$

In virtue of Karapetoff's innovation of indicating by H the ampere turns per centimeter, μ is no longer, as in former usage, the ratio of the flux density in a given material to the flux density in air (for the same m.m.f. gradient), but is smaller in the ratio of 10 to 4π, since a m.m.f. gradient of one ampere-turn per cm. occasions in air a flux density, not of 1 line (or 1 maxwell) per square cm., but of 1.257 lines.

A new unit, the "perm", is introduced. It is defined by stating that "a magnetic path has a permeance of one perm when one maxwell of flux is produced for each ampere-turn of magnetomotive force applied along the path." Thus the permeability, μ, may be expressed in perms per centimeter cube; for if a m.m.f. of one ampere-turn acts to occasion a magnetic flux between two opposite faces of a centimeter cube, the flux in maxwells (or lines) in the square centimeter of cross-section will be quantitively identical with the value of μ for the material of which the centimeter cube is composed. For air and other non-magnetic materials μ is equal to 1.257.

The chapters devoted to the preliminary discussion of the magnetic circuits employed in various types of electric machines are followed by a group of chapters dealing chiefly with the estimation of the magnetomotive forces required in the exciting circuits in concrete cases, to occasion prescribed electromotive forces in other circuits which are not carrying currents (and which, consequently, are not themselves the seat of magnetomotive forces), such as in the unloaded secondary circuits of transformers, and in the armature windings of generators and motors, when these windings are on open circuit. These chapters are replete with descriptions of methods dealing with practical cases.

The magnetomotive forces occurring in these secondary circuits when the machines are loaded are next taken into consideration. This involves the more complex phenomena associated with those magnetic circuits in which the resultant m.m.f. is obtained from components located in more than one electric circuit. This leads to discussions of the inherent variations in the pressure in electric machinery when the external load varies as regards quantity and as regards its nature (such as its phase), and is inextricably associated with the subject of magnetic leakage and inductance.

One of the most interesting chapters in the book is that entitled "The Inductance of the Windings of Electrical Machinery," wherein is found a large amount of valuable material of an eminently practical nature.

While the book is one of great importance to the professional designer of electrical machinery, the plan and execution are so logical and clear, that, notwithstanding the inherent difficulties of the subject with which it deals, the book can also be confidently recommended to the *determined* and *earnest* student. This hypothetical student should understand in advance that in undertaking to master the contents of the book, he is embarking upon no light task. The present reviewer is, however, not aware of any method by which the knowledge in question can be more readily acquired. There have been arranged for the student hundreds of carefully conceived problems. These have been distributed at approximate places in the text and the student can rest assured that he will be making excellent use of all the time which he devotes to the solution of these problems.

The diagrams and illustrations have been carefully prepared and are consistently appropriate.

H. M. Hobart

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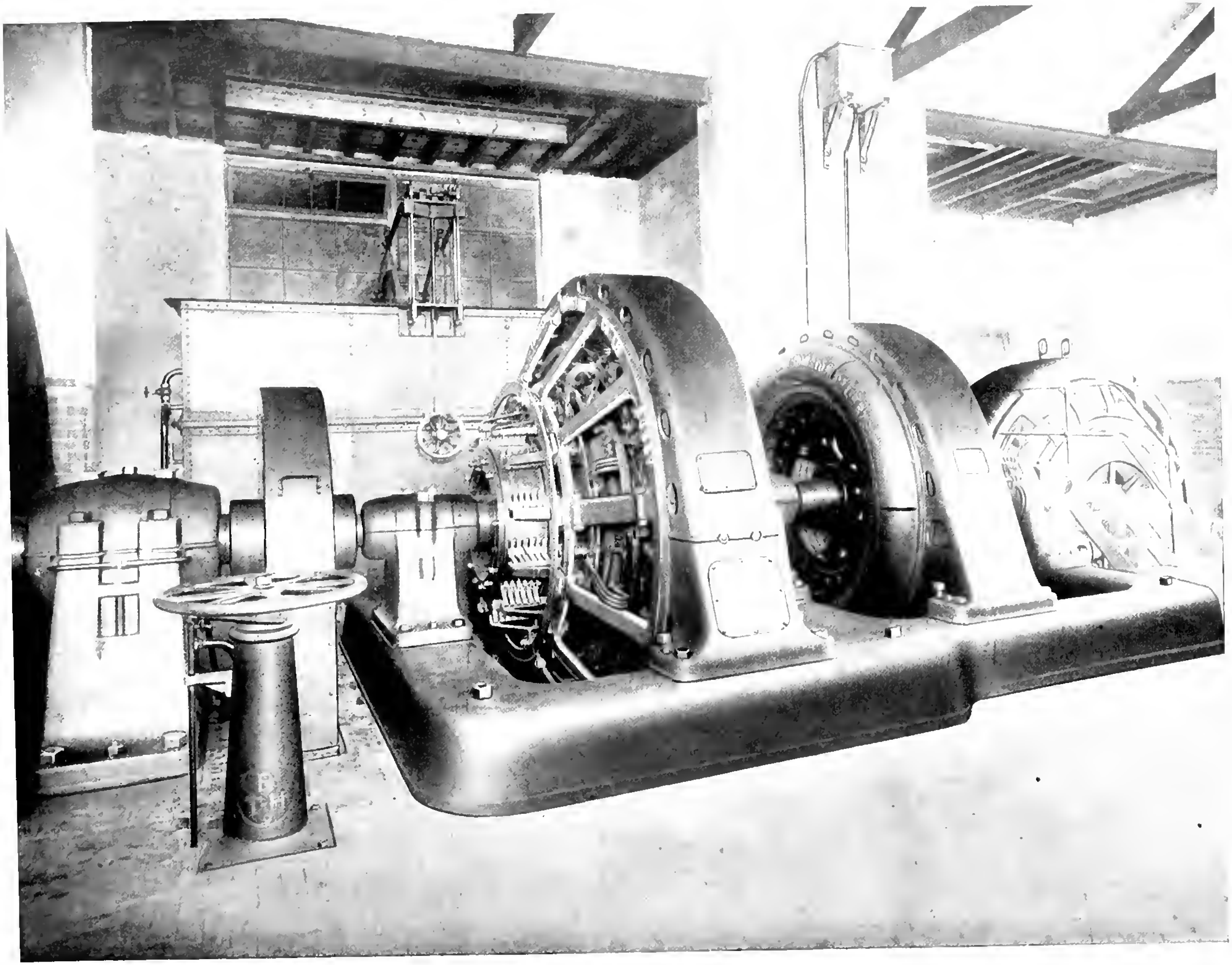


Generator and Motor of Flywheel Equalizer Set, with 1200 H.P. Direct Current Cogging Mill Motor, at the Works of Messrs. Dorman Long, Middlesborough, England.

(See Page 207)

GENERAL ELECTRIC REVIEW

ELECTRICAL PROGRESS IN BRITAIN AND AMERICA

Elsewhere in this issue appears an article describing an electrical steel mill installation in England,* which should prove of additional interest to American engineers by reason of the fact that the advanced practice which it represents has been achieved by manufacturers who have to conduct their business under circumstances considerably less favorable than any which obtain in the United States.

The severity of the competition among British electrical manufacturers is probably generally appreciated in this country; but few who have not come into personal contact with it can form any idea of the extent to which it ties the hands of the progressive manufacturer. Of the men who know—and there are comparatively few who possess the necessary experience upon which to base a judgment of any value—probably a majority are of the opinion that in lines of apparatus which are now fairly well standardized, the British manufacturer has brought his production to a higher point of efficiency than that of any other nation. His progress along the line of development of the big central station idea, however, has necessarily been restricted; and the layman is educated to consider bulk as the sole standard for making comparisons of relative progress. It is not proposed here to search for the reasons which have brought about the present state of affairs in the British electrical market; but it may be of interest to comment on the extent to which the activities of the manufacturer are restricted, and what must happen before any permanent improvement can take place. These comments are simply an expression of personal opinion.

First, progress in the development of the big-station idea has required an enormous amount of experiment and research, undertaken to obtain the fullest knowledge of natural laws, in order that the greatest economic gain may result from the application of these laws. Individuals may divide the work of investigation and of application; but the gain to the industry will be greatest when the activities of the investigator are directed along lines indicated by economic necessity or expedience. This conservation can only be achieved if the manufacturer, the party who has to meet commercial needs, is able to go after and obtain the necessary scientific knowledge upon which to base the design of his apparatus. *Second*, amongst the manufacturers some healthy competition is necessary in order to stimulate activity in producing and adapting apparatus for a widening field of usefulness; excessive competition is altogether harmful, since it almost invariably results in making the question of price pre-eminent, of starving each individual manufacturer, and hence of denying to him those financial resources required for prosecuting the research work which he sees to be necessary, if further progress is to be made. *Third*, in the United States the responsibility of producing electrical supplies for the nation has been carried by relatively few great houses, sufficient in number to promote healthy competition, but few enough to ensure that the producer can lay aside a considerable percentage of his annual profits in order to maintain a faculty in his organization, which will be concerned only indirectly with production and commercial questions, and which will act under the instructions of some of the most eminent engineers of the profession, employed by the manufacturer for the sole purpose of watching this new development work. *Fourth*, in Great Britain a large number of firms of approximately equal standing divide all the business of producing for the nation.

Whatever be the fundamental reason that brought it into being, this excessive competition is handicapping the electrical industry in Great Britain. Even if the manufacturers were permitted by English law to combine for the maintenance of prices, it is unlikely that this would result in any per-

*"A Notable Example of British Rolling Mill Electrification," by G. M. Brown, see p. 207.

manent improvement. For what it is worth, the opinion is submitted that relief will only be found when two or three firms can shake off their rivals and establish themselves in a strong position. In a "strong" position, they will enjoy many advantages at present denied to them. Factory costs will be less, through purchasing, manufacturing and stocking in bulk, and through earlier standardization of tools, parts and finished product; transportation rates for heavy shipments will be adjusted and reduced; selling costs will be less owing to reduced advertising rates and salesmen's expenses per sale; and competition over price will be transformed into competition over quality. Increased profits will permit the manufacturer to develop the research-consulting end, and to establish a better connecting link between academic and commercial questions than will ever be possible under existing conditions. The producer will then gradually shake himself free from the fetters of demand, and will be able to anticipate the demand with the supply.

All of these benefits are in reality cumulative. The result of them all is gradually to give to the big manufacturer a standing, a cherished possession which far outweighs in value all the other advantages. The acquirement of this standing alters his position relatively to that of the consulting engineer. He becomes more independent. In a country where a number of firms are engaged in a cut-throat battle over prices, it may be really necessary that a consulting engineer be employed, to frame a rigid specification, and to see that it is met by the manufacturer. From the purchaser's standpoint this is excellent; from the manufacturer's side the position is less happy. Under these conditions he may be called upon to fill, say, six contracts in the course of as many months for the supply of a number of motors of substantially the same rating and to meet similar requirements, but is bound by the specification to embody special features, all different, in each; to lay out new drawings or to modify old ones; to purchase or make new tools, gauges, templates, and so on; until at length he finds himself cheated out of the profits which should by all justice be his. If, seeing in his mind's eye these profits disappearing, he puts in a plea for his standard apparatus, the consulting engineer as a rule will have none of it; and he is brought to his knees with the threat "Build to my specification or take farewell of the contract." Give him a standing, and he can proffer his plea with a big chance of its receiving attention. Increase his standing, strengthen his financial resources, and you will find in course of time that his high-salaried experts are solving operating troubles in the research room or on the model transmission line, are embodying their findings in the design of special though (for them) standardized apparatus, and are producing the goods upon which no one, outside of that organization, has any qualification to dictate to them. No longer will the manufacturer feel himself compelled to stand back from risking money in experimental schemes which, although possibly containing all the essentials for ultimate success, yet show no certain indication of immediate gain; but will be enabled without hesitation to appropriate for such work sums of money which, if success were not immediate, might alone be sufficient to cause a smaller manufacturer considerable financial embarrassment.

In England, then, the universities and the consulting profession hold in their ranks men who could be more profitably employed by the manufacturer; they cannot be so employed until the manufacturer is making enough profit out of his business to pay them the salaries they require; he cannot get the profits out of his business until he has acquired the standing which renders a large part of the outside consulting work unnecessary; under the *regime* of fierce competition no manufacturer can acquire this standing, and close surveillance of all by the consultant is the rule. It is this state of affairs which has resulted in the extraordinarily high standard of efficiency which has been reached in all departments of the electrical manufacturing business in Britain, in the workmanship of the machine, as well as in the ingenuity of the designer which enables him to extract the very last watt out of each pound. It is this same condition which will continue to prevent the British electrical manufacturer from performing his full share in pioneer work toward the bulk electric supply systems prophesied by Steinmetz and Edison.

In the above essay the writer's purpose is simply to indicate the course of evolution or elimination which must be worked out before relief can be expected. He does not presume to specify the radical changes which presumably must take place before this course can be set in motion.

D. S. Martin

CENTRIFUGAL COMPRESSORS

Part II

By Louis C. Loewenstein

Engineer, Turbine Department, General Electric Company

The first part of this article, published in the March Review, consisted largely of the theory of air compression and centrifugal air compressors, and contained a quantity of data in the shape of formulæ, tables and curves. This data will be employed in a subsequent installment to solve a few typical problems. The present installment treats principally of the application of the centrifugal compressor to the blowing of blast furnaces, cupolas and Bessemer converters, and includes a description of a very ingenious constant volume governor for controlling the quantity of air delivered.—Editor.

Centrifugal compressors can be used wherever any compressible fluid is to be compressed or pumped. The various forms of compressing apparatus, besides centrifugal compressors, may be classified as follows: fans or blowers; positive pressure blowers; and reciprocating compressors.

Fans or blowers, such as are shown diagrammatically in Fig. 8, are chiefly used when the desired compression is very small and where efficiency is of less importance than first cost. It has already been shown that the ordinary fan or blower delivers simply a pressure approximately equal to the centrifugal pressure generated by the revolving impeller or runner. The velocity energy existing in the air at impeller exit is lost in the form of heat. Hence the centrifugal compressor, which recovers the larger part of this velocity energy in the form of pressure, must necessarily be much more efficient than the ordinary fan or blower. A good practical dividing line between the field of usefulness of ordinary fans and centrifugal compressors may be said to be at about ¾ pound pressure. This dividing line, however, is not a sharp distinction, as in some cases it is advisable to use a centrifugal compressor even for a pressure of half a pound, while in other cases, when efficiency plays no important part whatever, fans and blowers can be used to give pressures of almost a pound.

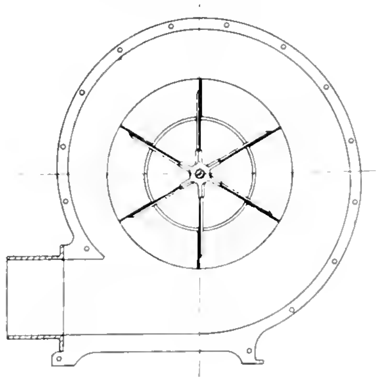


Fig. 8. Fan Blower

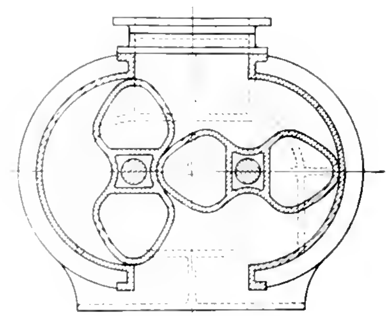


Fig. 9. Positive Pressure Blower

Positive pressure blowers are machines in which the rotating part consists of one or more drums with lobes running with close clearances to the casing, as is shown in Fig. 9. These lobes form pockets in which the air or gas is pocketed on the intake side of the compressor and carried in this pocket over to the outlet side of the compressor. If there is no resistance on the outlet or discharge end, the air is simply moved from inlet to outlet. If, however, a higher pressure exists at the discharge end, then the air delivered will be raised to the pressure of air existing on the discharge side. In other words, these machines are pure displacement machines and displace at every revolution a certain volume of air.

Some variations of design of positive pressure blowers are shown in Figs. 10 and 11. If the clearance between the rotating parts and the casing is exceedingly small, the efficiency will be good, but very close clearances mean rubbing and wear. If the clearances are large, on the other hand, the losses due to slippage, that is, return of air from the discharge end to the intake end through these clearance spaces, will be large and the efficiency thereby impaired. The usual practice on moderate and large size positive pressure blowers is to use a lubricant between

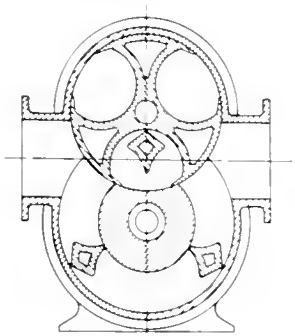


Fig. 10. Positive Pressure Blower

the rotating and stationary parts so that the amount of wear is reduced to a minimum. Wear, however, will occur and when the slippage losses become too great renewal of rotating parts is necessary. Positive pressure blowers are used mostly for compressions of from 1 to 5 pounds per square inch. Comparing this type of apparatus with a centrifugal compressor we may say that the positive pressure blower may with careful design give the same efficiencies when new, but will have much poorer efficiencies after the machine has been running for some time. Besides this, the difference in floor space required is considerably in favor of the centrifugal machine.

Reciprocating compressors are efficiently used when the desired pressure is 15 pounds per square inch or higher. There is a great deal of difference in design between various makes of reciprocating compressors which influence the commercial efficiency of this type greatly. The rating of reciprocating compressors (and also positive pressure blowers) is usually expressed in displacement air, that is, the volume swept through per minute by the reciprocating compressor piston. This displacement air is about 15 to 20 per cent. higher than the actual air delivered by the compressor. This can be easily understood if we remember that in a reciprocating compressor the pressure in the clearance spaces between the piston and the cylinder and in the ports up to the discharge valve is equal to the discharged air pressure when the piston reaches the end of its stroke. When the piston returns the air in the clearance space must expand to atmospheric pressure before any air from the atmosphere can be drawn into the cylinder; hence only part of the volume swept through by the piston represents air admitted to the cylinder, and the actual air delivered is usually less than the displacement of the reciprocating piston. The ratio between actual air delivered and displacement air is called volumetric efficiency.

Some designers have attempted to increase the volumetric efficiency of reciprocating compressors by increasing the velocity of the air at intake, that is, a high velocity of air is established when the piston is drawing air from the suction end. If this velocity is high enough there will be an actual compression of intake air when the piston reaches the end of its stroke and before it starts compression, due to this high velocity head. It is possible to bring the volumetric efficiency up to 100 per cent. and even above, but this is done at a sacrifice in energy efficiency, and the power loss due to establishing a high velocity of intake air more than counteracts the gain achieved by increasing the volumetric efficiency. The best that can be done is to make the clearance spaces as small as possible, and with good design the difference between displacement air and actual air delivered need not be over 12 to 15 per cent., if all valves are tight. In order to have low resistances to air flow, the intake and discharge valves of the reciprocating compressor should be large in area. The falling off in the efficiency of the compressor after running for some time is

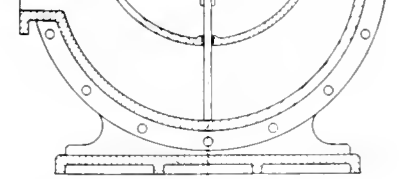


Fig. 11. Positive Pressure Blower

generally due to leakages past these valves, and good attention is necessary and periodical renewals should be made in order to maintain good efficiency on reciprocating compressors.

Centrifugal compressors have the great advantages of not having any close clearance to produce wear by rubbing, and of having no valves that can leak. A centrifugal compressor will have the same efficiency after years of service as it had when new. Besides this there is a decided saving in the cost of operation and maintenance of the centrifugal compressor over that of a reciprocating compressor. There is a decided difference in size between a centrifugal compressor and a reciprocating compressor of the same rating, and therefore the cost of foundations is very greatly reduced when centrifugal compressors are used. In discussing the centrifugal compressor for blast furnace operation more will be said as to relative size and cost of operation.

It may be interesting to take up several of the most important commercial applications of centrifugal compressors and explain the advantages gained by their use over other types of compressing apparatus.

Blast Furnace Work

One of the most interesting developments of recent years is the application of the centrifugal compressor to blast furnace work. The blast furnace is primarily an apparatus for producing pig iron, and incidentally it may also be regarded as a huge gas producer. The materials put into a blast furnace are the iron ore, the fuel, and the fluxes, which are charged at the top of the furnace or throat, and the air blast, which is blown in near the bottom of the furnace at the tuyeres. The materials discharged from the furnace are pig iron and slag, which are tapped from the bottom or crucible of the furnace, and the gases and dust, which pass out of the top of the furnace. The iron ore in a blast furnace is deoxidized or reduced, for which purpose the ore is charged with sufficient carbonaceous fuel to do two things: To abstract all the oxygen from the reducible metallic oxides and to furnish enough heat (or high enough temperature) to melt down to superheated liquids the pig iron and slag—combinations of irreducible metallic oxides—that are formed. The fuel must supply the reducing energy and the melting-down or smelting requirements; the first by acting upon the metallic oxides at a red to a white heat and abstracting their oxygen; the second,

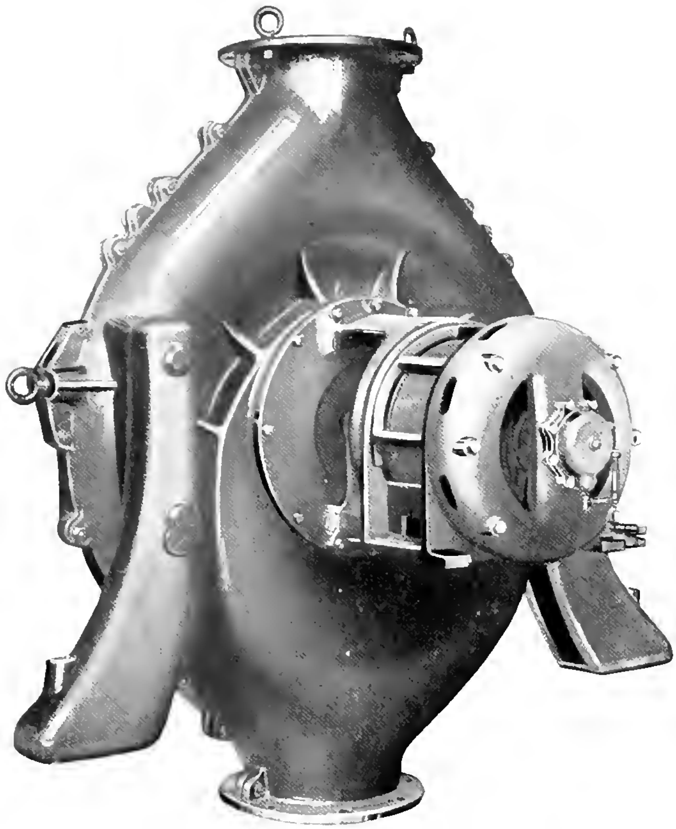


Fig. 12. Centrifugal Compressor Driven by 50 H.P. Induction Motor
Front to Back, 5 Ft. 2 In.; Width, 7 Ft. 3 In.; Height, 7 Ft. 8 In.

by being burned at the foot of the furnace by the hot air blast, and there generating the heat and higher temperatures necessary for the smelting down of the materials already reduced. The blast furnace may also be regarded as a huge gas producer, run by hot forced blast, in which the incombustible portions of the contents are melted down (with a little unburnt carbon) to liquid metal and slag, and are run out beneath, while the gaseous products pass upwards through 50 to 100 ft. of burden, and escape above. The escaping gases are primarily of the composition of producer gas, with some of its carbonous oxide changed to CO_2 by the oxygen abstracted from the burden; with some CO_2 added from the decomposition of the carbonates of the charge; and with the usual increment of moisture from the charge and volatile matter (if any) from the distillation of the fuel. Hence the blast furnace is a huge gas producer, giving a rather inferior quality of combustible gas in large quantities, while reducing to metal and slag the burden of iron ore and flux (limestone)

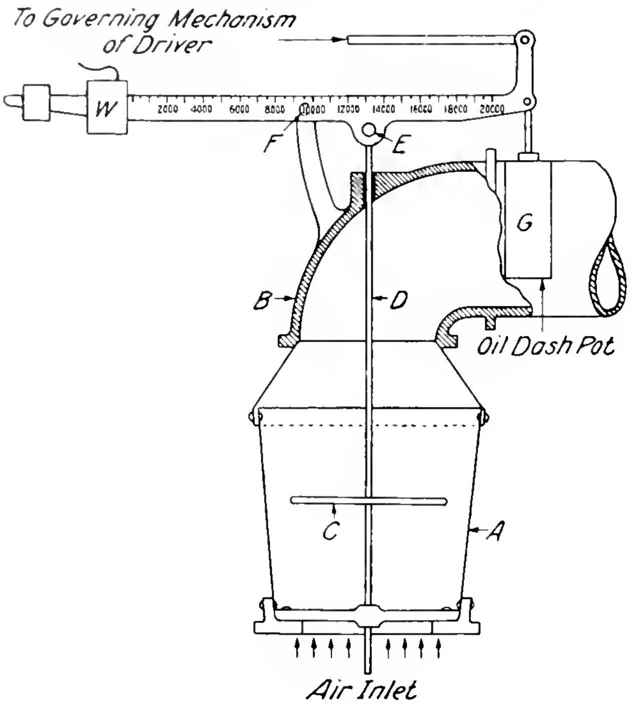


Fig. 13. Constant Volume Governor

which is put in with the fuel. But after all, the unoxidized and combustible ingredients of the gas escaping represent a large part, in fact, often the largest part, of the total calorific power of the fuel.

From the above it can be readily seen that if the charging of a furnace is uniform it is quite essential to have the amount of air supplied to the furnace also uniform in quantity. The air pressure required for forcing the air through the furnace varies with the condition of the burden or charge. If the particles of ore, fuel, and limestone are large, that is, the spaces between these particles ample, there is a freer passage for the air than if the particles of ore, fuel, and limestone are small and closely packed. Under certain conditions the furnace may require a pressure of 8 to 10 lb. to force a certain quantity of air through it, while under other conditions, when the material in the furnace is tightly packed, a much higher pressure, sometimes as high as 25 to 30 lb., is required to force through the same amount of air. It is therefore absolutely necessary that the air compressing apparatus installed be capable of supplying air under varying pressures, depending upon the condition of the furnace, and of delivering high pressures when the condition of the furnace demands it.

Up to the advent of the centrifugal compressor, reciprocating compressors were chiefly used for blast furnace work. The reciprocating compressor was run at a certain number of revolutions per minute, furnishing a certain quantity of air at a certain pressure. It was left to the judgment of the blast furnace operator whether or not the furnace was receiving the proper amount of air. If in his opinion the furnace was receiving too little air, that is, if it was underblown due to the charge on the furnace offering more resistance to air flow than previously, he would call for a higher speed of the reciprocating compressor. Speeding up the driver would then furnish a somewhat greater quantity of air at a higher pressure. If, however, the blast furnace was overblown, the reciprocating compressor was slowed down and less air and pressure furnished the blast furnace. This method of operating necessitated a decided change of condition in the furnace, before the furnace operator knew that the air supply to the furnace was not correct, and in many cases the furnace got into a very poor condition before the operator changed the air supply and improved conditions.

Knowing the exact amount of charge fed to the furnace, the weight of oxygen or air necessary to be supplied per minute can be closely ascertained; it would, therefore, be an ideal arrangement to have a governor which would govern the air compressor so that a constant weight of air (hence oxygen) can be supplied to the blast furnace, no matter what the resistance of the blast furnace to the air flow. If this quantity of air, for example, were 25,000 cu. ft. per minute, the governor should so regulate the compressor unit that 25,000 cu. ft. of free air would be delivered against any pressure necessary to force this air through the blast furnace. If the furnace were free and open, the usual air pressure would be, for instance, about 15 lb. per sq. in. If the furnace becomes more closely packed, or there is too great a production of slag, or anything else occurs in the furnace which will increase the resistance to air flow, the pressure required to force through the same amount of air may rise to 20 or 25 lb. Usually the limiting pressure of a blast furnace compressor is 30 lb., as this is the maximum pressure the stack itself will withstand with safety.

The General Electric Company has developed a constant volume governor, which can be attached to their centrifugal compressors for blast furnace work. Its principle can be understood from the diagrammatic arrangement shown in Fig. 13. The governor is placed on the intake end of the compressor, the air being admitted through a conical pipe (a) into an elbow (b), which is direct connected to the inlet flange of the compressor. In this conical pipe is mounted a horizontal float (c) suspended from a vertical rod (d). The latter is connected to a beam (e) which is free to move about a pin support (f). The beam is graduated to indicate the amount of air in cubic feet per minute that the compressor will deliver when the sliding weight (w) is placed at any particular graduation. An oil dashpot (g) is attached to one end of the beam to dampen any too violent oscillations. The method of operation of this governor when furnishing air to the blast furnace is as follows:

Suppose that 25,000 cu. ft. of air is to be delivered to the blast furnace: The sliding weight (w) is set at the graduation mark 25,000 cu. ft., and the float (c) will assume a definite position with relation to the conical pipe (a). Let us assume that this 25,000 cu. ft. of air is being delivered against a pressure of 15 lb. per sq. in., that is, with the driver of the centrifugal compressor running at such a speed as to produce an air pressure of 15 lb. If, at any instant, the charge in the furnace becomes more densely packed, or if the furnace is slowly beginning to get into an unhealthy condition through the formation of slag, the resistance to the flow of air through the furnace is increased. With this increased resistance the centrifugal compressor can no longer deliver 25,000 cu. ft. of air, because it would take a higher pressure than 15 lb. per sq. in. to force this quantity through the furnace, and we may say that momentarily a less quantity is delivered. Just as soon as this occurs, however, the float (c) can no longer remain in its present position, because it is not sustained by the original volume of air passing by it. As the volume of air decreases the float (c) will start to drop, whereupon the rod (d) will immediately move the beam (e) into a new position. The end of the beam arm is connected with the governing mechanism of the driver by means of suitable levers. In the case of a steam turbine drive it will admit more steam to the turbine and speed it up. This higher speed will increase the pressure delivered by

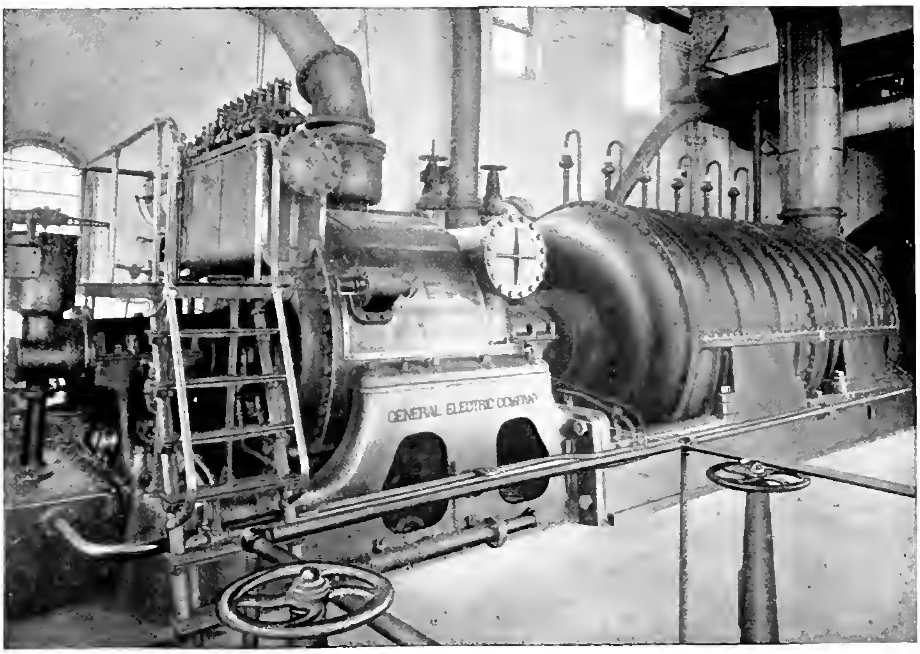


Fig. 14. Centrifugal Air Compressor Direct-Connected to Curtis Turbine. Installed at Empire Iron & Steel Co.'s Plant, Oxford Furnace, N. J., for Blast Furnace Work

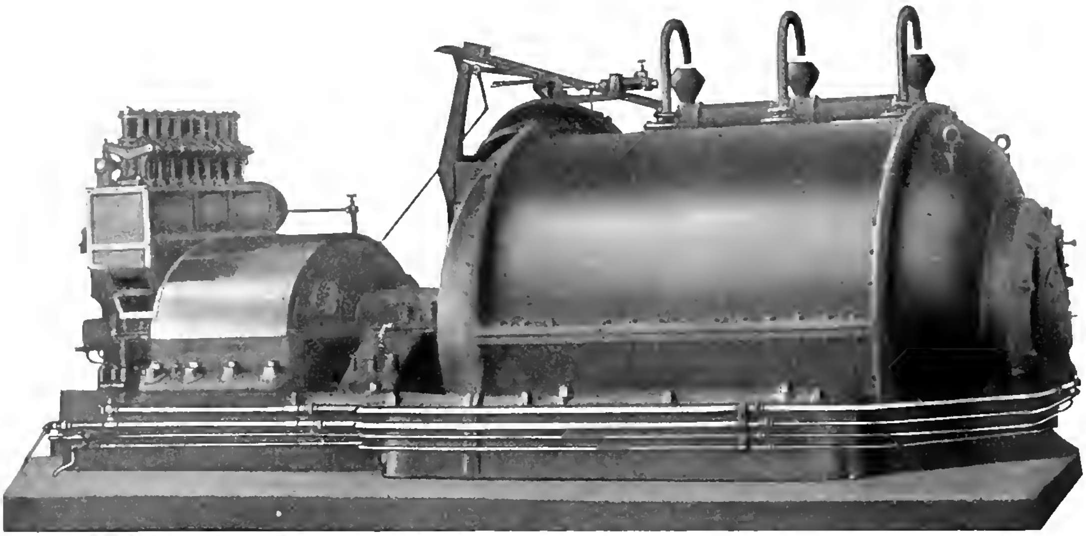


Fig. 15. Blast Furnace Turbine Compressor, Iroquois Iron Company, South Chicago

the compressor until the pressure is of sufficient magnitude to force through the original quantity of air, 25,000 cu. ft. per minute. As the turbine speeds up the pressure continues to increase slowly, and therefore also the volume of air, until the constant volume governor has almost returned to its original position. The governor will then keep the turbine running at the increased speed necessary to deliver the volume of air required. The constant volume governor therefore immediately responds to any change of condition in the blast furnace, and the compressor unit will speed up or down, depending upon whether a greater or less pressure is required to force through a constant volume of air. From this it can be seen that the constant volume governor responds instantly, long before the furnace operator could notice any change, and therefore the furnace is kept in a more uniform condition. This results in a larger output of pig iron of a more constant and better quality.

It will be noticed that the constant volume governor is placed on the intake end of the compressor, where the air is always at atmospheric pressure and therefore at constant density. Hence, if the constant volume governor calibrations or markings on the beam are determined and checked at the factory they are always sufficiently correct for blast furnace operation. The usual changes of barometer readings and the usual variations of moisture in the air do not change the volume calibrations to any noticeable extent. If, however, a constant volume governing device were installed at the discharge end of the compressor decided corrections would have to be made for variations in the density of the air when it is discharging against varying pressures.

The first centrifugal compressor installed for blast furnace work in this country was at the Empire Iron & Steel Co's. plant at Oxford, N. J. The compressor is a six stage unit direct connected to a four stage Curtis steam turbine and operating at a normal speed of 1650 r.p.m. At this speed the compressor delivers 22,500 cu. ft. of air against a pressure of 15 lb. per sq. in. It is, however, capable of furnishing 25,000 cu. ft., against a pressure of 25 lb. per sq. in. Fig. 14 gives a photographic view of this installation.*

A more recent development of a centrifugal compressor for blast furnace work, and no doubt the largest unit ever built in this country, is the machine shown in Fig. 15. It consists of a three stage centrifugal compressor direct connected to a five stage Curtis steam turbine. At its normal rating the machine delivers 35,000 cu. ft. of air per minute against a pressure of 15 lb. per sq. in. when running at 2500 r.p.m., the power required being approximately 2700 horse power. It is capable of delivering 40,000

* (For a complete description of this unit, its efficiency and its operation in practice on the blast furnace see article by Mr. R. H. Rice in the GENERAL ELECTRIC REVIEW, May, 1911.)

cu. ft. of air per minute up to a pressure of 30 lb. per sq. in.; the power required in this case being about 5400 horse power and the speed 3250 r.p.m.

The turbine is designed to operate with steam at 150 lb. per sq. in. pressure and to exhaust into a vacuum of 28 in., although overload valves are provided which allow the turbine to give full load when running non-condensing. The turbine is fitted with a centrifugal speed governor, which is set to limit the speed of the unit to 3250 r.p.m. It also is provided with an emergency governor which automatically shuts off the steam supply in case the centrifugal governor fails to work. When in operation the unit will usually be under control of a constant volume governor, the principle of which has already been described. In the present case, the governor may be set to deliver any desired quantity of air between 5000 and 40,000 cu. ft. per minute, the control being effected by altering the speed of the turbine so that the unit will deliver any pressure necessary, up to 30 lb. per sq. in., to pass

Fig. 16. Constant Volume Governor for Turbine Compressor of Fig. 15

the desired volume of air. A photographic view of the inlet cone and constant volume governor scale beam is shown in Fig. 16.

The compressor impellers are of the double inlet type, that is, air is admitted to both sides of the impellers in order to obviate any axial unbalanced thrust. European designed centrifugal compressors have impellers with inlet on one side only, and with such an

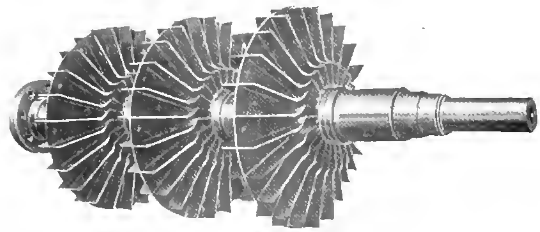


Fig. 17. Rotating Element of Three-Stage Blast Furnace Compressor

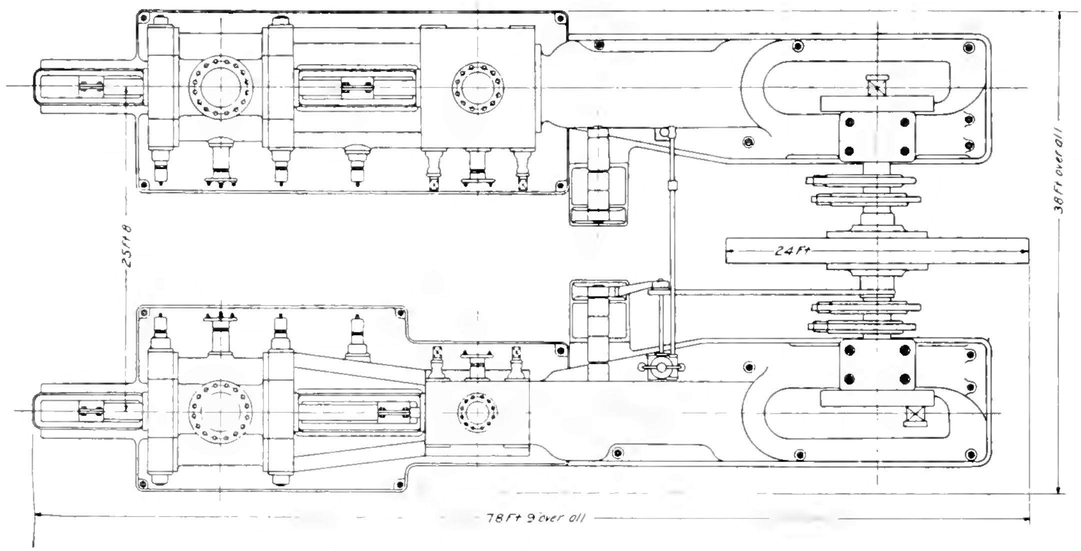
arrangement half of the impellers are usually assembled for air admission from one end and the other half with air admission from the other end, the axial thrust of each set of impellers being thus balanced against each other.

Fig. 17 shows a photographic view of the three impellers mounted on the compressor shaft. The impellers are 54 inches in diameter. The workmanship is excellent, great care being taken that the air passages are smooth. Surrounding the impellers are stationary discharge vanes mounted within the casing, and between any two successive impellers is a water-cooled diaphragm, so shaped and mounted in the casing that the proper air passages are obtained.

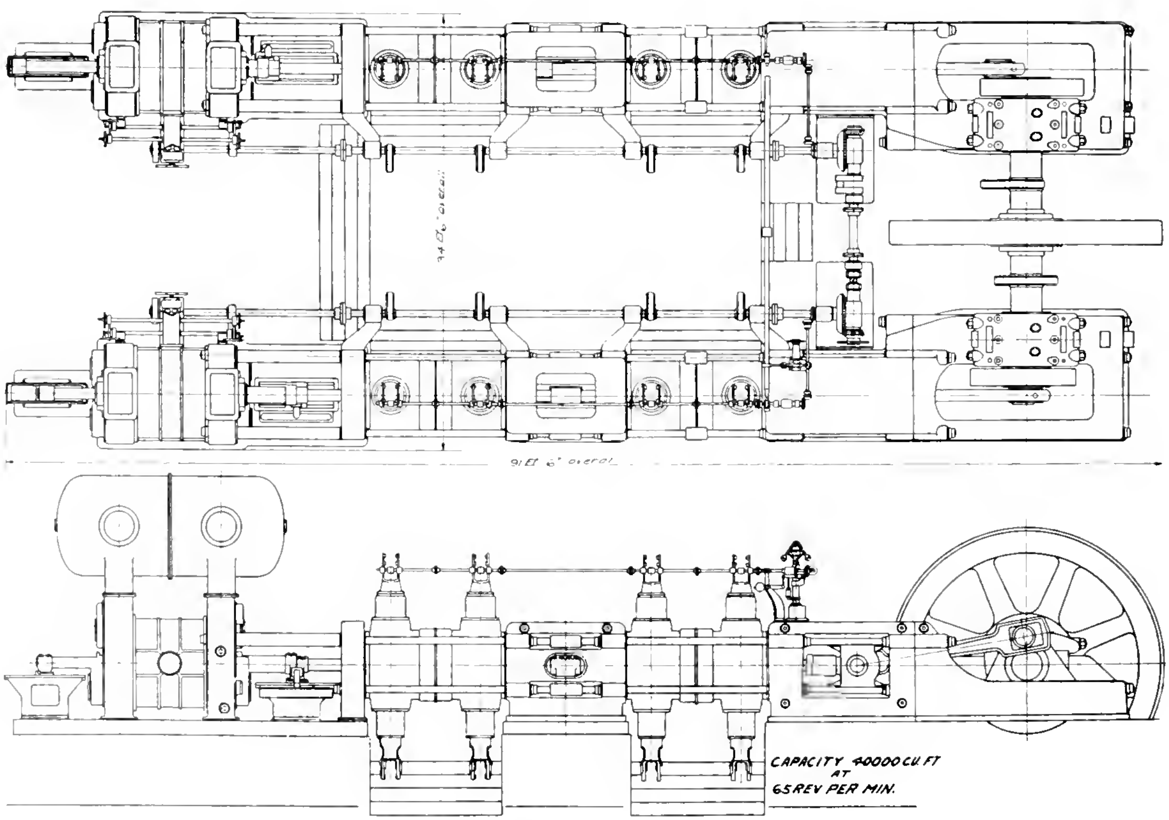
The unit has three bearings, all of which are of the ball seat type with ring and forced lubrication and with water cooled linings. The compressor shaft is connected to the turbine shaft by a solid coupling.

The mechanical operation of the machine is excellent. In operating the blowing unit it is necessary to manipulate the main throttle valve in the main steam pipe only when it is desired to bring the compressor to rest. At all other times control is effected through the scale beam of the constant volume governor with wide open throttle. At times of checking the furnace, or casting, the sliding weight on the scale beam is moved to the extreme end of the beam at the position indicating the minimum volume of air. After checking or casting, the sliding weight is returned to its normal position, when the unit again speeds up and delivers the necessary quantity of air.

When the required quantity of air or pressure is much less than the normal quantity



Cross Compound Steam Engine Driven Blower



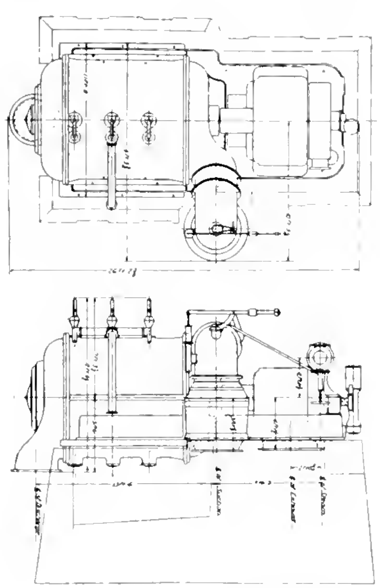
Gas Engine Driven Blower

Fig. 19. These diagrams are reproduced to the same scale and show

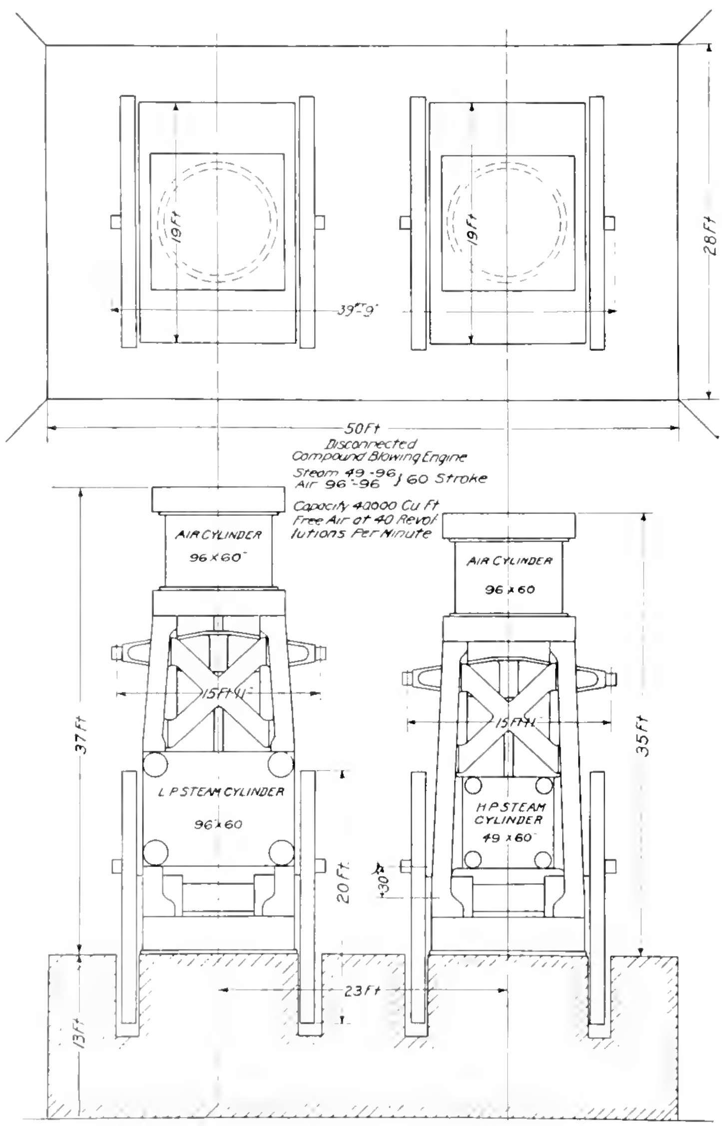
or pressure, the discharged air from the compressor will be found to pulsate in pressure. These small pulsations are an inherent characteristic of all centrifugal compressors and they occur when the apparatus is operated at loads and pressures differing widely from those for which the apparatus is designed. To overcome these pulsations a blast gate is installed on the inlet end of the compressor and by slightly closing the blast gate or throttling the air at intake all pulsations cease.

Fig. 18 shows the shaft and hydraulic efficiencies of this unit derived from shop test. Curves are also shown which represent the change of quantity of air with the load coefficient, $\frac{Q}{N}$, in which Q is the quantity of air per minute and N the number of revolutions per minute. The results here shown are excellent.

Three of these units are installed at the Iroquois Iron Company, South Chicago; the shop tests on which show that the guarantees made were fully met. It is interesting to note the small size of these units compared to the size of reciprocating sets. The floor space occupied is 26 ft. in length and 16 ft. in width over all, and the height of the unit is about 11 ft. Fig. 19 shows the overall dimensions of a vertical disconnected compound steam engine driven blower, a horizontal cross compound steam engine driven blower, and a horizontal gas engine driven blower, each of the same capacity as the turbine driven centrifugal compressor just described, the outline of these units being shown to the same scale. The gas engine driven blower weighs over one and one-half million pounds,



Curtis Turbine Driven Centrifugal Compressor



Disconnected Compound Steam Engine Driven Blower

the relative sizes of four types of compressors of equal capacity

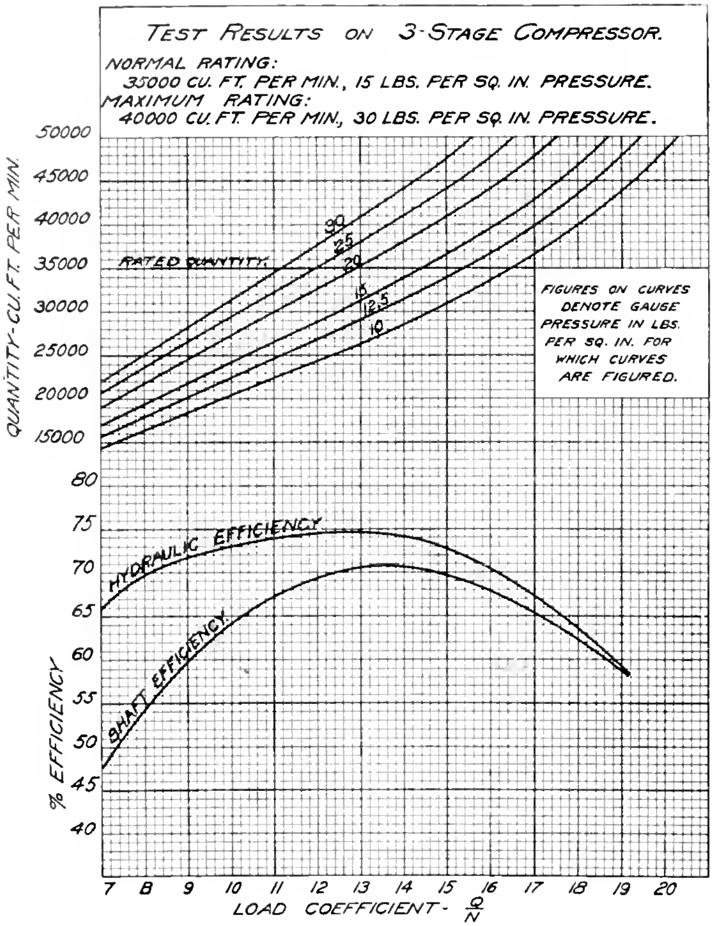


Fig. 18

while the weight of the turbine compressor is about 150,000 pounds. It has been found that, considering efficiency, this centrifugal compressor set should supersede all of the steam engine driven reciprocating blowers; and not only this, but considering first cost, cost of installation and operation, cost of cleaning and scrubbing the gas, cost of repairs and oil supply, etc., it would pay to replace also the gas engine driven blower operating on blast furnace gas with this new type of turbo-compressor, even if we do not take into consideration the improved output and the other great advantages derived from the constant volume governing feature, which cannot be installed on reciprocating blowers because the flow of air is not steady enough from these machines to allow the governor to operate.

Cupola Work

The problem of providing a proper supply of air for the operation of a foundry cupola is in many respects analogous to the problem of providing a proper supply of air to a blast furnace. The blast furnace requires much larger volumes of air and must be in operation for many months continuously; whereas, the operation of a foundry cupola is usually only a few hours each day. Hence the foundry cupola is not subject to the great variations in conditions of operation which occur in blast furnaces. It has been found that the blast conditions in the cupola are much more uniform than they are in the blast furnace and the requirements for properly operating a cupola at all times can be fulfilled by apparatus producing practically a constant pressure; therefore, no constant volume governor is required, as in blast furnace apparatus. For general cupola work single stage compressors are mostly used, which are capable of delivering $\frac{3}{4}$ to 1 lb. pressure and have capacities ranging from 1000 to about 10,000 cu. ft. of air per minute. One of the important points in connection with applying centrifugal compressors to cupola work is the extreme steadiness of the blast. The steady melting of iron and the steady descent of the charge from the cupola are dependent on the maintenance of uniform conditions of air pressure, because the charge in the cupola is to some extent supported by the pressure of the blast, and if this pressure varies the charge is likely to descend in a more or less irregular manner, which causes unsatisfactory working of the cupola.

Before the introduction of centrifugal compressors the positive pressure blower was mostly utilized for this class of work. In determining the amount of air necessary for a cupola, calculations have always been based on the displacement volume of the positive pressure blower, and it has been usually assumed that about 500 cu. ft. of air per minute were necessary to melt a ton of iron per hour. It has been found, however, that this is merely in terms of displacement air and not air actually needed. Careful tests have shown that only 400 cu. ft. of actual air per minute are required for each ton of iron per hour. This figure should be used in determining the proper rating of a centrifugal compressor to meet the require-

Fig. 20. Motor-Driven Centrifugal Compressor

ments of any cupola. If 500 cu. ft. of air per minute per ton of iron per hour are used, the centrifugal compressor would be too large for the work it is to perform.

Fig. 20 is a view of a motor-driven centrifugal compressor as used for cupola work. This compressor delivers 10,200 cu. ft. of air per minute against a pressure of 1 lb per sq. in. It is direct connected to a 75 h.p. squirrel cage induction motor running at 3450 r.p.m. Compressors for cupola work are also direct connected to direct current motors and steam turbines. The advantages of a centrifugal compressor over the positive pressure blower are not only its high efficiency and its uniform steady blast, but also the high maintained efficiency after months of operation, the great difference in weight and floor space occupied, the lower cost of foundations, the absence of any necessity of repairs or renewals, and a minimum amount of attention and cost of operation.

Bessemer Converter Work

The Bessemer process is used for converting pig iron into steel. Briefly stated, melted pig iron is put into the converter and numerous air jets are blown through this molten liquid. The impurities of the iron—carbon, silicon, manganese and, in a special case phosphorus—oxidize relatively faster than the iron, and the final product is usually nearly pure iron. This is recarburized to steel by spiegel-eisen. During the blow very little free oxygen escapes from the converter, and the gases produced are principally nitrogen, carbon monoxide and some carbon dioxide, while some hydrogen may come from the decomposition of the moisture of the air. The silicon, manganese, phosphorus and iron form silica, manganous oxide (MnO), ferrous oxide (FeO), phosphorus pentoxide (P_2O_5) which go into the slag, while a little Fe_2O_3, Mn_3O_4 and SiO_2 escape as fume.

The amount of air required depends on the analysis of pig iron used, and also on the analysis of the blown metal. The feature of the Bessemer operation which strikes the observer as most wonderful is, that cold air is blown in great quantity through melted pig iron, and yet the iron is hotter at the end than

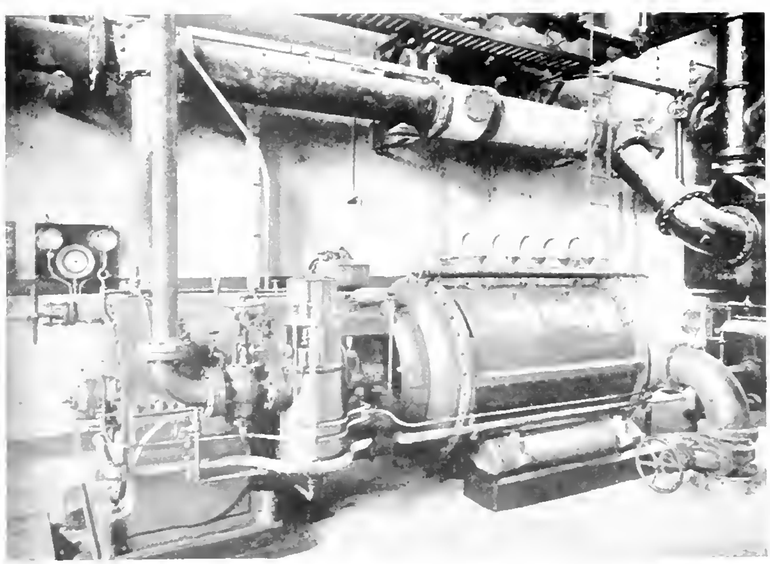


Fig. 21 Turbine-Driven Centrifugal Compressor for Bessemer Converter

at the beginning of the blow. If the observer will reflect a moment, however, he will see that if nothing but fuel, on fire, were in the converter, it would certainly be made much hotter by the air blast; and in a similar manner, the oxidation or combustion of part of the ingredients of the pig iron furnishes all the heat required for the process.

The air pressure required is simply that necessary to overcome the static pressure or the metallic bath and that of the slag formed, as well as the back pressure in the converter, and to give the required velocity to the air in the tuyeres and to overcome the friction in them. When the tuyeres are near to the surface of the bath, a pressure of 1 or 2 pounds per square inch will run the small converter, but the ordinary converter with bottom tuyeres requires from 15 to 30 pounds per sq. in. For a good approximation, the ferro-static pressure of the bath is practically $\frac{1}{4}$ lb. per sq. in. for each inch depth of metal. The metal lies 12 to 24 inches deep in converters in general use today.

As the resistances to air flow are constant in a converter, the centrifugal compressor needs no constant volume governor. The pressure delivered by a centrifugal compressor is almost constant over the entire range of capacity of the machine. Fig. 21 shows a view of a turbine-driven centrifugal compressor which can be used for converter work. The compressor has six stages and runs at 3450 r.p.m., delivering 5000 cu. ft. of air against a pressure of 15 lb. per sq. in. The prime mover is a 350 h.p. Curtis steam turbine.

(To be Continued)

ADVANCED COURSE IN ELECTRICAL ENGINEERING

PART II

BY ERNST J. BERG

PROFESSOR OF ELECTRICAL ENGINEERING, UNIVERSITY OF ILLINOIS

Example No. 4

Prove that all energy stored is spent in heat. The instantaneous value of the current was found to be

$$i = I\epsilon^{-\frac{r}{L}t}$$

therefore the energy expended in i^2r from time zero to infinite time is

$$\int_{t=0}^{t=\infty} i^2 r dt = I^2 r \int_0^\infty \epsilon^{-\frac{2r}{L}t} dt$$

$$= I^2 r \left[-\frac{L}{2r}\epsilon^{-\frac{2r}{L}t} \right]_0^\infty = -L\frac{I^2 r}{2r}(0-1) = \frac{1}{2}LI^2$$

It is of interest to study the rate at which the field flux, or what is equivalent, the field current, can build up when closing the field winding on a constant potential busbar, and to see how much quicker the field can be made to build up when a considerable resistance is inserted in series therewith.

To illustrate this, it will be assumed that the winding described in Example No. 3 is used, i.e., that its resistance is 36.5 ohms and its inductance 25 henrys. This circuit is connected to a constant potential direct current busbar of 110 volts. Referring to equation (14).

$$i = \frac{E}{r}\left[1 - \epsilon^{-\frac{r}{L}t}\right] = 3\left[1 - \epsilon^{-1.46t}\right]$$

Fig. 8 gives the result of this calculation in the lower curve, a few of the values being given numerically in Table A.

If, instead of exciting the winding from a 110 volt main, it is connected to a 220 volt circuit and sufficient resistance inserted in series to keep the permanent current at 3 amperes, the rise in current will be more rapid than in the first case, as shown in the upper curve, Figure 8, and Table B.

It is well to check these curves.

Prove that the current would rise according to curve b if, instead of connecting the winding to a 220 volt main, the two field poles were connected in parallel and excited by 110 volts, limiting the current in each field winding to 3 amperes by external resistance.

It is of interest to see the mechanical analogy of starting or stopping a current in an inductive circuit.

TABLE A

For $t=$	0	.05	.10	.50	1.00	1.5	2.
$\epsilon^{-1.40t}$	1	.93	.86	.48	.22	.105	.025
i	0	.21	.42	1.56	2.34	2.69	2.92

TABLE B

For t	0	.05	.10	.5	1.00	2.00
$\epsilon^{-2.92t}$	1	.86	.75	.23	.05	.0025
i	0	.42	.75	2.32	2.85	2.99

To bring a train up to speed a certain force is necessary: this force must overcome the friction and give the acceleration.

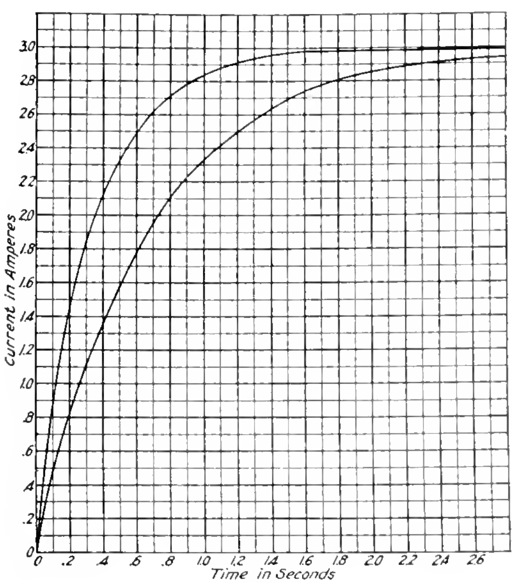


Fig. 8

Let F be the total force necessary.

fv the force of friction which, for simplicity's sake, will be assumed proportional to the velocity v,

and M the mass.

Then $F = fv + \text{mass} \times \text{acceleration}$

$$= fv + M\frac{dv}{dt}$$

$$\therefore \frac{dv}{dt} + \frac{f}{M}v = \frac{F}{M}$$

If the drawbar pull F as well as the coefficient of friction f is assumed constant during acceleration

Then $v = \frac{F}{f} + C\epsilon^{-\frac{f}{M}t}$

where C is the integration constant.

If the train starts from rest then for $t=0$, $v=0$.

$$\therefore 0 = \frac{F}{f} + C \text{ or } C = -\frac{F}{f}$$

$$\therefore v = \frac{F}{f}\left[1-\epsilon^{-\frac{f}{M}t}\right]$$

Compare this equation with the equation of the starting of a current in an inductive circuit, which is

$$i = \frac{E}{r}\left(1-\epsilon^{-\frac{r}{l}t}\right)$$

It is seen that in electrical problems current corresponds to velocity, the e.m.f. to the mechanical force, the ohmic resistance to friction resistance and the inductance to the mass.

The analogy can be carried further. The energy stored in the magnetic field, $\frac{1}{2}LI^2$, corresponds to the kinetic energy of a moving body $\frac{1}{2}Mv^2$. The electromagnetic momentum LI corresponds to the mechanical momentum Mv, etc.

Up to this point the problems have dealt with inductive circuits on which have been impressed a constant e.m.f. E.

In alternating current work the voltage varies from instant to instant, and while a harmonic e.m.f. is usually assumed, frequently the variation represented by a wave is much more complex. As long, however, as the e.m.f. is obtained from a dynamo of symmetrical poles, no matter how shaped, the e.m.f. wave can be expressed by a series of sine functions of odd frequencies.

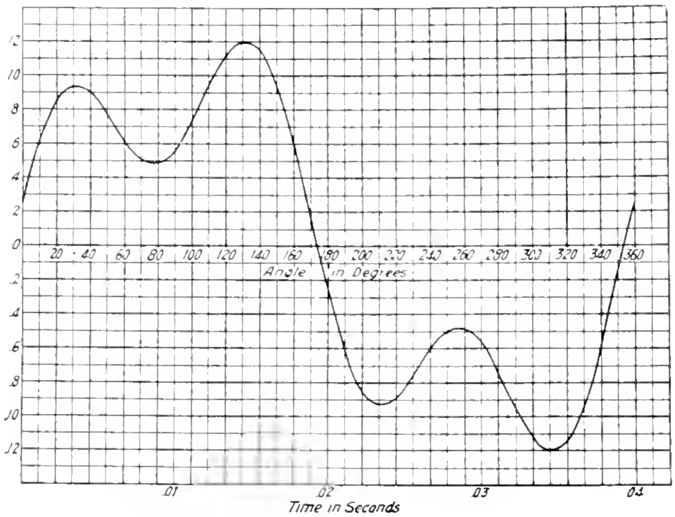


Fig. 9

In the study of transient phenomena in connection with alternating current, the equations are derived for the fundamental wave only, that is, the instantaneous values of the e.m.f. are represented by $e = E \sin \theta$.

If it is desired to know the result with distorted waves, the simplest method is to treat each harmonic independently and to add the instantaneous values so obtained. If the effective value is desired the square root of the sum of the squares of the effective value of each wave should be taken.

As stated previously, the instantaneous value of the e.m.f. is generally expressed in two ways, either $e = E \sin wt$ or $e = E \sin \theta$, or the expression may be of more general form: $e = E \sin(wt + \alpha)$ and $e = E \sin(\theta + \alpha)$. In these expressions, e is the particular value of the e.m.f. at time t, or at phase angle θ, and E is the maximum value of the e.m.f. In the first case, the angle wt is expressed in radians, not in degrees. ω is the angular velocity $= 2\pi f$, where f is the frequency. The relation between radians and degrees is $360° = 2\pi$ radians, thus 1 radian is $\frac{360}{2\pi} = 57.3°$

To reduce equation $e = E \sin(wt + \alpha)$ to degrees it should therefore be written $e = E \sin(57.3\, wt + \alpha)$, where in all cases α is expressed in degrees, as is customary. To reduce the expression to radians it should be written $e = E \sin\left(wt + \frac{\alpha}{57.3}\right)$

Note in connection with this that in the expression, $y = \sin x$, x is expressed in radians, not in degrees. To bring it to degrees the equation becomes $y = \sin 57.3\, x$.

In the development the value of the sine function

$$\sin x = x - \frac{x^3}{\underline{|3}} + \frac{x^5}{\underline{|5}} - \frac{x^7}{\underline{|7}} t \ \ldots\ldots$$

x is again expressed in radians.

It is important to have this clearly in mind. It is well worth while to plot some curves of distorted waves from equations involving phase angle as well as radians.

Example No. 5

Verify the e.m.f. wave in Fig. 9, $e = E_1 \sin wt + E_3 \sin(3\, wt + \alpha)$ for $E_1 = 10$, $E_3 = 5$, $\alpha = 30°$ and the frequency 25 cycles.

It has been proven by Fourier's series that the effective value of a distorted wave is the square root of the sum of the squares of the effective values of the individual waves. Thus in this instance, since the effective value of the fundamental wave is $\frac{E_1}{\sqrt{2}} = \frac{10}{\sqrt{2}} = 7.07$, and that of the triple harmonic is $\frac{E_3}{\sqrt{2}} = \frac{5}{\sqrt{2}} = 3.53$, the effective value of the wave recorded on a voltmeter is $e = \sqrt{7.07^2 + 3.53^2} = 7.9$.

Referring to Fig. 10: prove that ammeter A when placed in a circuit carrying 10 amps. direct current, 8 amp. 60 cycle current, and 5 amp. 125 cycle current reads 13.7 amps.

Harmonic e.m.f. Impressed on a Circuit of Resistance and Inductance in Series

Let time be counted from zero value of the impressed e.m.f. and let the e.m.f. be rising.

Thus $e = E \sin wt$ where e is the instantaneous value of the harmonic e.m.f. at time t. E is the maximum value. $w = 2\pi f$, is the angular velocity, f the frequency, r the resistance and L the inductance of the circuit.

If i is the instantaneous value of the current when the e.m.f. is e then:

$$e = E\ sin\ wt = ir + L\frac{di}{dt} \qquad (27)$$

or

$$\frac{di}{dt} + \frac{r}{L}i = \frac{E}{L}sin\ wt \qquad (28)$$

By comparing this equation with equation No. 1, it is seen that $\frac{r}{L} = a$ and $\frac{E}{L} sin\ wt = b$.

α is not a function of the independent variable t, but b depends thereon, thus the solution is given in equation (3).

It is $i = \epsilon^{-\frac{r}{L}t}\left[\int \epsilon^{+\frac{r}{L}t}\frac{E}{L} sin\ wt\ dt + C\right]$ (29)

The solution of this equation depends upon solving

$$\int \epsilon^{+\frac{r}{L}t}\frac{E}{L}sin\ wt\ dt = \frac{E}{L}\int \epsilon^{+\frac{r}{L}t} sin\ wt\ dt.$$

$\frac{E}{L}$ is a constant and can be left out of consideration at present. It is also convenient to substitute a single letter for $\frac{r}{L}$. Let then $\alpha = \frac{r}{L}$.

The immediate problem then is to solve $\int \epsilon^{\alpha t} sin\ wt\ dt$.

An integral involving exponentials or sine functions is usually easy to solve, because the differential of the functions are almost identical with the functions.

It is: If $y = \epsilon^{\alpha x}$ then $\frac{dy}{dx} = \alpha\epsilon^{\alpha x}$.

Similarly if $y = sin\ \omega x$, then $\frac{dy}{dx} = \omega\ cos\ \omega x$,

or if $y = cos\ \omega x$, then $\frac{dy}{dx} = -\omega\ sin\ \omega x$.

Thus $\int \epsilon^{\alpha t}\ dt = \frac{1}{\alpha}\ \epsilon^{\alpha t}$ and

$$\int sin\ wt\ dt = -\frac{1}{\omega}cos\ \omega t\ dt$$

Fortunately for the engineer there are only very few methods of integration that need to be known. One of these is "Integration by Parts."

That is:

$$\int udv = uv - \int vdu \qquad (30)$$

In integral $\int \epsilon^{\alpha t}\ din\ \omega t\ dt$

let $u = \epsilon^{\alpha t}$ and $dv = sin\ \omega t\ dt$

$\therefore du = \alpha\epsilon^{\alpha t}$ and $v = -\frac{1}{\omega}cos\ wt$

$$\therefore \int \epsilon^{\alpha t}\ sin\ \omega t\ dt =$$

$$-\frac{\epsilon^{\alpha t}}{\omega}cos\ \omega t + \int \frac{\alpha}{\omega}\epsilon^{\alpha t}\ cos\ \omega t\ dt \qquad (31)$$

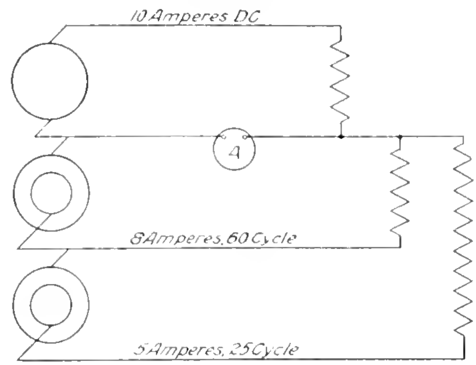


Fig. 10

This equation is indeed more complicated than the original. It is evident, however, that by again integrating the last term in 31, an integral results which contains an exponential term $\epsilon^{\alpha t}$ and a sine term instead of the cosine term. Thus the final expression will contain integrals of the same trigonometrical and exponential functions, which therefore can be solved directly. However, it is somewhat more convenient to use another method.

Referring again to (30) and let in this case:

$u = sin\ \omega t$ and $dv = \epsilon^{\alpha t}\ dt$

$\therefore du = \omega\ cos\ \omega t\ dt$ and $v = \frac{1}{\alpha}\epsilon^{\alpha t}$

$$\therefore \int \epsilon^{\alpha t}\ sin\ \omega t\ dt =$$

$$\frac{\epsilon^{\alpha t}}{\alpha}sin\ \omega t - \int \frac{\omega}{\alpha}\epsilon^{\alpha t}\ cos\ \omega t\ dt \qquad (32)$$

By multiplying 31 by $\frac{\omega}{\alpha}$ and 32 by $\frac{\alpha}{\omega}$ and adding the two equations, it is readily seen that

$$\int \epsilon^{\alpha t} sin\ \omega t\ dt =$$

$$\frac{\epsilon^{\alpha t}\alpha\omega}{\omega^2 + \alpha^2}\left(\frac{sin\ \omega t}{\omega} - \frac{cos\ \omega t}{\alpha}\right) \qquad (33)$$

Substituting $\alpha=\frac{r}{L}$ and remembering that x, the reactance corresponding to the inductance L is $2\pi fL=\omega L$ and that the impedance $z=\sqrt{r^2+x^2}$

then $\int \epsilon^{+\frac{r}{L}t} \sin \omega t\, dt =$

$$\epsilon^{+\frac{r}{L}t}\frac{L}{z^2}[r \sin \omega t - x \cos \omega t] \qquad (34)$$

Let the angle of lag of current be β thus

$$\tan \beta=\frac{x}{r} \quad \text{and } r=z \cos \beta \qquad (35)$$

$$x=z \sin \beta \qquad (36)$$

Substituting the values in 34:

$$\int \epsilon^{+\frac{r}{L}t} \sin \omega t\, dt=\epsilon^{+\frac{r}{L}t}\frac{L}{z} \sin (\omega t-\beta) \qquad (37)$$

Referring to equation 29

$$i=\frac{E}{z} \sin (\omega t-\beta)+C\epsilon^{-\frac{r}{L}t} \qquad (38)$$

The integration constant C is determined from the particular problem under consideration.

Assume that it is desired to find the value of the current at any instant after the switch is closed and the alternating e.m.f. is impressed upon the circuit, and that the switch is closed at time $t=t_1$, when the instantaneous value of the e.m.f. is $e=E \sin \omega t_1$.

Since, as has previously been discussed, it is impossible to establish a magnetic field instantaneously, the current can not flow at the first instant. Thus for $t=t_1$, $i=0$. Substituting these values in equation 38, then:

$$0=\frac{E}{z} \sin(\omega t_1-\beta)+C\epsilon^{-\frac{r}{L}t_1},$$

$$\therefore C=\frac{E}{z}\epsilon^{+\frac{r}{L}t_1} \sin(\omega t_1-\beta),$$

Substituting this in 38

$$i=\frac{E}{z}\left[\sin (\omega t-\beta)-\epsilon^{-\frac{r}{L}(t-t_1)} \sin(\omega t_1-\beta\right] \qquad (39)$$

It must be remembered that ωt and ωt_1 are expressed in radians and not in degrees, whereas β is expressed in degrees.

To make the equation consistent it should therefore either be written in radians or degrees all the way through.

When expressed in radians, it is:

$$i=\frac{E}{z}\left[\sin\left(\omega t-\frac{\beta}{57.3}\right) - \epsilon^{-\frac{r}{L}(t-t_1)} \sin\left(\omega t_1-\frac{\beta}{57.3}\right)\right] \qquad (40)$$

Since, however, the trigonometric tables are worked out for degrees, it is most convenient to have the expression consistent in degrees; it is:

$$i=\frac{E}{z}\left[\sin\left(57.3\ \omega t-\beta\right) - \epsilon^{-\frac{r}{L}(t-t_1)} \sin\left(57.3\ \omega t_1-\beta\right)\right] \qquad (41)$$

It is most convenient, however, to eliminate t entirely from the expression and to use the phase angle θ only and to express θ in degrees.

That is, the e.m.f. is expressed as $e=E \sin \theta$ In that case $\theta=\omega t=2\pi ft$.

The exponential term $\epsilon^{-\frac{r}{L}(t-t_1)}$

becomes $\epsilon^{-\frac{r}{L\omega}(\theta-\theta_1)}=\epsilon^{-\frac{r}{x}(\theta-\theta_1)}$

if θ and θ_1 are expressed in radians or $\epsilon^{-\frac{r}{x}\frac{(\theta-\theta_1)}{57.3}}$ if θ and θ_1 are expressed in degrees.

Thus when θ and θ_1 represent degrees

$$i=\frac{E}{z}\left[\sin\left(\theta-\beta\right)-\epsilon^{-\frac{r}{x}\frac{(\theta-\theta_1)}{57.3}} \sin\left(\theta_1-\beta\right)\right] \qquad (42)$$

The equation is, however, always written

$$i=\frac{E}{z}\left[\sin\left(\theta-\beta\right)-\epsilon^{-\frac{r}{x}(\theta-\theta_1)} \sin\left(\theta_1-\beta\right)\right]$$ and

it is understood that the exponential term should be expressed in radians.

Equation (42) can, of course, be derived directly by using the phase angle θ instead of ωt.

Thus $E \sin ir=er+L\frac{di}{dt}$ may be written

$E \sin \theta=ir+x\frac{di}{d\theta}$, where x is the reactance.

Thus, $x=2\pi fL=\omega L$
and $\omega t=\theta$

$\therefore d\theta=\omega dt$ or $dt=\frac{d\theta}{\omega}$

Prove that equation 42 is the solution of

$E \sin \theta=ir+x\frac{di}{d\theta}$

(To be Continued)

A HUNT FOR A GREAT METEOR AND ITS LESSONS

By Prof. Elihu Thomson

This paper is abstracted from a lecture delivered before the Schenectady Local Section of the A.I.E.E. On a trip through Arizona, the author visited a crater called Coon Butte near the Canyon Diablo. A description is given of the appearance of the exterior and interior of this crater, and the paper shows how it was proved that the iron which was found in vast quantities in the vicinity of the crater was meteoric iron. Great sums of money were spent in exploration, and the author gives some hypothetical figures to show the enormous commercial value of some of these deposits by virtue of the iron, nickel, platinum and diamond which they contain. He then comments on the nature of this particular meteor, and upon the chemical changes which the various parts of a meteor undergo in its passage through the air. It is then shown why comparatively few of these craters are to be found on the earth compared with the great number of lunar craters, although probably both earth and moon received such meteoric masses much more frequently millions of years ago. The paper concludes with the theory of the nature and movements of comets and planets, and the view that the latter are themselves built up upon a nucleus of a large comet; so that the meteor which attached itself to the earth at Coon Butte was quite possibly the nucleus of one of these comets.—Editor.

When I was a young man, I came into possession of a piece of meteoric iron which was called a Canyon Diablo meteorite. It was said to have come from Canyon Diablo in Arizona, and to contain diamonds in addition to the usual constituents of nickel and iron. When I got this piece of iron I tried it on glass, and at last I found one little corner where I could draw it across the glass so that it left a mark like a diamond. There was a little piece of diamond imbedded in it which could be seen though the microscope. That meteor evidently has a story to tell us, but it was as late as about five or six years ago that I heard much more about this particular fall of meteoric iron, and then I learned that there was a crater about two miles to the east of Canyon Diablo, called Coon Butte. This crater has given rise to considerable discussion as to its mode of actual formation. Some claim that it is a volcanic crater; some that it is the result of a steam explosion, however produced; and others again aver that it was caused by the impact of a great meteor from the sky. I did not know at first which theory to accept as correct, but I have recently come to the conclusion that it indeed was the result of impact of a large meteor.

Last spring in going West over the Atchison, Topeka and Sante Fe Railroad, the opportunity came for me to visit the place and at least make up my own mind as to what happened at this point. I am going to try to give my reasons for thinking that it is a true meteoric crater, and where we can see a great many such meteoric craters if we look for them. On our trip we passed through the central part of Arizona, stopping over night at Winslow, and going the next morning a few miles further west to the place that was so famous. We soon saw off in the distance to the southwest of the railroad track a peculiar kind of elevation on the plain, which all around was quite flat, although there were mountains in the distance on both sides. We were now in sight of Coon Butte, eight or ten miles away perhaps, which looked something like a water reservoir, with sloping sides and nearly flat top; but the color of the slopes was entirely different from that of the plane around—a kind of greenish gray as compared with the red soil which covers a great part of the territory known as the "Painted Desert." The Painted Desert is itself very beautiful, covered with sage brush and with red sandstone outcrops here and there. The peculiar hill, different from anything in the landscape, was the thing we were going to see.

We reached a little station called Sunshine, and indeed the sun did shine all the time we were there. It shone upon our enterprise too, for we found a team which was to take us to Coon Butte six miles to the southward, the "meteor crater." We drove over a level country to the foot of Coon Butte and then up the slope for about 150 feet of height. As we were approaching it we passed fantastic outcrops of red sandstone, sage brush and other desert plants, here and there, all interesting; but for a long time the crater did not seem to get much nearer. This was due to the very clear air, so prevalent in that section of the country, shortening distance. As we at last went up the slope, we noticed the peculiar soil, a white silica soil—nearly pure silica—in which rested and over which was strewn large and small rock fragments grayish in color and apparently limestone. As we neared the top of the slope, of 150 feet, we had our first view of the crater, an enormous hole in the ground. It was a very impressive sight, indeed, that great bowl-shaped opening before us. Its greatest depth from rim to rim is 1200 feet, and the average diameter is about three-quarters of a mile. The depth of the hole from the rim down is approximately 570 feet. From almost vertical sides at the top, the walls sloped down to an almost flat bottom.

To go around the rim was a long walk over irregular surfaces, and we did not expect to do that. The contour of the rim was very irregular, with broken and uplifted strata and rocks, pieces of rocks some times as large as a house, tossed out in apparent helter-skelter fashion. There were pieces of many tons in weight thrown a distance of thousands of feet on the plain. The outer slopes went down gradually to the plain, and were covered with broken masses and scattered materials evidently thrown out from this crater. But what threw them out? All over that territory, even to distances of several miles, hundreds of pounds of meteoric iron have been gathered and sent to all the museums in the world. Last summer I understand there was picked up on the plain, about a mile and a half away, a piece that weighed about 1700 pounds; and there have been gathered pieces weighing 400 and 500 pounds all around there. Innumerable pieces of iron and oxidized meteoric iron are found in the material of the sloping rim.

Down in the crater all over the bottom is the white silica sand, a kind of fine white sand, called the rock flour, which looks like flour. It extends down in the crater to a great depth, all pulverized and mixed with small bits of meteoric material. Some of the iron rusted and corroded into brown hematite, called here shale ball iron. It is a peculiar feature of some of this iron that it rusts so rapidly. Some pieces of solid iron will, in our air, oxidize so rapidly that they are converted into this shale ball iron in a few months. This rapid corrosion is believed to be due to chlorine present in the particular pieces.

But how do we know that this is a meteoric iron? Well, every specimen gives what is called Wiedmanstatten figures, that is, if it is etched, it shows after smoothing a peculiar crystallization indicative of meteoric origin. There is still in this piece of corroded iron which I found at the crater a metallic center that is still uncorroded, but which will probably corrode in time. Another piece which I have is a bar of rectangular section cut on a planer. There was great trouble in cutting it; for every time the tool ran against a bit of diamond, it lost its edge. The iron can be ground by carborundum and materials like that, but in any case it is still a tedious process.

Mr. D. M. Barringer, of Philadelphia, to whom I am indebted for slides, specimens, etc., and for the opportunity to make our visit to the crater conveniently, was the first to indicate the possibility of finding a large meteoric crater, with probably a large amount of meteoric iron buried at some depth. A considerable amount of money has been spent in exploration, and the bulk of this was furnished by Mr. Barringer. The original intention was to sink a shaft, and drift sidewise when the shaft had reached such a depth that the rock showed no further signs of disturbance. According to all advices the sinking of such a shaft would be easy, because it would go through dry ground. Contrary to expectations, however, when the shaft reached about 200 feet below the floor of the crater, passing through this depth of fine, white silica or rock flour into the worst possible quicksand, it became impracticable to sink the shaft any further. This plan of attack, which was, of course, for the purpose of finding the meteoric body, had to be abandoned. A resort was then had to bore-holes.

There were put down 28 bore holes, some to the depth of 1100 feet. In these were found pulverized rock, meteoric material, while at the bottom of the deepest holes undisturbed rock layers were struck. These were red sandstone underlying the white rock above. The trouble with these borings was that they were based on the supposition that the meteor had fallen straight down. In reality such a fall would be rare or unusual. These bodies almost invariably come on a slanting course through the air, and in this case the mass which fell is probably nearer or under the walls somewhere, but in a part of the crater not yet explored. I have made some rough calculations of the number of bore holes which would be required to make sure of finding it if it lay in the crater itself, and assuming the meteoric mass to have been 500 feet in diameter. It would require about 600 bore holes, which, at a cost of $2000 per bore hole, would mean $1,200,000 spent in exploration. As I have said a large sum has already been so spent.

Why should anybody try to find this great meteor? As a commercial matter, of course, for the iron, nickel, platinum and diamond that it contains. There seems to be a general agreement that this crater would have required a meteor of about

400 or 500 feet in diameter for its production. The amount of rock thrown out and now existing in the crater walls is perhaps two or three hundred millions of tons. A great body of the material originally displaced must, of course, have fallen back into the crater, so that the actual displaced material is probably much in excess of the figure mentioned. But if we assume that one ton of material in the meteor was capable of displacing, say, some thirty tons of rock when it struck, then the mass of the meteor should have been approximately at a low estimate, say, five millions of tons, mostly iron. Eight per cent., however, would be nickel; and in each ton, by analysis, the average amount of about 0.6 (six-tenths) of an ounce of platinum and iridium exists. This would give about three million ounces of platino-iridium say; which at a valuation, say, of $30 to $35 an ounce, would equal about $100,000,000. If we assume, and of course it is a mere assumption, that one one-hundredth of 1 per cent. of diamond exists in the mass, then the 500,000,000 tons would contain about 500 tons of diamond. There was indeed enough prospect of great value, even in case these figures should be largely exaggerated; and it is no wonder, therefore, that explorations were undertaken for the purpose of locating this great body. Thus far, as I have indicated, they have been without success.

Electrical men will naturally ask why the hunt was not carried out with a magnetic compass needle, or some instrument of that sort. Prof. Magie of Princeton actually did this. He used a very, very delicate dip needle, but absolutely failed to get any indications. He was naturally much disappointed when the magnetic instrument did not give the expected results; but it will be understood by those who have studied magnetism, that the permeability of iron, under very low magnetic forces, such as would exist there, is so small that it could not be expected to give any decided indications. Prof. Magie also found that while each individual specimen would show magnetic effects on the compass, a considerable body of them massed together gave little or no effect, the polarities apparently neutralizing one another. He has also told me that, in testing a large specimen, he found as many as twenty north poles, but that he could not find a single south pole on it. I am led to think that if this great meteor is found, it will probably be by some method using the induction balance; and I have planned a scheme which may possibly be useful in detecting the presence of this metallic body, or cluster of them, which, I have the utmost confidence, is still buried deep down in that hole.

One significant fact is, as pointed out by Mr. Barringer, that the south wall of the crater is uplifted 100 feet. A part of the plane and the strata immediately below are lifted upward almost horizontally 100 feet. It seems to indicate that something went under this part of the wall and lifted up the low land. There is again the finely pulverized rock—silica made by crushing from solid rock which is nearly pure silica. Some of it is evidently half fused by steam and heat, and looks like fused silica. It would indicate that great pressure or force has pushed the rocks laterally. These great masses of rock have been thrown out over the plain. The rim of the crater is, in fact, an enormous mass of ejected material; and one cannot escape the inference that something hit the earth there and hit pretty hard.

Mr. D. M. Barringer has been strong in his faith that it was a meteor and nothing else that made this hole, and I agree with him in his conclusions, assuming that it took an oblique course.

Now, what really took place at this part of the earth? I think the correct opinion is that, not one large meteor, but a cluster of them made up the total mass of iron. Now, a hole three-quarters of a mile in diameter is a large hole. We must admit that a very large mass of meteoric iron must have fallen from the sky into that hole. It was steam and gas liberated, coupled with the shock of impact that made the crater. The next question naturally is: how long ago did it happen? It rains out in that country at times, and there are high winds which shift the sands. There is but little evidence of erosion. The rock masses are broken very sharp, and the walls are not worn down. The slopes, although consisting of fine silica flour to a large extent, are not washed down. Certain cedar trees on the slopes appear to indicate that it has been there several hundreds of years at least; and there are other indications which make it appear that perhaps 2000 or 3000 years ago may be the time this great meteor fell upon the earth. North of this crater there is a large Indian reservation where the Navajo Indians live. These Indians, it is said, have a tradition handed down from generation to generation, which says that three large bodies fell out of the sky, and one of them struck the earth at the south of the present railroad tracks, i.e., where the present meteor crater is; and that when that body fell a number of their tribe were killed. These Indians now apparently send to this crater when they have their ghost dances, and get the white silica to sprinkle around where they dance, indicating that they still retain some superstition in regard to this peculiar natural phenomenon.

What actions take place when meteors enter the air? In the first place, that they come from space at a very high rate of speed is generally known. They certainly come from out of space, but we do not know from exactly where. The speed may be as high as forty or fifty miles a second. If it be a stony meteor, it may be crushed into dust by the air pressure in front of it. Even if of iron, it may be torn into fragments as if an explosion had occurred in front. If, however, it is a rounded piece of iron like this lump, then it would take a tremendous pressure of the air to crush it; and I have no doubt whatever that most iron meteors of rounded form would escape fracture unless they were moving at the very highest speeds. At such speeds, the air pressure developed in front of them may blow them to pieces; but if they are moving, say one-third as fast, they may, and probably will, survive unless they succumb to another action which takes place with iron, namely, combustion. Ordinary air contains one-fifth of its volume of oxygen. When at a pressure equal to 1500 lbs. per square inch the oxygen is condensed 100 times, and there is virtually an atmosphere of oxygen in front of the iron 20 times as dense as if the air were all oxygen. The compression produces an enormous heat in the gas and sets fire to the iron; the iron burns rapidly, almost like tinder. Now, if it burns for any length of time it will burn completely away, and if the meteor is a large one and it comes into the air with sufficient velocity to smash it, then the small pieces will burn vigorously in the oxygen of the air and may be consumed completely before they reach the ground; but if they are slow moving, or if the velocity is not high enough to crush them, then, instead of burning up, some part of them will come to the earth. When we find a piece of meteoric iron, it is one of these survivors. The pieces of iron, although they have been burning vigorously in the air may at last reach the ground solid and comparatively cool.

It is commonly thought that the meteor in passing through the air must get quite hot, but when we study the action more closely we see that this is not the case. The iron body, rushing along in the dense oxygen, burns and forms an oxide coating which is blown off as rapidly as it is formed. This coating is a thin film of fused, black oxide of iron, but the violent rushing of the meteorite through the air prevents any of this material remaining on the surface of the meteorite for more than an instant of time. The result is that the hot skin is, so-to-speak, stripped off in too short a time to communicate its heat to the interior of the mass; and the only heated portion at any instant is very thin skin which constitutes the extreme outside surface of the body. This is a somewhat different idea from the one most people have, I think. I will try to illustrate it. Suppose I take a block of ice and I set that block of ice on a stand and apply a hot blast of air to it. The ice would melt on the outside and the water would be blown off, but the ice would remain ice to the very end of the process. We might stop the process at any time and find a nucleus of ice remaining, which would be, of course, solid.

Take a solid combustible, such as a piece of coal or wood, and apply a hot blast of oxygen to consume it rapidly. The coal or wood remains at a low temperature inside until the whole is consumed, assuming that it does not crack or fracture by sudden heating. The inside will be comparatively cold, because there is not time enough for the transfer of heat to take place from the outside to the inside. In the case of a meteor, the flight only lasts a few seconds, and that is a very short time for the heat to be transferred from the outside of the iron mass to its interior. The oxygen acts only on the outside; while the inside remains intact to the last, with its peculiar crystalline structure shown on etching, the Wiedmanstatten figures, which are not consistent with a high temperature. When we consider all sides of the case, it appears probable that the meteor that made the large crater at Coon Butte was moving at not more than two or three miles per second when it struck.

The question arises, why are there not more of these craters on the surface of the earth? There can be no doubt that there were a great many on the surface of the earth in the early ages, but the rains and erosive processes have long ago wiped them out. But let us take a look at our moon. In what kind of surface do we find the moon to be? There are a large number of craters all over its surface. These craters have been explained to be those of volcanoes on the moon; but in 1873 Proctor said that he did not think they were volcanic craters, but that they were meteoric craters, while 15 years ago a scientist by the name of Gilbert reiterated and enforced this view. I have often examined the moon through a large telescope and thought that the lunar craters have the appearance as if something had struck there; but when I came to see this meteor crater in Arizona, I felt sure that here we had a lunar crater on earth. We find on the earth an example of just such craters as are on the moon. The proportions are the same. In the meteor crater slopes are 150 to 175 feet high, while the hollow is down below the level of the plain or general surface, and that is just what is found with the craters all over the moon.

Furthermore, if one looks at the lunar craters through a telescope, they show characteristics which are different from volcanic craters on the earth—no great rivers of lava, no cinder cones. One will often find in the large craters of the moon, encircled by their sloping walls, a mountain in the middle of the crater—some of them even something like 4000 or 5000 feet high. These central mountains are not topped with craters; there are no crater cavities to be detected at their summits, as is the case with the vents which form in the interior of the earth's volcanic craters at times. On the moon, however, the smaller craters seen through the telescope do not as a rule have these hills or mountains in the center; they are flat bottomed as in the case of the Arizona crater. It is only when the lunar crater is large that it has the central mountains, although, as a matter of fact, some very large ones do not contain this feature. How large, in fact, are these craters on the moon? Some of them 150 miles or more in diameter, others 40 or 50 miles, and others of sizes ranging down to a quarter of a mile or so in diameter, or as small as the revolving power of the telescope can show them. Why are there so many of these craters on the moon and so few on the earth? I have only to tell you that the moon is a body which has no atmosphere, no vapor, no gas, no water. All around the moon is a vacuum; there is no washing by rains to eradicate the surface marks, no erosion to level hills; and consequently all records of impacts remain. For that reason all the great holes on the moon created by meteoric masses are never disturbed unless another meteor strikes in the same place and obliterates, more or less completely, the first record. We have heard of one that was broken up into eight or nine groups. They split up, some of them are destroyed; and whenever we get anywhere near them we grab them.

It is probable that in the early history of both earth and moon many millions of years ago, they both received meteoric masses with a vastly greater frequency than has been the case in later years. From the fact that the peculiar bodies known as comets, which move in nearly elliptical orbits around the sun, are known to undergo the process of breaking up and dissipation into meteoric streams, the separate meteors or pieces being gradually gathered up by the planets, it is a legitimate thought that this process which is now going on is only the last stage of the grander cleaning-up of space which went on when cometary bodies were far more numerous and many times larger than they are at present. Indeed it is quite consistent with our ideas that the meteor which descended at Coon Butte was the nucleus of a small comet or a portion of one. It is a reasonable idea, too, that the planets themselves have to a large extent been built up by the gathering in of masses from space, like comets, through a long period of years. This process is still going on and will continue to go on until the whole of the cometary masses now moving around the sun are disintegrated, deposited or gathered up. It may be said to be a case of survival of the fittest. The cometary masses have erratic highly elliptical orbits in most cases, while the planets have orbits more or less approximating the circular. Naturally, then, the bodies moving around the sun having the more stable orbits would seem to feed upon those having the less stable orbits, with the result that the planets are built up out of the material composing their more erratic neighbors. In fact it is quite conceivable that the nucleus of a planet itself was originally just such a cluster as a large comet; but that it happened to be one which moved around the sun in a fairly circular orbit, with the result that it has grown at the expense of its neighbors. That comets do break up and disintegrate is evident, not only from the stream of material driven out in the tail, but in the fact that some of them actually are seen to split up into two or more bodies, and one is reported as having broken up into eight or nine groups of particles.

I remember as a boy seeing the great meteor shower in November of 1867. This shower had been recurrent every 33 years and was due to reappear in 1900. The path of the body of the meteors which furnished the shower was found to be coincident with that of Tempel's comet which had undergone disintegration. The earth was then gradually gathering up the *debris* or disintegrated material of the comet. Some perturbation of the orbit must have occurred which prevented the reappearance in 1900 of the brilliant meteoric display. But whence do they come, all these pieces of matter or fragments which move in cometary orbits? They are evidently fragments. They represent something which has been broken up. If we examine a piece of meteoric iron we find that it has a solid crystalline structure; possesses characteristics which could not have been imparted to it by the mere condensation of gases or vapors in space. It bears all evidences of having been consolidated at least by pressure, and possibly by heating. It appears probable that it was at one time a part of a much larger body, which body was disrupted or crushed and scattered into fragments, and that the gathering up process, which has built up the planets out of these moving masses, began soon after some great catastrophe happened to a former system. What is the nature of such a catastrophe? Do they really happen? To answer these questions briefly is to point out the fact that occasionally there is a sudden outburst in the sky which we call a new star. We may also state the fact that there are in space hundreds and thousands of so-called spiral nebulae in all stages of aggregation. Now, two systems like the solar system, or large bodies like the sun, whether hot as the sun is, or cooled off to a black body through the lapse of time, may, and unquestionably do, sometimes pass by each other at comparatively close range, such as a few millions of miles one from the other. The result of such passage is, from the enormous strains due to the variation of gravitation and centrifugal forces, to practically crush the bodies and cause them to emit diametrically opposite streams of fragments and more or less heated particles, which streams, revolving, give us the peculiar phenomenon of the spiral nebula. The effect is the direct result of the condition which exists, that gravity is partly neutralized when the large bodies approach on the line joining them, while the centrifugal forces are greatly increased by their swinging around each other. The pressure of gravity in other directions is maintained at its full value, resulting in the inevitable crushing and emission of material from the bodies in two directions, like enormously exaggerated tides formed upon them. As the bodies pass by each other, with the formation of the spiral nebula from each of them, the gathering up of the *debris* or the scattered material begins, with the possible evolution of a new system from it. This, in fact, from all that we can learn, seems to be the order of nature. The process is seemingly a natural one, and has gone on for an illimitable past, and will continue to an illimitable future.

The action just outlined, as producing a spiral nebula, it must be borne in mind, is not that of a collision. Collisions of large bodies in space undoubtedly do occur, but from the nature of things, they will be extremely rare as compared with the cases of bodies which pass by each other comparatively near together. I use the word "comparatively" in this case as meaning that such distances as 5,000,000, 10,000,000, or even 50,000,000 of miles may be small as compared with the distances which now separate the stars or systems. Thus, the meteor which came down at the meteor crater in Arizona, if we could unravel its whole story, would tell us of the grand actions occurring in space in times inconceivably remote from the present. It would tell us of the possible breaking up of a former planetary system, and the gradual gathering up of material to form a new system—our own. It would tell us of the real processes which have built up the universe as it is, and which in the lapse of time will continue re-forming and re-making the systems with which it is filled.

A NOTABLE EXAMPLE OF BRITISH PRACTICE IN ROLLING MILL ELECTRIFICATION

By G. M. Brown

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This article describes the electrical equipment of a 28 in. cogging mill at the steel works of Messrs. Dorman Long, Middlesborough, England. The 1200 h.p. direct current mill motor receives its current from a reversible generator which constitutes part of a two-unit flywheel equalizer set, driven by a 3-phase motor running from the works supply, and coupled to a thirty-ton flywheel. The requirements were severe; and the general scheme which was adopted, the mechanical and electrical design of the individual machines, the regulating system including a three-unit exciter set, and the control equipment, present many features of interest, all of which the author fully covers.—Editor.

The intense and increasing competition in all branches of the iron and steel trade have rendered it incumbent on British manufacturers to adopt every possible means of effecting economies, in order to maintain their position in the industrial world. Thus the use of blast furnace gas for the generation of the power required, not only for driving blowing engines, but for other processes in iron and steel works, is now extending rapidly, and electric motors are replacing steam engines in the mills. Even in works where there is no blast furnace gas available, steam engines are being rapidly replaced and superseded by electric motors, and scattered batteries of boilers by the central power station with its comparatively uniform load and attendant saving in fuel and labor.

Our rivals in the race for international industrial supremacy have already gone far in these directions, as have also several of the more enterprising iron and steel manufacturers in this country. Among these we may mention Messrs. Dorman Long & Co., of Middlesborough, who have recently made considerable alterations and additions to their plant. These include the installation of a large turbo-generating equipment, which will utilize the exhaust steam from their existing steam engines, and supply power for driving a 28 in. two-high reversible cogging mill, a 16 in. two-high reversible finishing mill, a 14 in. three-high roughing mill, and a 12 in. three-high finishing mill, as well as saws, shears, skids, live rollers and other auxiliaries. The entire electrical equipment of the cogging mill, which is designed to reduce mild steel ingots 12 in. square and weighing approximately one ton each, to billets 3 in. square, at the rate of 15 tons per hour, was supplied by the British Thomson-Houston Company of Rugby.

The mill itself consists of one stand of rolls and one pair of pinions directly connected to the shaft of the driving motor by a special sleeve coupling, designed to avoid the transmission of any severe thrust to the shaft and bearings. The motor (Fig. 1) is capable of giving continuously an output of 1200 b.h.p. at a speed of 70 r.p.m., and a maximum torque corresponding to an output of 3,600 b.h.p. at the same speed. It is fitted with commutating poles and a special compound winding to which further reference will be made; and arrangements are made whereby the speed can be raised to 90 r.p.m. for the lighter and longer passes. The armature core is built on a very heavy spider with hollow arms and heavy clamping rings, extended further than usual in order to afford the necessary support to the conductors, which are subject to unusually heavy strains from the sudden overloads to which the motor is subject. The steel binding bands securing the ends of the conductors to the supporting rings are made in sections held together by keys and cotters, and are thus much more readily removed when necessary than the usual type of binding bands secured by soldered clips. The commutator shell is mounted on an extension of the armature spider, and the segments are held in place by steel clamping rings made in sections. The shaft is of mild steel, and the bearings, which are self-aligning and arranged for both forced and oil-ring lubrication, are of exceptionally heavy design. They are fitted with phosphor-bronze thrust rings to take any pressure transmitted from the pinion shaft by the sleeve coupling mentioned above. The bearing at the driving end is 14 in. diameter and 28 in. long, and that at the commutator end 12 in. diameter by 24 in. long; and although they are arranged for forced lubrication it has been found in practice that this is not necessary, the oiling rings alone being quite sufficient.

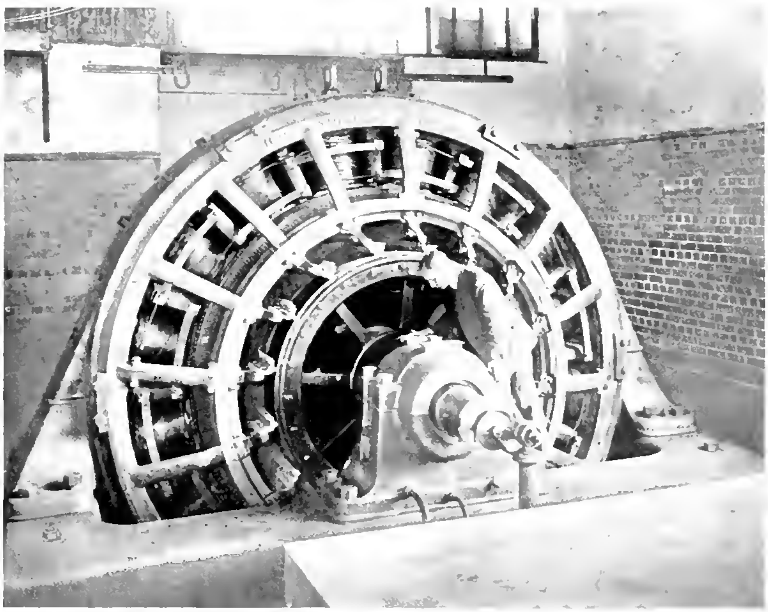


Fig. 1. 1200 H.P. Direct-Current Motor for Driving 28 In. Cogging Mill

Current is supplied to the mill motor by a reversible continuous current generator which forms part of the flywheel equalizer set (see Fig. 2 and frontispiece). The generator, which is capable of giving continuously an output of 1000 kw. at a pressure of 400 volts, is coupled directly to a three-phase induction motor of the slip ring type, designed for a continuous output of 950 b.h.p. at any speed between 400 and 480 r.p.m. when supplied with current at 2750 volts and 40 cycles per second. Both machines are mounted on a cast-iron base-plate with three self-aligning self-oiling bearings; and are connected to the flywheel shaft by a reversible flexible coupling fitted with steel springs, in place of the usual leather-covered pins or wooden blocks.

Control of the mill motor is effected entirely by regulation and reversal of the current in the shunt windings of the generator field, thus eliminating rheostatic losses and making possible the restoration to the flywheel of the energy stored in the rotating parts of the mill motor and mill. During the early part of each pass the generator is called upon to supply a very heavy current at an exceedingly low voltage, and towards the end of the pass it has to receive the large braking current required to bring the motor quickly to rest preparatory to reversal. From both the electrical and mechanical points of view the conditions are extremely severe; but thoroughly satisfactory operation was ensured by the application of compensating windings and commutating poles, and special attention to the design of the brush gear. The generator will carry currents up to 9000 amperes without any signs of sparking.

The induction motor of the flywheel set is capable of exerting not less than two-and-one-half times its normal torque; and is arranged so that the stator may be moved along the base plate till it is quite clear of the rotor, should repairs to either be necessary at any time.

The flywheel to which these machines are coupled has a weight of 30 tons, and a peripheral speed of approximately 310 ft. per second. It is composed of a central disc with a heavy ring on each side to form the rim, the three parts being riveted together. This construction ensures the most effective disposition of the material and the maximum moment of inertia. The flywheel is mounted on a solid steel shaft provided with two self-aligning bearings arranged for both ring and forced lubrication, and provided with duplicate systems of pipes and passages for the cooling water. In order to reduce the windage losses as far as possible, the flywheel is completely enclosed in a close-fitting steel casing. In case of emergency, the whole flywheel set can be brought to rest in less than two minutes, by the use of the special brake provided with compound levers and whole water-cooled cast-iron brake blocks. The brake blocks are mounted on spring supports so that their application does not cause the slightest jarring or chattering.

A barring gear of the self-releasing type driven by a 15 h.p. compound wound variable speed motor is provided for turning and starting the flywheel set, the barring wheel being mounted on an extension of the flywheel shaft. The use of this barring gear makes it possible to start the set with considerably less than the normal full load current. It is mounted on an independent sole-plate and can be removed and used for driving the mill motor, should it be necessary to true the commutator. The current for the barring motor is supplied from the exciter for the mill motor and generator at a pressure of 220 volts. It is interesting to note that although 100 amperes are required to set the gear in motion, 20 amperes suffices to keep it running at the maximum speed of 30 r.p.m.

Current for the excitation of the generator and mill motor is supplied by the special three-unit exciter set visible in the foreground of Fig. 3. This set includes an ordinary compound wound continuous current generator for supplying the current to the shunt fields of the mill motor and the generator of the flywheel set, and a special series exciter the field coils of which are connected in the main circuit. These are both coupled to a 75 h.p. 440 volt 40 cycle 3-phase motor with short-circuited rotor. The series exciter supplies current to cumulative coils on the mill motor, and differential coils on the generator, in almost exact proportion to the current flowing at the instant in the main circuit; and prevents such large rushes of current as might occur were both machines simply shunt wound. Thus a sudden increase of load on the mill motor, due, for instance, to the rolls biting the ingot and tending to increase the current in the main circuit, causes the speed of the motor to decrease and renders available the energy stored in its armature. The general effect is to prevent large rushes of current which would otherwise occur either in the normal working of the mill, or through careless manipulation of the controller, and cause annoying delays by opening the main circuit-breaker. Incidentally the operation of the motor is exactly similar to that of a steam

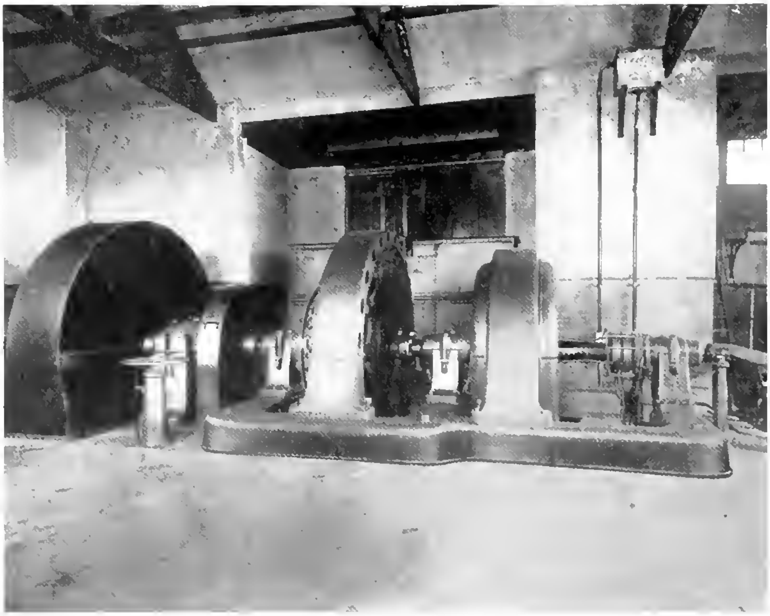


Fig. 2. Flywheel Equalizer Set for Supplying Current to 1200 H.P. Cogging Mill Motor

engine, in that the entrance of the material into the rolls causes a slight decrease of the speed, which indicates to the driver the correct instant for moving the lever towards the full running position. Somewhat similar results could have been obtained with a shunt wound mill motor and generator, by designing the equipment for a large voltage drop, i.e., for a high ohmic resistance; but this would have been less economical and efficient, although cheaper as regards capital cost. The obvious alternative, of using the main current directly in the series windings of the mill motor and generator, is quite impracticable on account of the necessity for reversing the motor connections, and the very large currents that would have to be handled; whereas the use of the special system of excitation described makes it possible to reverse the necessary connections by means of four small contactors or electrically-operated switches contained in a small box mounted under the driver's platform.

Fig. 3. 3-Unit Set for Excitation of Cogging Mill Motor and its Special Generator. Main Switchboard for Flywheel Set and Mill Motor on the Right

The whole of the control—starting, regulating and reversing—is effected by a "tramway"-type controller fixed on the driver's platform and provided with one lever only. The general arrangement of the controller is shown in Fig. 4. There are separate barrels for regulating and reversing the generator field, regulating the excitation of the mill motor where specially high speeds are required, and controlling the reversing switches for the mill motor cumulative field coils respectively. The necessary resistances are all contained in one frame, with sheet-iron cover and expanded metal sides, mounted on the driver's platform. Here also are a cast-iron instrument pillar, carrying an ammeter to indicate the current taken by the mill motor, and two speed indicators—one for the flywheel equalizer set and the other for the mill motor; as well as a small switch by means of which the main circuit-breaker may be opened instantly in case of emergency.

The mill motor can be reversed from the normal full speed of 70 r.p.m. in one direction to full speed in the opposite direction in about four seconds. This is quite quick enough for all practical purposes, especially in view of the fact that in a large proportion of the passes the full speed is never attained, and that in the initial passes it is not possible to reach even one-half of the normal speed. Greater speed of reversal could easily have been obtained if necessary, by introducing in the field circuit of the generator sufficient non-inductive resistance to reduce the time constant to a suitable value. Such a course would, however, have necessitated the use of a much heavier exciting current, and would have been objectionable not only on account of the increased losses due to the presence of the resistance, but also because of the necessary increase in the power required for acceleration and retardation.

The main switchboard for the flywheel set and mill motor, which is seen on the right of Fig. 3, is of the steel-plate type. All switches, circuit-breakers and fuses are mounted behind the panels, so that there is no live metal exposed, and no possibility of the attendant receiving shocks during the performance of his ordinary duties. The incoming feeder panel is equipped with a triple-pole oil-break switch with overload trip coils, an indicator for maximum demand during one hour, and an integrating wattmeter, the readings of which are carefully logged at the end of each shift. The panel for controlling the induction motor of the flywheel set carries a triple-pole oil-break switch with overload and low-voltage release attachments, interlocked with the liquid starting and slip-regulating rheostat in such a manner that it cannot be closed unless the latter is in the starting position.

A full equipment of instruments is provided for indicating the current, voltage, input, frequency of supply, and speed of the motor-generator. A further panel is provided for controlling the 75 kw. transformer which supplies current to the exciter set; in addition to panels for controlling the various field circuits, the barring gear and the mill motor. Protection against excessive overloads on the mill motor and generator is afforded by a circuit-breaker mounted on the mill motor control panel, and so arranged that the connection between the two machines cannot be maintained unless the motor field is fully excited. In case of emergency this circuit-breaker may be opened by the use of the small switch on the driver's instrument pillar.

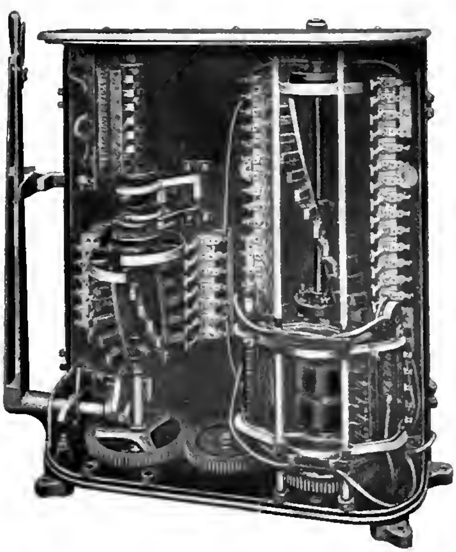


Fig 4. Internal View of Controller for Starting, Regulating and Reversing Cogging Mill Motor

A feature of the new mills is the general use of induction motors of the slip-ring type, not only for driving the cranes, skids, saws and shears, but also for the arduous and exacting work of driving the live roller tracks. The motors for the latter purpose (about twenty in number) are made with specially heavy frames, shafts and bearings; and are capable of giving continuously an output of 20 h.p. at 460 r.p.m., and exerting not less than four-and-a-half times their normal torque for short periods. For the heavy billet shears between the cogging and finishing mills a special enclosed slip ring induction motor shown in Fig. 5 is used. This machine is of the totally enclosed pipe-ventilated type with internal blower and is designed for a continuous output of 75 b.h.p. at 580 r.p.m. The air inlet, as will be seen in the illustration, is directed downward and is provided with gauze protecting covers. The control of all the circuits supplying currents to the numerous auxiliary machines is effected by the switchboard seen in the background of Fig. 3. This is also of the steel-plate type, with all live parts mounted behind the panels, and with all oil-break switches and circuit-breakers fitted with overload and low-voltage release devices.

Fig. 5. Totally Enclosed Pipe-Ventilated Induction Motor for Driving Billet Shears

The consulting engineers for the contract were Messrs. Merz and McLellan.

ALTERNATING CURRENT APPARATUS TROUBLES

Part VIII—TRANSFORMERS

By F. C. Green

Transformer Engineering Department, General Electric Company

This paper, which brings to a close our series on Alternating Current Apparatus Troubles, considers transformer operation under two main headings, viz., troubles which occur on first exciting, and those which develop during service. Under the first heading, a number of diagrams are shown illustrating the conditions which have to be met in the satisfactory multiple operation of transformers, single-phase and three-phase. The necessary theory is introduced to show how these methods may be generally applied to typical every-day problems. Section 2 considers mechanical troubles which may interfere with the proper ventilation of water-cooled, air-blast and oil-cooled transformers; and concludes with a consideration of the precautions which must be observed in load connections, where three-phase Y generators are used for 4-wire distribution.—Editor.

Transformer troubles may be divided into two general classes, viz., those that occur on first putting the transformer into service, and those that develop from the conditions under which it operates. The conditions may involve the character of the service, the

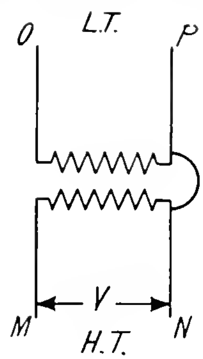


Fig. 1

transformer itself, or the auxiliary apparatus upon which the transformer necessarily depends for its satisfactory operation. The first-mentioned class of troubles distinguishes the transformer from most electrical apparatus, in that it is customary to put the transformer instantly under full excitation. Thus, if there are errors in connections, or serious defects in the transformer, they instantly evidence themselves, sometimes with considerable damage, not only to the transformer, but to other apparatus that may be connected with it. Under the second classification come those influences which, while not showing up immediately, may cause the life of the transformer to be abnormally short, or its operation to be unsatisfactory.

SECTION I. TROUBLES ON FIRST EXCITING

Connections

It rarely happens that a transformer, except the small size for lighting, is connected alone for individual service. Even in this case it may show distress for which it is in no sense responsible. If the connections to its load, or to any auxiliary apparatus, such as instruments and switches, should be short-circuited or otherwise improperly made, it is not always clear whether the trouble lies inside or outside of the transformer. In a case of this kind, however, it is a small matter to trace out the approximate location of the fault, with the wiring to the load disconnected at the transformer, making sure that the circuit from which the transformer obtains its excitation is properly made and insulated. The same remarks apply whether the transformer is operating alone or with others. There have been instances of the destruction of transformers on first exciting them when connected in multiple with others, the destruction resulting from a condition of connections that gives a dead short-circuit. The rush of current under this condition may be so great as to cause the windings to collapse. We are thus led to consider the connection of transformers in multiple and in bank for three-phase service.

Connecting in Multiple

In connecting transformers in multiple there are three things to be considered:

Polarity. The polarities must be the same; otherwise there exists a dead short-circuit. A simple test for polarity is to apply a low voltage to the high tension winding, with corres-

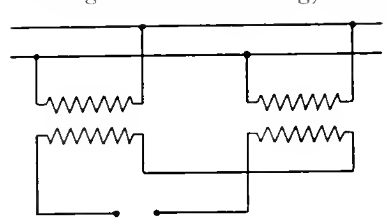


Fig. 2

ponding high tension and low tension leads connected together, and to read the impressed voltage and the voltage between the high tension and the low tension leads not connected together. If, under the connections shown in Fig. 1, the voltage between M and O is found to be greater than the impressed voltage between M and N, one polarity is indicated. If the voltage between M and O is found to be less than the voltage between M and N, the opposite polarity is indicated. The difference between the two readings will be small in most cases, depending upon the ratio of rated high tension voltage to low tension voltage. Thus, if a given transformer which is to be connected in multiple with others should show a greater voltage between M and O than the impressed voltage between M and N, then all of the transformers to be connected in multiple must show the same relation of voltages. It often happens that the multiple connection is made through leads at a point some distance from the transformer, which condition admits of having the leads crossed, thereby producing the same effect as having the polarity of the transformers reversed. In a case of this kind, it is advisable always to make a test at the location of the multiple connection to determine whether it can be safely made. To make this check, connect two points together that are supposed to go together, and insert between the other two points sufficient voltage-reading capacity to indicate double the voltage of the windings being connected in multiple. If no voltage is indicated, then it is safe to make the multiple connection. If double voltage is indicated, the leads from one of the transformer circuits should be crossed and the test repeated

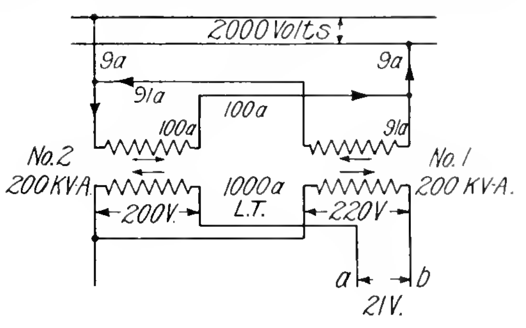


Fig. 3

to make sure that no voltage exists between points to be finally connected together. The connections under this test are shown in Fig. 2.

Ratio. The ratios of high tension windings to low tension windings must be the same, otherwise a circulating current will flow through the transformers connected in multiple. Let it be assumed in Fig. 3, with the high tension windings connected together and voltage impressed upon them as indicated, that on account of the difference in ratios between the two transformers a reading of 21 volts is measured between the points a and b. Assuming the percentage impedance volts of each transformer to be 5, 21 volts represents 5 per cent of the sum of the low tension voltages. Upon connecting a and b together, this pressure of 21 volts becomes effective in circulating current through the transformer windings against the impedance of the transformers. The value of current is obtained from the formula

$$\text{per cent. full load } I = \frac{\textit{volts difference} \times 100}{\textit{sum of impedance volts of both transformers}}$$

it being understood that by volts impedance is meant the volts necessary to be impressed on one winding, with the other short-circuited, to give full-load current. For instance, it is customary to say that a transformer has 3 per cent. impedance or 5 per cent. impedance, as the case may be; it being understood that 3 per cent. or 5 per cent. of the rated voltage of the winding upon which voltage is impressed, with the other winding short-circuited, is necessary to force full load current through both windings of the transformer.

Substituting the formula for the case shown in Fig. 3,

$$\text{per cent. full load } I = \frac{21 \times 100}{21} = 100 \text{ per cent.}$$

For the 200 kv-a. size given, the low tension circulating current would have a value of 1000 amperes. The high tension and low tension currents being inversely proportional to the respective voltages, there results a current of 91 amperes in the high tension of transformer No. 1, and 100 amperes in the high tension of transformer No. 2; the difference between these values being the amount of current drawn from the source of excitation for producing the circulating currents. Thus, under the conditions shown in Fig. 3, we find that a difference of 10 per cent. in ratios of primary and secondary voltages results in the circulation of 100 per cent. full load current. Correspondingly, a difference of 2 per cent. in the ratios would result in a circulation of 20 per cent. full load current; hence the necessity for having the ratios always identically the same.

Impedance. While the differences of polarity and of ratio are most serious in their effects, the difference of impedance among transformers to be connected in multiple is the most common trouble met with and the most difficult to provide against in designing. To exactly provide for the correct division of current among transformers connected in multiple, it is not only necessary to have the same percentage impedance, but the relation between the reactance and resistance components of the impedances should be identical. However, since the reactance component is so much greater as a rule than the resist-

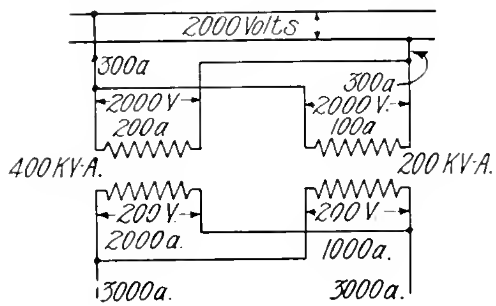


Fig. 4

ance component, the difference between these relations is usually neglected; and it is customary to have the percentage impedances approximately the same.

Since it is customary to express impedance in percentage of rated voltage, it is desirable to understand the meaning of the term as applied to the problem. In Fig. 4 are shown two transformers connected in multiple, one being a 400 kv-a. and the other a 200 kv-a. making a total of 600 kv-a. The full load value of the combined low tension currents is 3000 amperes, the total of the high tension currents being 300 amperes. Assuming the percentage impedance of each size to be the same, the manufacturer when furnishing information on the impedance of the transformers would say that the impedance of the 200 kv-a. size was, say, 5 per cent. and that the impedance of the 400 kv-a. size was 5 per cent. It is necessary to understand that, while the impedance voltages are the same, the current values used in determining the percentage impedances are not the same. For determining the impedance of the 200 kv-a. size, the low tension winding would be short-circuited, and sufficient voltage impressed on the high tension to circulate through the high tension winding full load current, or 100 amperes, and through the low tension winding full load current or 1000 amperes. The voltage necessary to be impressed on the high tension winding for circulating these currents, as previously assumed, is 5 per cent. of the rated voltage, or 100 volts. In the case of the 400 kv-a. transformer, 100 volts impressed upon the high tension winding, with the low tension short-circuited, would result in the circulation of full load current, which in this case amounts to 200 amperes for the high tension winding and 2000 amperes for the low tension winding. Thus, while the impedance voltages of the two sizes are the same, the currents are different, and it is generally understood that when the percentage impedance is said to be of a given value, that value is based upon the circulation of full load current for the size of the transformer given.

The division of current among transformers connected in multiple is inversely proportional to their impedances, and is governed by the same laws that obtain for the division of current among resistances. For example, if the 200 kv-a. size should have an impedance of 10 per cent., the amount of current that it would take is one-half load or 500 amperes, under the condition that would give a load of 2000 amperes or full-load current in the 400 kv-a. size. Therefore, in order to prevent overload in the 400 kv-a. size, the total current delivered would have to be reduced to 2500 amperes.

The multiple operation of transformers of different sizes and different makes should

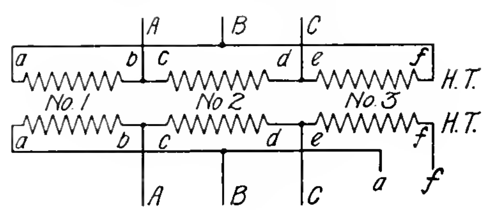


Fig. 5

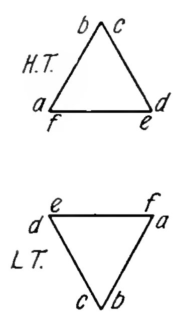


Fig. 6

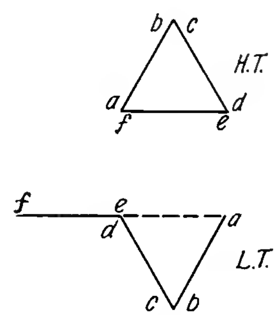


Fig. 7

be avoided wherever possible; but, when it is necessary that they shall operate in multiple, the requirements should be clearly set forth in the specifications. As a rule it should not be expected that transformers of different sizes or different makes should divide their currents within less than 10 per cent. of the correct values. In many cases the difference may be less; but on account of the difficulty of predetermining the impedance exactly, and also considering that most transformers are designed with sufficient liberality safely to admit of 10 per cent. overload, the figure given may be stated to represent a reasonable approximation.

Three-phase Connections

It has already been pointed out that transformers are rarely used for single-phase service except for lighting, and in nearly all cases single-phase lighting is taken from three-phase mains. The requirements given for the multiple operation of transformers apply whether they are connected single-phase or three-phase. The polarities must be the same, the ratios the same and the impedances approximately the same, where the transformers are connected in multiple for three-phase service. In addition, all three members of a three-phase bank, whether each member is made up of one or more units, should have the same ratio of high tension to low tension turns, and preferably the same impedance. In case the polarity of one member of the three-phase bank is different from that of the other two, a short-circuit will result where the delta-delta connection is used or the Y-delta. In the case of Y-Y connection the secondary voltages will not have correct values or phase relations. Transformers of the same rating and of the same manufacture are, as a rule, assumed to have the same polarity, ratio and impedance; so that in this case it is not necessary to make any other check than one of inspection, except where the connections are made at some distance from the transformers, which would thereby introduce a chance of getting the leads crossed. If the transformers are not of the same rating nor of the same manufacture, the final connections for three-phase should not be made without some preliminary tests to determine whether the conditions are satisfactory.

Figs. 5, 6 and 7 are used to show a convenient and positive method of determining whether it is safe to make the final connections in the delta-delta transformation. With voltage impressed on the high tension there exists no voltage between points *a* and *f* of the low tension, where the polarities of all three transformers are the same. Assuming the polarity of transformer No. 3 to be the reverse of that of the other two, there would exist a voltage between *a* and *f* of double the value of the voltage across any one of the low tension windings, as indicated in Fig. 7; so that connecting points *a* and *f*

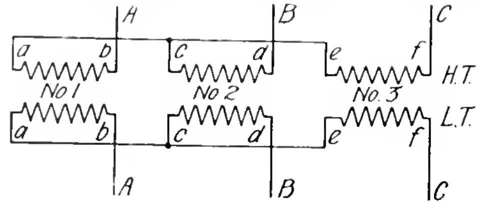


Fig. 8

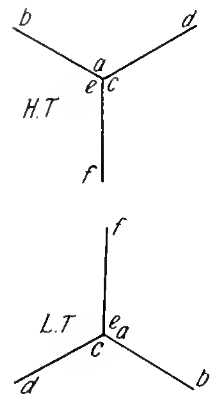


Fig. 9

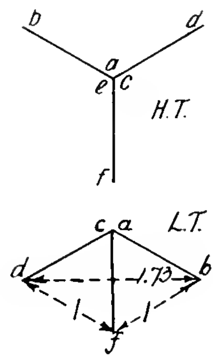


Fig. 10

together under these conditions would result in a short-circuit. The same reasoning holds true where the transformation is Y-delta. With Y-Y transformation, the reversal of polarity of one member would not give a short-circuit, as shown in Figs. 8, 9, and 10. Fig. 9 shows the correct phase relations of the voltages when the three members have the same polarity. Fig. 10 shows the relations when one of the three members has reversed polarity. Indicating the correct value of the secondary line voltage to be 1.73, the actual voltages are 1, 1, 1.73, as shown.

In order to prevent circulating current or unbalanced voltages, it is necessary to have the ratios the same. A difference in impedance of the different members of the three-phase transformation does not have such a pronounced effect as the difference would have in the straight multiple connection of transformers. The transformer impedance in this case constitutes only a part of the total impedance of the entire circuit.

It sometimes happens where a bank of transformers of one manufacture is to be connected with a bank of another manufacture, that the polarity of the one is the reverse of the polarity of the other. In a case of this kind each three-phase transformation may be completed satisfactorily; but when an attempt is made to connect the two banks

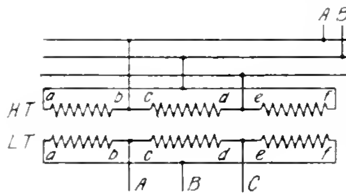


Fig. 11

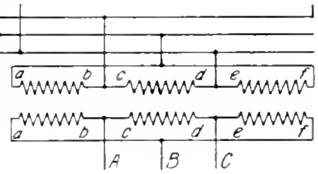


Fig. 12

together trouble is encountered in the circulation of heavy currents. The phase rotation may be the same, as indicated by operating the same motor from each of the banks; but the difficulty lies in the fact that where the polarity of one bank is reversed from that of the other, there results a six-phase relation. In a case of this kind it is necessary to open up all the high tension or low tension members of one bank and reverse each member, re-making the proper formation. Figs. 11 to 16 show the conditions described. By reversing the leads of all three windings of either the high tension or low tension of either bank, and re-making the delta, the necessary correction is made.

It may be well here to go into some detail in explaining the figures referred to, their formation and what they mean. Many other similar problems arise in every-day operation and it is believed that the methods here used and described are of sufficient simplicity to be taken advantage of by operating engineers. It is appreciated that the conventionalities of theory do not lend themselves readily to the solution of every-day problems of operation, even though the operator may have a thorough knowledge of them.

It is understood that Figs. 11 and 12 represent the high-tension and low-tension windings of the two banks of transformers. In winding transformers, the high tension and low tension windings are wound either in the same direction around the core, beginning, say, with the *a* points, or the low tension is wound opposite the high tension, beginning with the *a* points. Where both high tension and low tension are wound in the same direction around the core, one polarity obtains. Where they are wound in opposite directions around the core, the opposite polarity obtains. It is understood that by reversing the leads of either winding of a transformer the polarity is reversed. This is evident from what has been said regarding the relation between the direction of winding around the core, and polarity.

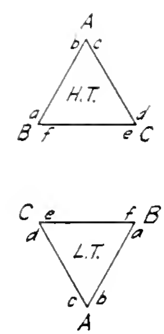
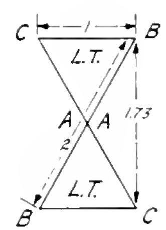


Fig. 13

Fig. 13 represents the actual relations of the voltages of the transformers shown in Fig. 11. These transformers are assumed to have the polarity obtained by winding the high tension and low tension in opposite directions around the core. The high tension of Fig. 13 shows the same points connected together as the high tension of Fig. 11. The low tension of Fig. 13 shows the same points connected together as the low tension of Fig. 11. Since the low tension windings are wound in the opposite direction around the core from the high tension, in forming the low tension of Fig. 13, it is seen that the points *a* and *b* are opposite their respective locations in the high tension of Fig. 13.

The *b* position of the high tension becomes the *a* position of the low tension, and the *a* position of the high tension becomes the *b* position of the low tension: *ab* of the low tension must lie parallel with *ab* of the high tension. In other words, the low tension winding must always lie parallel with the corresponding high tension winding. Following out this reasoning, with reference to the other two windings of Fig. 11, we obtain the formation shown in the low tension of Fig. 13, which points in the opposite direction

Fig. 16



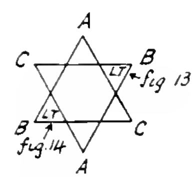


Fig. 15

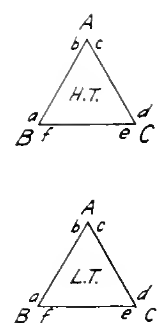


Fig. 14

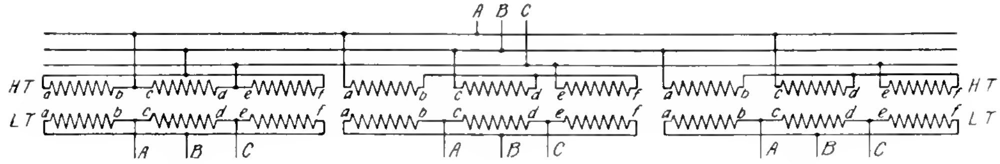


Fig. 17 Fig. 18 Fig. 19

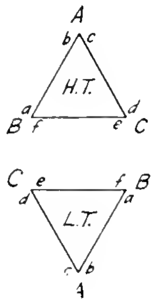


Fig. 20

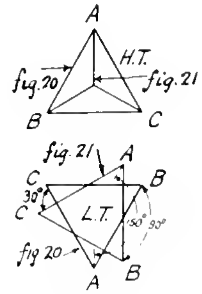


Fig. 22

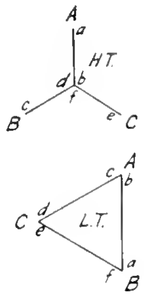


Fig. 21

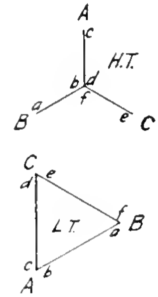


Fig. 23

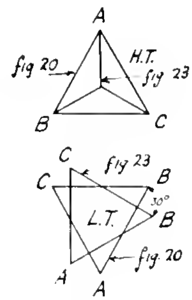


Fig. 24

from the high tension of Fig. 13. The transformers of Fig. 12 are assumed to have the high tension and low tension windings wound in the same direction around the core, making the polarity of this bank of transformers opposite to that of the other bank. Since the high tension and low tension are wound in the same direction around the core, the low tension of Fig. 14 points in the same direction as the high tension. That is, the corresponding points of the high tension and low tension windings have the same relative locations in both high tension and low tension formations of Fig. 14.

Figs. 11 and 12 show the usual connections for delta-delta transformations. When connecting the two banks in multiple, the practice is to join the *A* points, the *B* points and the *C* points of the high tension together. Having made these connections, the question is whether it is safe to connect together the *A* points, the *B* points, and the *C* points of the low tension. A convenient and positive test is to connect the *A* points together, and measure the voltage between the *B* points or between the *C* points. In case the two banks of transformers are of the same polarity there will be no voltage between the *B* points or between the *C* points, with the *A* points connected together; but in the case assumed, the transformers of Fig. 12 have a polarity the reverse of those of Fig. 11. Therefore, as shown in Fig. 16, by connecting the *A* points together, double voltage will exist between the *B* points and between the *C* points. Assuming that all six points are free, and none connected together, Fig. 15 shows the relations between the low tension of Fig. 13 and the low tension of Fig. 14. This is a balanced six-phase relation. Connecting the *A* points together, as was done for the test, does not change the relative directions of any of the windings, but gives the condition shown in Fig. 16. That is, the low tension must always be parallel with the high tension, as shown in these formations. It is seen, therefore, that in order to make these two banks of transformers run in multiple it is necessary to cross the leads, say of each of the low tension windings, Fig. 12; which operation will cause the low tension of Fig. 14 to coincide with the low tension of Fig. 13, and no voltage will exist between the points *B* or the points *C* with the *A* points connected together. It is seen also that without reversing the windings, as specified, it is impossible to make the banks run in multiple by juggling the connections of the line leads *A*, *B*, *C*. Another important feature shown in these figures is the relative phase rotation. Referring to the low tensions of Figs. 13 and 14, the direction "*A*-*B*-*C*" is the same for both banks. This fact indicates that the phase rotation is the same, notwithstanding that they cannot be connected in multiple as they are shown.

Occasionally considerable inconvenience is caused by difference of phase rotation resulting between the standard connections for the delta-delta transformation and the Y-delta transformation. While these two transformations cannot be worked in multiple, as will be explained later, it is sometimes necessary to use them in connection with separate machines to rotate in the same direction. Figs. 17 to 21 show the connections and the results. It is seen that the direction of phase rotation *A-B-C* in the low tension of Fig. 20 is opposite the direction of phase rotation *A-B-C* shown in the low tension of Fig. 21. It is understood that, in order to reverse phase rotation, it is necessary only to reverse any pair of line leads, either of the high tension or low tension.

The same figures may be used to show that the delta-delta transformation cannot be run in multiple with the Y-delta. The voltages *AB*, *BC* and *AC* of the high tensions, Figs. 20 and 21, must coincide since they are assumed to be taken from the same line. Superposing Fig. 20 on Fig. 21, we obtain Fig. 22, which shows that it is not possible to make the low tension formations coincide because of the fact that each low tension voltage must be parallel with its corresponding high tension, it being seen in the high tension of Fig. 22 that the high tension transformer voltages do not coincide but are 30 deg. apart. In the low tension of Fig. 22 it is shown that the corresponding points *A*, *B*, and *C* of the two banks, are from 30 deg. to 150 deg. apart. By reversing the leads *a* and *c* of the high tension Y bank, as shown in Fig. 19, thus reversing the phase rotation of this bank so as to make it the same as the delta bank, we find the corresponding points *A*, *B* and *C* to be 30 deg. apart, Figs. 23 and 24.

SECTION 2. TROUBLES THAT DEVELOP IN SERVICE

Troubles of this nature result from poor cooling conditions, abnormal load and voltage conditions, and from improper load connections. Conditions that result in abnormal temperatures should be guarded against, and where they cannot be eliminated entirely it is possible to offset some of the objectionable effects by giving the transformers proper attention.

Water-cooled Transformers

In water-cooled transformers the temperature of the cooling water may be too high, or the amount of water may not be sufficient. Sometimes the cooling coil is attacked or lined by impurities in the cooling water; either the flow of water being restricted by the residue of chemical actions, or the efficiency of the cooling coil being much reduced by a lining of organic matter or mud. Also, on account of allowing the oil to reach a high temperature, a deposit from the oil is accumulated on the cooling coil. This deposit is an excellent heat insulator, and unless it is removed will cause the condition to become worse, and result in dangerous overheating of the transformer.

Cooling coils should be kept clean inside and outside, and the accumulation from chemical actions between the water and the cooling coil should be removed when necessary. To clean the deposit on the *outside* of the cooling coil, it is necessary only to remove it from the tank and wipe or scrape off the deposit, as may be necessary. For cleaning the *inside* of the cooling coil of any sort of accumulation, the following treatment has been found excellent. After blowing or siphoning the water from the cooling coil, fill it with a solution of equal parts of hydrochloric acid and commercially pure water. Let the solution stand about one hour in the coil and then flush out thoroughly with clean water. Usually one treatment of this kind is sufficient, but more may be used. The treatment is effective for removing all sorts of accumulation from coils of the various metals used. In applying the treatment it is not necessary to remove the coil from the tank, but extreme care should be exercised in order to prevent any acid from coming in contact with any part of the transformer.

Conditions are sometimes met with that cause condensation of moisture on the inside surfaces at the top of the transformer. Where the atmosphere is unusually moist and the service of the transformer is not continuous, precautions should be taken to prevent condensation. The cooling water should be shut off during the period that the transformer is out of service, and during the service period the flow of water should be so regulated as to give an oil temperature of 35-40 deg. C., which temperature represents sufficient stored heat to keep the transformer warm during a considerable period of idleness. Transformers in continuous service should not have so much water put through them that the temperature of the oil is reduced to less than 10 deg. above that of the atmosphere. In some instances it is necessary to attach a "breather" to the top of the transformer to prevent condensation. The breather is usually a vessel of chloride of calcium, so constructed as to allow the water taken out of the air to drain off without mixing with the air that is going in on account of the contraction of the transformer oil in cooling. Conditions that cause condensation are rarely met with, but, in case there is doubt, periodical observations should be made to find out if the under side of the cover is accumulating rust, which is evidence of condensation.

In operating water-cooled transformers at excessive overloads there is danger of the windings reaching a higher temperature than is indicated by the oil temperature, especially where the amount of cooling water is increased for the overload condition. A thermometer located in the tank, near the cooling coil, indicates a temperature considerably lower than the actual oil temperature. It is difficult to fix a maximum limit of overload that will insure the transformers running well within safety, and at the same time meet conditions that the operator sometimes has to contend with. There are occasions of emergency that would warrant the sacrifice of some of the strength of the transformer, if the operator could be sure that it would stand up until the emergency were passed. The only safe basis on which to consider overload operation, however, is the one laid down in the specifications to which the transformer was built.

Air-blast Transformers

The efficiency of the cooling of air-blast transformers is decreased through the accumulation of dirt in the ventilating spaces. A high-pressure stream of air put through the spaces occasionally will have a material effect in keeping them cleaned out. There should be free escape from the room for the outgoing hot air, and the cold air should be drawn from an outside location that will give as little dirt or foreign matter as possible.

Oil-cooled Transformers

Oil-cooled transformers rely upon the natural circulation of the air for preventing undue temperatures. When it is considered that with a number of large transformers of this type in one station there may be more than 50 kilowatts of energy to be dissipated, the necessity for the thorough ventilation of the station in which they are installed, is realized. Since the air in becoming hot tends to flow upward, the openings in the station for the inlet of the air should be near the bottom, and those for the outlet should be near the top, all being well distributed. If the ventilation is not sufficient the transformer is bound to have a shorter life than it would have with the proper cooling. The first indications of a dangerous condition are darkening of the oil and a slight deposit on the surfaces inside of the transformer. Once the deposit begins to form the tendency is accelerated because of the lessening efficiency of heat dissipation from the transformer. Where the oil has thickened to a considerable extent and a deposit has accumulated, the remedy is to thoroughly clean the transformer by scraping it and washing it out with oil under high pressure, putting in new oil after the treatment.

Load Connections

In the distributing systems of some of the large cities, it is a practice to generate at a voltage sufficiently high to make transformers unnecessary, except to step down at the location where the power is to be used. The generators are wound Y, and the 4-wire distributing system employed. This system admits of 3-phase, distribution with single-phase service between the neutral wire and the phase wires. For three-phase service, in many instances, transformers are connected with their high tension windings in Y, and the low tensions in delta. It has been found objectionable to connect the fourth wire to the neutral of the bank of transformers for 3-phase service on account of the circulation of heavy no-load currents through the transformers. In order to eliminate these currents the practice has been adopted of leaving the neutral wire disconnected from the bank of transformers for 3-phase service. This is permissible, as there is no real necessity for the fourth wire to be connected to the neutral of the bank. It is often desirable, however, to ground the neutral of the generator for the purpose of preventing objectionable static electricity in the system. When this is done, the fourth wire connected to the neutral of the generator may still be used for single-phase service.

Where a seriously unbalanced 3-phase voltage is impressed upon a motor, there is liable to be objectionable circulating current due to the tendency of the motor to generate a balanced counter electromotive force. There have not, however, been many instances of this kind of trouble.

Where the Y-Y transformation is used for 4-wire distribution, it is necessary to observe certain precautions to prevent serious unbalancing of voltages. Figs. 25 to 28 are used to bring out important points. It is assumed in all these figures that the distribution requires three-phase current, as well as single-phase current to be drawn between the neutral, or fourth wire, and the phase wires, which distribution always results in more or less unbalancing of current in the transformers shown. Fig. 25 shows a Y-wound generator connected to a bank of Y-Y transformers. In order to take care of the unbalancing of current in the distributing system, it is necessary to have the neutral of the primary of the bank connected to the neutral of the generator. In Fig. 26, the neutral would have to be run from the high tension of the distributing bank to the high tension of the bank of transformers at the generating station, the low tension neu-

ratio resulting from the failure. The change of ratio that usually attends a failure admits of a difference in voltage which circulates current against the impedance of the three transformers connected in delta. A small difference in voltage may result in the circulation of a heavy current. Thus it may happen that when one transformer of a delta-delta bank fails, the other two may be subjected to damaging effects if the bank is not taken out of service soon enough.

In the case of the Y-delta transformation, the action is different. The effect here of a change of ratio of one of the transformers,

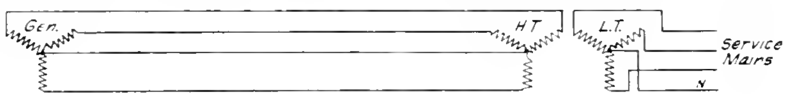


Fig. 25

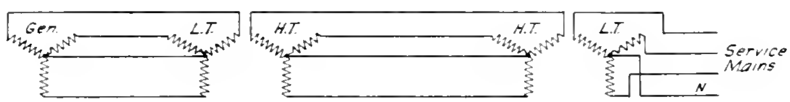


Fig. 26

Fig. 27

Fig. 28

tral of this latter bank being connected to the generator neutral. The combination shown in Fig. 27 is not practicable, for the reason that the neutral from the high tension of the distributing bank cannot be connected to the generator bank. The combination shown in Fig. 28 is made practicable by connecting the neutral of the high tension of the distributing bank to the neutral of the high tension of the generator bank, the low tension being connected in delta to the generator. In this case, the unbalancing of the voltages in the low tension of the distributing bank will be prevented by the circulation of current in the delta of the generator bank.

It has been observed in practice that when one of a bank of transformers connected delta-delta partially fails, the other two are subjected frequently to heavy currents which are circulated on account of the change of

due to partial failure, is an unbalanced secondary voltage. No appreciable current circulates in the secondary delta even where the difference in ratio of the damaged transformer is considerable. Instances are recorded where transformers connected Y-delta have run several months with one of their number in a damaged condition. In this case therefore it is not necessary to cut the bank of transformers out of service immediately unless the one damaged should fail entirely. The treatment in this case, however, is based upon the assumption that the neutral of the Y under consideration is not connected to any other neutral. If the neutral is connected to the neutral of another bank and both banks are tied in multiple, the effect in regard to circulating current would be the same as obtained with the delta-delta transformation.

ORNAMENTAL LUMINOUS ARC LIGHTING AT NEW HAVEN

By C. A. B. Halvorson

Designing Engineer, Arc Lamp Department, General Electric Company

The article introduces briefly the factors that influenced the officials of the local illuminating company in selecting the ornamental luminous arc lamp as the illuminant for the proposed system of decorative street lighting in New Haven. A detailed account of the method of setting up and wiring the lamps, and a discussion of the resulting illumination, in connection with a number of curves plotted from tests (curves reproduced) are included. Daylight and night views along the principal streets are also shown.—Editor.

At New Haven on the evening of December 15, 1911, there was inaugurated, with fitting ceremonies, what now has become the most celebrated lighting system in this country, and in all probability, the equal of any in the world. In the estimation of many engineers qualified to venture such an opinion, the New Haven installation of ornamental luminous arc lamps marks an epoch in the history of the art of illumination. Furthermore, it is freely predicted that an era of street lighting by highly efficient ornamental arc lamps is before us.

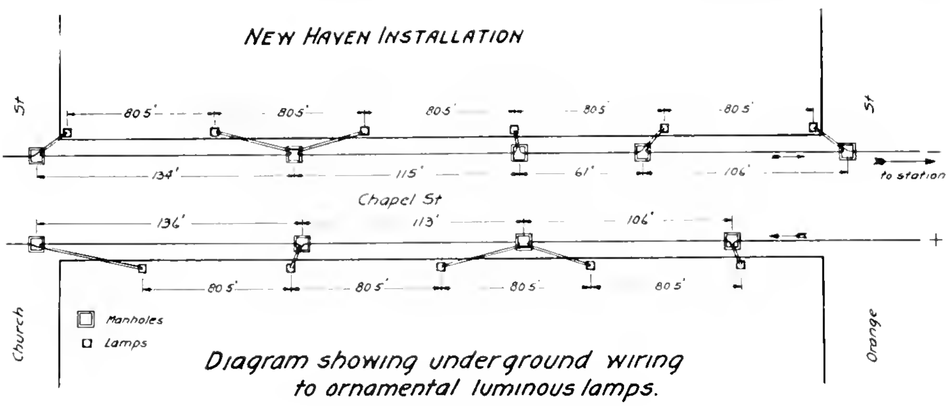


Fig. 1

As nearly every technical and trade journal in the country has reported the details of the celebration, and also has commented on the enthusiasm and co-operation of the various civic bodies responsible for the success of the occasion, it is the purpose of the present article to describe briefly through what agencies the "Great White Way" at New Haven came into being, and to give all the salient data available on the illumination and installation of this system of ornamental arc lighting.

The idea of better lighting for the business section of the city originated with The United Illuminating Company of New Haven, after which its solicitors spent much time in conscientious work, instilling into the minds of the merchants the benefits to be derived from brightly illuminating their streets by means of some form of ornamental street lighting fixture. Finally plans were adopted to install an ornamental system of lighting, using clusters of small lighting units. Before work was started on the installation of this system, the officials of the company heard of a decorative system of arc lighting by the General Electric Company about to be exploited commercially. Consequently, on September 19, 1911, Messrs. Adams and Manwaring of the Illuminating Company made a trip of inspection to the Lynn Works, where there was a trial installation of the new lamps. While there they were so impressed with the advantages of this new form of illumination that they immediately changed their plans and decided to adopt this new system of ornamental luminous arc street lighting for New Haven.

On September 23rd, a sample ornamental luminous lamp with post was installed in front of the New Haven Company's office building, where a demonstration of the illuminating qualities of the new unit was made for the benefit of the merchants, who afterward agreed unanimously in favor of the

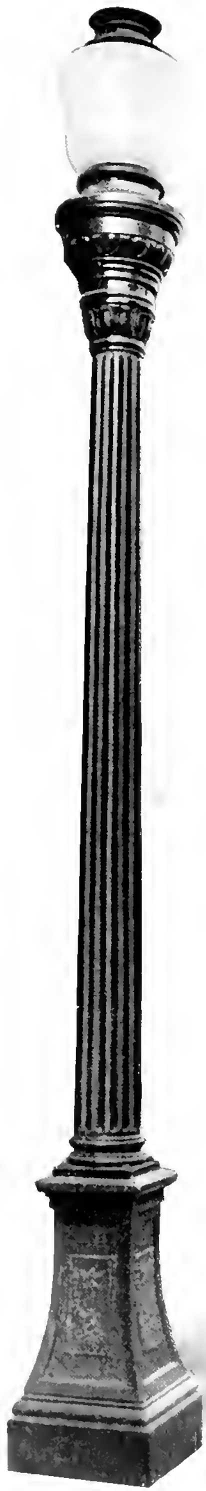


Fig. 2. New Haven Lamp and Post

change. It was stated that the splendid illuminating qualities of the light, from the viewpoint of volume, color and distribution, appealed to them, as also did the appearance of the lamp and supporting column as a unit. On October 2nd, an order was placed with the manufacturers for 75 of these lamps, including the necessary central station equipment. The speed with which the whole transaction was consummated is worthy of note; less than ten weeks having elapsed between the date on which the order was placed and the date of completion of the entire system, including all construction and details of installation.

The cost of this display lighting is borne by the merchants, each merchant paying a certain amount per linear foot frontage. The cost of maintenance and operation also is levied upon them on a foot frontage basis. The United Illuminating Company collected all subscriptions and in general supervised all details connected with the installation. The lamps burn nightly from one half-hour after sunset to 1 a.m., the streets being lighted for the remainder of the night by a circuit of series luminous arc lamps which formerly furnished all the light for the streets.

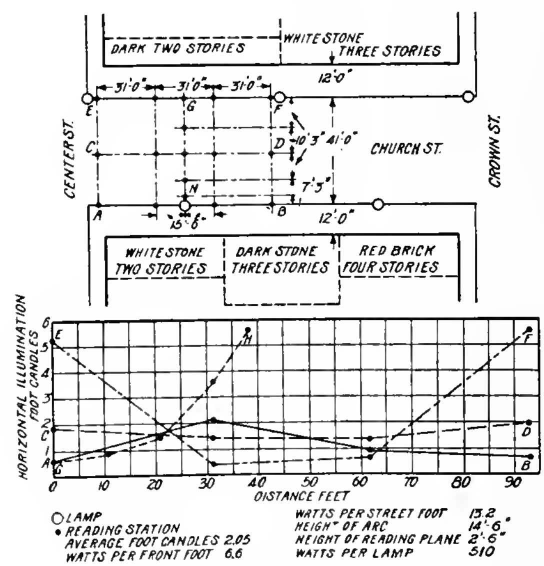


Fig. 3. Illumination Test on Church Street

The installation consists of seventy-five, 6.6 amp. direct current ornamental luminous arc lamps, mounted on ornamental cast iron columns, each lamp consuming 520 watts at the terminals. A lamp thus mounted is

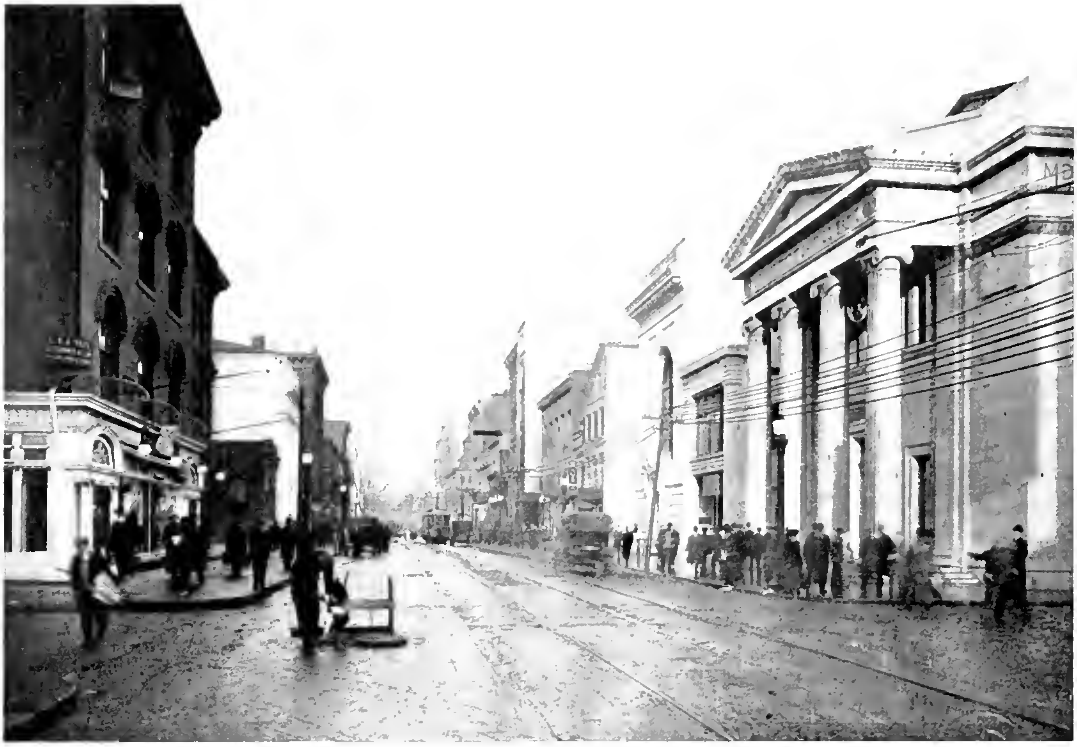


Fig. 4. Church Street by Daylight

Fig. 5. Church Street Illuminated by Ornamental Luminous Arc Lamps

shown in Fig. 2. Within the base of the column is located an absolute cutout, so that the lamp may be entirely disconnected from the circuit when desired (Fig. 11). The lighting current is taken primarily from the 60 cycle, 2300 volt mains, and is then transformed and rectified for the arc lamp circuit by means of a 75 light combined unit type constant current transformer, and a two-tubes-in-series mercury arc rectifier. A description of a similar outfit may be found in the December issue of the GENERAL ELECTRIC REVIEW, pages 625 and 635, Figs. 8 and 3, respectively.

The method of mounting the lamp to the ornamental column is shown in Fig. 11. The lamp proper is insulated from the column by a high voltage strain insulator. A complete description of the arc lamp mechanism and proper method of installing it may be found in the December 1911 issue of the GENERAL ELECTRIC REVIEW, pages 584 to 589.

Along the streets on which the new lighting system was installed conduit was already laid, as all lighting wires had previously been placed underground. A spare duct was used for the new series arc lamp circuit. Within this duct five miles of lead covered cable, consisting of No. 6 copper wire with $\frac{7}{32}$ in. rubber insulation and $\frac{3}{32}$ in. lead covering, was laid. From the nearest manhole to the base of lamp post, a 2 in. extra heavy japanned wrought-iron pipe was laid, 2 ft. deep, the cable being pulled through afterward. Fig. 1 shows the manner in which cables were looped from manholes to lamp posts.

Each post is wired from absolute cutout to lamp with No. 10 flexible twin cable insulated with $\frac{5}{32}$ in. rubber and bound round with heavy braided cotton outside covering. To insure proper polarity connections to lamps, one cable has red rubber covering and the other black.

The lamp posts are spaced at an average distance of 87 ft. on both sides of the street, in a staggered arrangement. They are mounted on concrete foundations $2\frac{1}{2}$ ft. square and 18 in. deep, set flush with the sidewalk. Within the foundation are imbedded four bolts, $\frac{7}{8}$ in. diameter, and 12 in. long, that were held in place by a wooden template while the concrete set. Set nuts, screwed down firmly to the concrete, were used to level the base of the column, after which the base was set in place and lock nuts screwed down tight to the casting by means of an S wrench, operated through the handhole in the base of the pole.

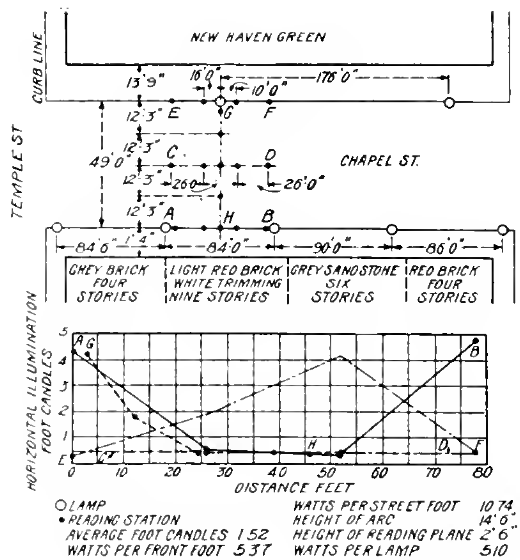


Fig. 6. Illumination Test on Chapel Street, Between Church and Temple Streets

The handhole also gives access to the absolute cutout, which is fastened to bosses cast in the base and drilled and tapped for this purpose. After the base was properly mounted, the column was placed in position and fastened to the base by four bolts. The details of this construction may be seen in Fig. 11. Casting the column in two parts greatly facilitates its setting up, as some

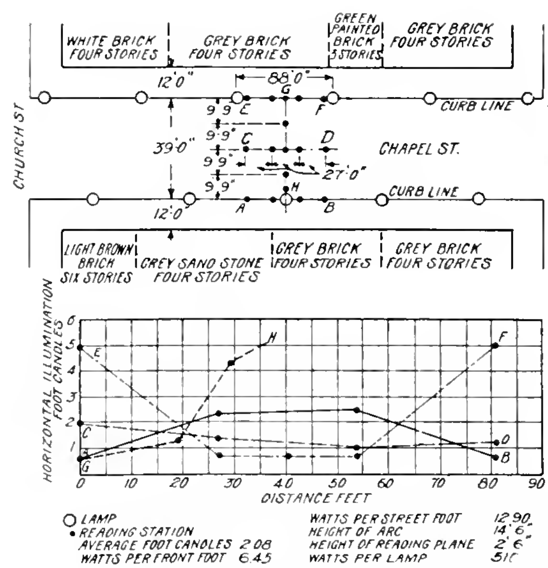


Fig. 7. Illumination Test on Chapel Street, Between Church and Orange Streets

Fig. 8. Chapel Street, Between Church and Temple Streets

Fig. 9. Chapel Street Illuminated by Ornamental Luminous Arc Lamps

work, such as drawing in the cables, can be accomplished through the opening in the top of the base.

The dimensions of the column are as follows:

Bottom of base, 18 in. square.
Top of base, 13½ in. square.
Height of base, 3 ft. from sidewalk.
Height of column proper, 9 ft. 3 in.
Diameter of column proper, 8 in. at bottom, tapering to 6 in. near top, and then flaring to 9 in. at point of support of arc lamp insulator.

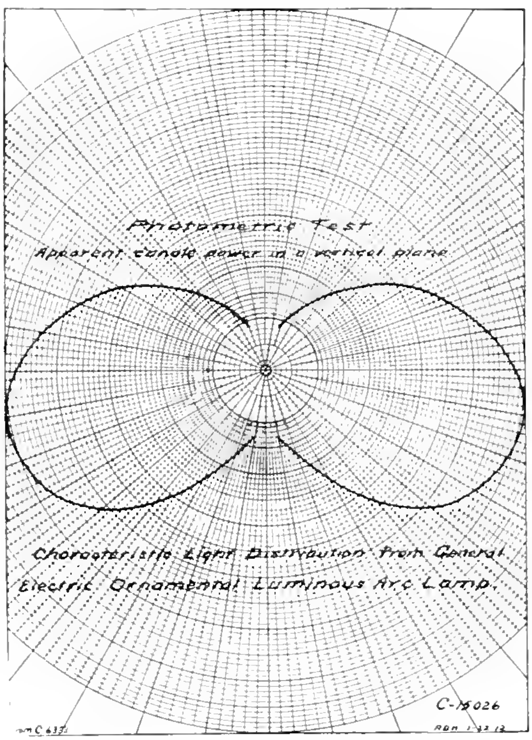


Fig. 10. Characteristic Light Distribution on Ornamental Luminous Arc Lamp

The posts were finished with bronze paint and all visible arc lamp parts above the insulator were finished in the same manner.

The characteristic light distribution from this specially designed light source is shown clearly in Fig. 10. It will be observed that the maximum intensity is at an angle of 10 degrees below the horizontal; also, that there is a generous amount of light supplied at proper angles above and below the horizontal.

Perhaps a better way to show the ornamental features of the installation as well as the values of the illumination is by means of photographs and tests made by the manu-

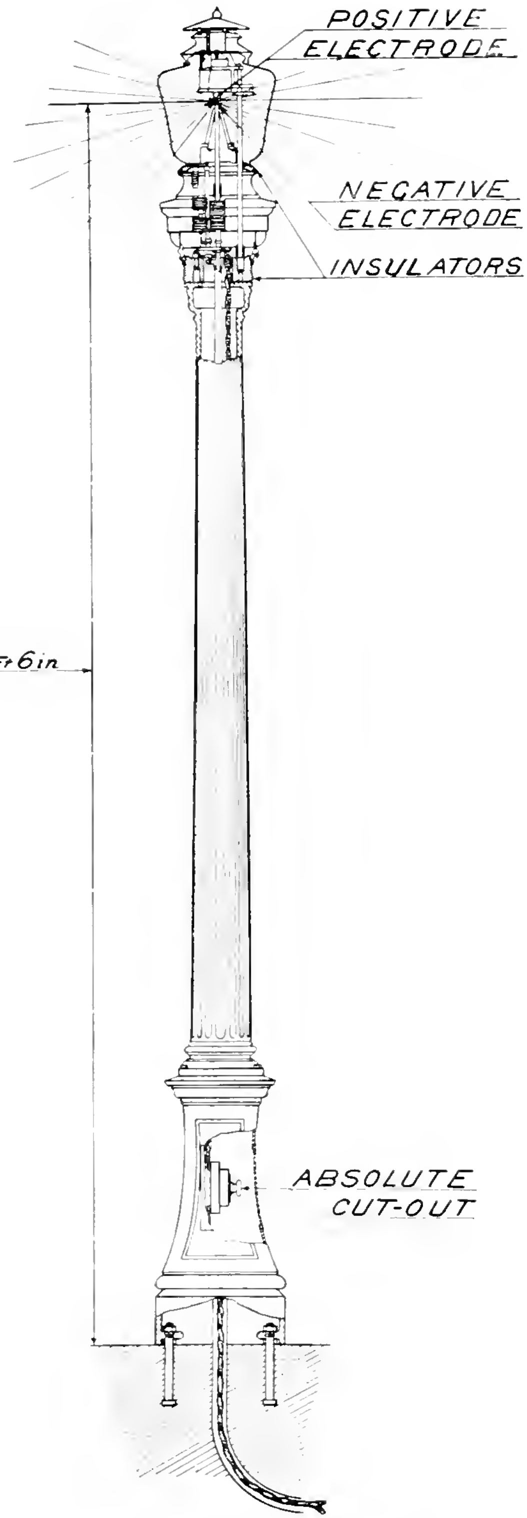


Fig. 11. Diagram Showing Method of Mounting Ornamental Luminous Arc Lamp

facturer's illuminating engineers. The photographs and tests of the illumination were taken at corresponding locations, so that the block in foreground of each photograph is the same as that over which the photometric tests were made. The height of the arc is 14 ft. 6 in. The tests were made with the Ryan luximeter, the reading plane being 2 ft. 6 in. from the ground. Ten readings were taken at each station, and the mean taken as a result. The data sheets on the illuminating tests are self-explanatory, the full line on plots being curve of foot candles at different distances along curb line between stations A and B; the dash line being curve along middle of street between stations C and D; the broken line being curve along opposite curb between E and F; and the dotted line being curve across street between stations G and H. Fig. 5 was taken along Church Street, and illumination test, Fig. 3, was taken in the same location; Figs. 8 and 9 were taken along Chapel Street, and the tests, Figs. 6 and 7, in the same positions, respectively. A clear idea of the amount of light distributed can be had by a comparison of Figs. 4 and 5, which are views taken by daylight and at night, respectively, from as near the same spot as possible.

By referring to Figs. 3, 6 and 7, it will be noticed that there is an increase of approximately 35 per cent. average illumination on Chapel Street between Orange and Church, and on Church Street between Chapel and Crown streets, over the average illumination on Chapel Street between Church and Temple streets. This is due to the fact that in the latter section there are no buildings on one side of the street and only one-half the number of lamps are installed on that side.

Referring to Fig. 6, the average illumination on the line AB is 2.08 foot candles, and in Fig. 7, the average illumination on line EF is 2.42 foot candles, showing an increase of 16 per cent. This increase is due in part to building reflection and in part to the fact there is an equal number of lamps on each side of the street represented by Fig. 7.

The resulting illumination is an apparent uniform distribution over street areas and building fronts, the facades and cornices of nine-story buildings being beautifully illuminated in all their details. Such results have long been desired in ornamental street lighting, not only for the decorative effects obtained, but from a utilitarian viewpoint, as the upper floor merchants are enabled to participate in the advantages accruing from such a system of illumination.

Never before has the appellation "Great White Way" been used so appropriately in connection with a system of street lighting. The illumination emanates from large globes unique in design and of such density that they form a beautiful secondary source of pearl white light of high efficiency and low intrinsic brilliancy, the arc being invisible. Moreover, the globe is perfectly filled with light, there being a noticeable absence of circular shadows upon its surface. Emphasis should also be laid on the pleasing appearance by day of the dignified single-light columns.

PROGRESS OF MECHANICAL CLEANING

The use of vacuum for interior cleaning, while of comparatively recent origin, has long since passed the experimental stage, and is today a proven success. This method of dust disposal is applicable to buildings of all classes, large or small, and particularly to residences, hotels, apartment buildings, hospitals, office buildings, stores, schools, theatres, churches, etc. It thoroughly removes dust and dirt and thereby prevents its accumulation. It is cleanly, efficient and economical, and saves time, expense and labor as compared with any other method.

During the last few years, thousands of vacuum cleaning plants have been installed in the leading buildings of every city of importance in the country. Architects and engineers of highest standing in their professions endorse and specify vacuum cleaning, recognizing its superior merits over any other system.

Elements of a Vacuum Cleaning System

Any practical vacuum cleaning system is necessarily composed of four distinct elements, viz.:

1. *The vacuum producer*, which exhausts the air from the vacuum piping, thereby producing the suction which draws the dust and dirt from fabrics or surfaces to be cleaned.

2. *The dust separators*, which collect and separate the dust from the air drawn through the vacuum system during the cleaning operation, thus preventing dust from entering the vacuum producer.

3. *The vacuum piping*, which extends from the dust separators to the several floors of a building and through which the dust-laden air is drawn down into the dust separators.

4. *The cleaning tools*, which are connected by hose to the vacuum piping or to the machine itself (for portable use) and by means of which the suction is applied to the fabrics and surfaces to be cleaned.

A Modern Type of Portable or Stationary Vacuum Cleaner

The Vacuum Producer

The vacuum producer is the most important element of the system, and for mechanical cleaning purposes there are six distinct types that may be used.

1. Turbine fan type
2. Rotary water seal pump type
3. Piston pump type
4. Rotary contact pump type

(1–4: Electric, gas, gasolene or steam power)

5. Diaphragm pump type. Water gas or gasolene power
6. Aspirator. Steam, water or compressed air.

One type is better in certain cases and the other types are better in others. It all depends upon the conditions in the case, and there is no one particular type that would be suitable for all requirements.

Automatic Control of Power

Aside from the satisfactory working of the apparatus in general, the most essential feature for the success of vacuum cleaning systems is the control and regulation of the power consumption, according to work performed; in other words, economy of operation.

The "Richmond" automatic control is typical of the highest development in automatic governing systems. By its use the power consumed is exactly in proportion to the amount of vacuum used, and systems which prior to its introduction had been unsatisfactory, wasteful, and costly to operate, are by its use rendered practicable, successful and commercially desirable.

The Dust Separators

Inasmuch as the air which is sucked toward the vacuum producer is filled with dust, dirt, and gritty particles, it is evidently essential to provide some method of separating the dirt from the air before it reaches the pump. In some systems "dry separation" is used, that is, the air is strained through a linen bag. In others is used a combination of the "dry and wet" systems, in which the bulk of the dirt is disposed of in a whirlwind tank, and the remainder is drawn through an atomizer which thoroughly saturates every particle and deposits it in the water of the wet separator tank. The latter tank is connected with the water service pipes, while a drain pipe leads to the sewer, which permits of the easy changing of the water.

The Vacuum Piping

In vacuum cleaning all dust, dirt, burnt matches, toothpicks, broom-corn, ravellings, lint, etc., etc., is drawn through the cleaning tools and cleaning pipes, thence into the dust separator. It is obvious, therefore, that these tools and conduits should present smooth interior surfaces, free from pockets and obstructions, to prevent clogging. The presence of pockets, obstructions and short bends also tends to obstruct the flow of air, cause waste of power, and decrease the cleaning efficiency. Standard pipe fittings with rough interior surfaces, short turns, etc., may answer well enough for pipe lines carrying steam, water and other fluids or gases under pressure, but are wholly unfitted for vacuum cleaning mains, for the reasons stated.

Instead of the short turns of steam and gas piping, the bends must have a long sweep. It is also necessary in vacuum piping to be able to detach and remove sections of the pipe in case of clogging. This is easily accomplished by what is known as the Clamp System, in which each length of pipe is clamped to the other one. One section may be removed without disturbing the others; and it is an easy matter for any ordinary mechanic to install the piping in any job.

The Cleaning Tools

Upon the cleaning tools devolves the important function of applying the vacuum to the fabric or surface to be cleaned, and gathering in the dust. Various kinds of surfaces demand separate and distinct treatment, and what is effective for one may be wholly inefficient for another. For instance, different tools should be furnished for cleaning carpets and rugs, bare floors, wall and ceiling, upholstery, lace curtains, etc. The tools should be light, and so constructed as to operate without injury to even the most delicate and expensive fabrics.

The Cleaning Operation

To one unfamiliar with the operation of a vacuum cleaning system, its first demonstration seems little short of marvelous; for as already stated, by means of the "automatic power control," the vacuum produced by a stationary cleaner may be kept constantly "on tap" in the cleaning mains, ready for immediate use, at any hour of the day or night, like water, gas or electric service. To make it available, it is but necessary to connect the flexible service-cock in the cleaning mains, attach the proper cleaning tool to the universal guiding handle at the other end of the hose, open a valve, and rapidly pass the tool over the surface to be cleaned. The swift inrush of air through the cleaning tool, into the vacuum created by the vacuum producer, carries with it all dust, dirt, sand grit, moths, moth eggs, lint, etc., with which the tool comes into contact, whisking it away like a flash through the cleaning conduits to the dust separator in the basement, from which it is removed at convenience.

A thoroughly efficient vacuum cleaning system is just as essential to any modern building as heating, sanitary plumbing, electric light, or hot water on tap. As a convenience it exceeds steam heat. As a health measure, it exceeds sanitary plumbing. As a luxury, it exceeds electricity and hot water on tap. And, unlike all other luxuries, it offers a positive economy,—an actual saving in labor, an actual dollars and cents saving in the wear and tear of furnishings.

Portable-Stationary Turbine Vacuum Cleaner

The typical machine shown in the illustration is semi-stationary. It can be placed in the basement and attached and detached at will to a system of piping running to all parts of the house, with hose connections at convenient points; or the machine can be moved from one place to another and the cleaning hose and tools connected direct to the machine. On this account it is especially useful where it is desired to clean garages and other outbuildings.

The vacuum producer consists of a four-stage vertical rotary turbine. No special wiring arrangements are necessary. The machine operates from any ordinary electric lamp socket supplied with current through a suitable fuse, and is supplied with 35 ft. of cable to enable a wide range of operation. The electric motor is of ¼ h.p., for direct or alternating current as specified. Standard motors are wound for either 115 volts direct current, or for 110 volts, 60 cycle single-phase alternating current. The machine is readily started and stopped by a push button or ordinary switch. If the machine is placed in the basement and attached to piping system, push buttons may be arranged on every floor so that it would not be necessary to go to the basement to start and stop the machine. Cost of operation is less than four cents an hour. Dust separation is accomplished by the dry-strainer process, with detachable dust container. The machine can be used as a blower as well as a vacuum cleaner, if desired, or both blower and suction can be used at the same time. The handle is detachable. It can also be folded up against machine if desired. The cleaner is automatic in operation, preventing the overloading of motor without the aid of auxiliary mechanism. It requires no attention but oiling twice a year.

This type of apparatus is peculiarly adapted to the use of families living in rented houses, for in case they desire to change their place of residence, the machine is very easily removed, as it weighs but 80 lb., and is mounted on substantial rubber-tired wheels.

GRAPHICAL METHODS IN THE DESIGN OF SHAFTS

PART II—THREE-BEARING SETS

BY A. SCHEIN

DRAFTING DEPARTMENT, GENERAL ELECTRIC COMPANY

No attempt should be made to work through the following examples of the application of graphical methods to shaft design for three-bearing sets, until the four cases given in the March REVIEW for two-bearing machines are thoroughly understood and mastered. When this has been done, the two cases given herein may be easily followed. The method is based upon the same well-known principle with similar modifications.—EDITOR.

In the following two cases the method of procedure is to assume first that the shaft is supported only at the two end bearings and the deflection then determined for these conditions. Next it is assumed that the shaft is supported only at the center bearing, and the deflection again obtained. Determining the elasticity of the shaft, the reactions at each of the bearings can then be figured. From these values, and when all the forces acting on the shaft have been found, the bending moment diagram may be plotted and the deflection at any given point for the whole set calculated.*

In cases where the shaft is made up of two parts which are fastened together by means of a bolted (solid) coupling, the portion of the shaft upon which the coupling is fitted should be taken to represent a solid shaft, provided that the moment of inertia of the bolts is equal to the moment of inertia of the shaft upon which the coupling is fitted. The stiffness of the spiders, or any other rotating part which is fitted on to the shaft, may be neglected, as the ordinary press-fit does not represent a perfect fit. In cases where a shrunk fit is employed, the stiffening effect should be taken into consideration.

Case 5

In this case is considered a motor-generator set, of which the weight of the revolving parts including the shaft is 8105 pounds. The various diameters of the shaft along its length are as shown in the drawing.

Figure 1. The shaft is drawn to scale, 1:12, or $S=12$. Locate the acting loads.

Figure 2. In Figs. 2, 3, 4 and 5 we neglect the center bearing, as pointed out above, and make the assumption that the shaft is supported upon two bearings only. On the vertical line in the weight vector polygon, plot down the weight 900 pounds, 905 pounds, etc., to a scale of 2000 pounds = 1 in., or $W=2000$. The pole distance is taken as 6 in., or $h=6$.

Figure 3. Draw out the bending moment diagram and obtain (from Fig. 2) the reactions R_1, R_2 in a manner similar to that indicated in Case 2.

Figure 4. The areas from Fig. 3, which are obtained in the same way as explained in Case 2, are plotted down to a scale of 3 sq. in. = 1 inch, or $a=3$.

With a ratio of $\frac{I}{H}=25$, we get:

For a diam. of 6 in., $I=63.6$
and $H=63.6:25=2.56$ in.
For a diam. of 7 in., $I=117.9$
and $H=117.9:25=4.72$ in.
For a diam. of $7\frac{1}{4}$ in., $I=135.6$
and $H=135.6:25=5.42$ in.
For a diam. of 8 in., $I=201$
and $H=201:25=8.02$ in.

Then complete the polygon.

Figure 5. Draw the deflection curve and mark the ordinate D_2 under the center bearing.

Figure 6. In Figs. 6, 7, 8, 9 and 10, the shaft is assumed to be supported at the center bearing only. On the horizontal line, locate the loads as given in Fig. 1.

Figure 7. On the vertical line AA plot the weights to the same scale as in Fig. 2, $W=2000$ and $h=6$. From the horizontal line OO', the loads to the left of the center bearings in Fig. 6 are plotted down, beginning from the extreme left; or $Os=900$ pounds, $sk=905$ pounds, $kl=2100$ pounds.

The loads to the right of the center bearing are then plotted upwards, beginning from the extreme right; or $Om=2000$ pounds, $mn=2200$ pounds. Then complete the polygon.

Figure 8. Draw a horizontal line ad. Make ab parallel to sO', bc parallel to kO' and ce parallel to lO'. Now beginning from d,

*In the following examples torsional stresses are neglected, since the torsion only influences the bending moment diagram and deflection to a very slight extent the resulting increase in deflection rarely exceeding 2 per cent. for small machines, and, say, 4 per cent. for the larger sizes. When the torsional stress has to be considered, the deflection curve is drawn from the combined bending and torsion moment diagram. Where B_m = ordinate for bending, and T_m = that for torsion moment then the ordinate for combined moment $=\frac{B_m}{2}+\sqrt{\left(\frac{B_m}{2}\right)^2+T_m^2}$

CASE 5

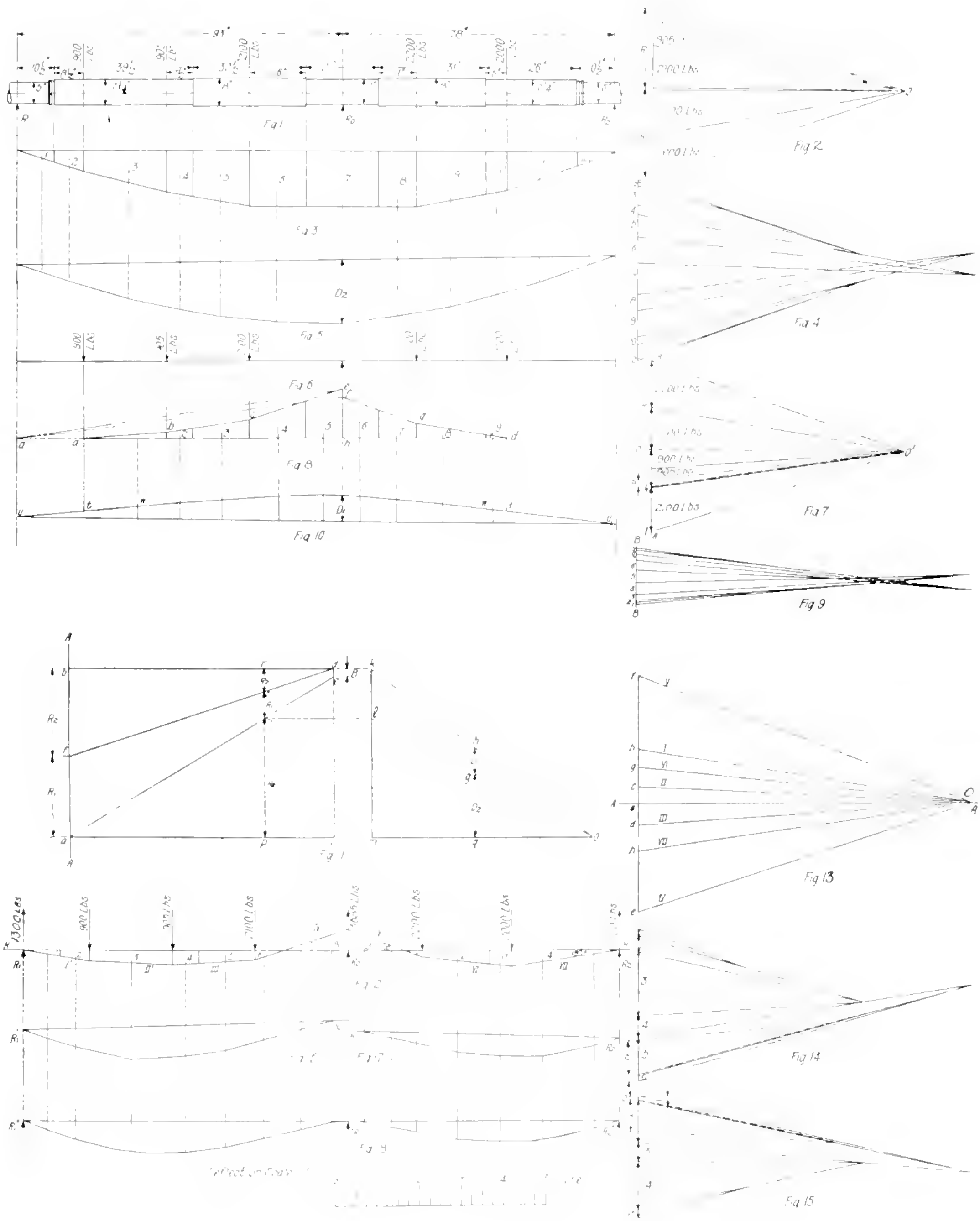


Fig 1
Fig 2
Fig 3
Fig 4
Fig 5
Fig 6
Fig 7
Fig 8
Fig 9
Fig 10
Fig 13
Fig 14
Fig 15
1300 LBS
900 LBS
2100 LBS
2000 LBS

make dg parallel to mO' and gf parallel to nO'. The area $a\ h\ c\ e\ b$ is the bending moment area for the loads on the left, and the area $d\ h\ f\ g$ for the loads on the right of the center bearing. The maximum bending moment for the left side loads is $L=ch$, and for the right side loads, $L=fh$. The distance cf shows that the shaft has a greater momentum on the side towards R_1. Connect c and f with a'. Draw parallel lines from O' (in Fig. 7) to the lines $a'c$ and $a'f$. Then B is the unbalancing load. In other words at R_1, we have to apply a force B upwards, in order to keep the shaft in a horizontal position. Treat the bending moment diagram in the same way as in Fig. 4 and divide it into convenient areas (say nine parts).

Figure 9. On the vertical line BB, plot the areas from Fig. 8 up (as the bending moments are negative). Use the same scale for H and a as in Fig. 4; or $\frac{I}{H}=25$, and $a=3$.

Figure 10. Draw the deflection curve. Since the shaft is supported on the center bearing, it forms a curved line between the acting loads t and t'. From t to u and t' to u', the shaft is to be considered straight. Therefore tu is the continuation of wt. Connecting u and u', mark D_1 under the bearing R_0.

Figure 11. On a vertical line AA make $af=R_1$ and $fb=R_2$ (use the same scale as in Fig. 2. In case the bending moments to the right of a vertical line through the center bearing [*i.e.* at R_2 end] are greater than those to the left, make $af=R_2$, and make $fb=R_1$). Make ac of convenient length and complete the rectangle. Make de equal the unbalancing B (from Fig. 7.) Connect d with f and e with a. At q on the extended line ac plot the deflection up; where $qg=D_2$ (deflection from Fig. 5) and $gh=D_1$ (deflect from Fig. 10). Connect o (where om is any length) with h and extend the line to k, which is on the same level as bd. From k drop a vertical line km. Connect o with g and extend it up to l. Draw a horizontal line from l to intersect ca at n. Through the point n draw a vertical line, and then

$pn=R_0=5685$ lb.
$ns=R_1=1300$ lb.
$sr=R_2=1120$ lb.

This assumes that the three bearings are on the same level.

Figure 12. On a horizontal line HH, representing the shaft, locate the loads in the same directions as they are actually acting. From Fig. 11 we get the reactions which are acting up, and from Fig. 1 the loads which are acting down. Complete the bending moment diagram after Fig. 13 has been drawn.

Figure 13. Draw a horizontal line AA. Beginning with point a plot the weights to scale 1000 lb = 1 in., or $W=1000$. The first load is $R_1=ab=1300$ lb., $bc=900$ lb., $cd=905$ lb., $de=2100$ lb., $ef=R_0=5685$ lb., $fg=2200$ lb., $gh=2000$ lb. and $ha=R_2=1200$ lb. The first and last points in plotting these forces must be on the horizontal AA.

Complete the bending moment diagram in Fig. 12, by drawing line I' parallel to I, II' to II. . . . VII' to VII. The last line must intersect HH at R_2, as otherwise the diagram is wrong.

Figure 14. On a vertical line, to scale 1 sq. in. = 2.5 in., or $a=0.4$, plot the areas 1, 2, 3 . . . . 8 (from Fig. 12) for the part of the shaft between R_1 and R_0. Positive areas are plotted down, negative areas up; the areas above HH being positive, and those below negative. The ratio $\frac{I}{H}=25$.

Figure 15. This figure is similar to 14, the areas taken being those between the reactions R_0 and R_2.

Figure 16. Draw the deflection curve, using the vector polygon from Fig. 14.

Figure 17. Fig. 15 is used for this deflection curve.

Figure 18. This figure is copied from Figures 16 and 17. The deflection scale for Fig. 18 is

$$\text{Scale}=\frac{29{,}000{,}000\times I}{S^3\times W\times h\times a\times H}$$
$$=\frac{29{,}000{,}000\times 25}{12^3\times 1000\times 8\times 0.4}=131$$

In the above equation the values for W, h, a and H are to be taken the same as were used in Figs. 12, 13, 14 and 15.

Case 6

A motor-generator set with an overhung booster is taken as the last case; the diameters and loads being as shown in the figure.

Figure 1. The shaft is drawn to scale, 1:10, or $S=10$. Locate the acting loads.

Figure 2. Assuming the shaft to be supported on the two end bearings only, and proceeding as in Case 4, we plot the weights to same scale here, 2000 lb = 1 in., or $W=2000$. With a scale of $h=6$, we complete the polygon.

CASE 6

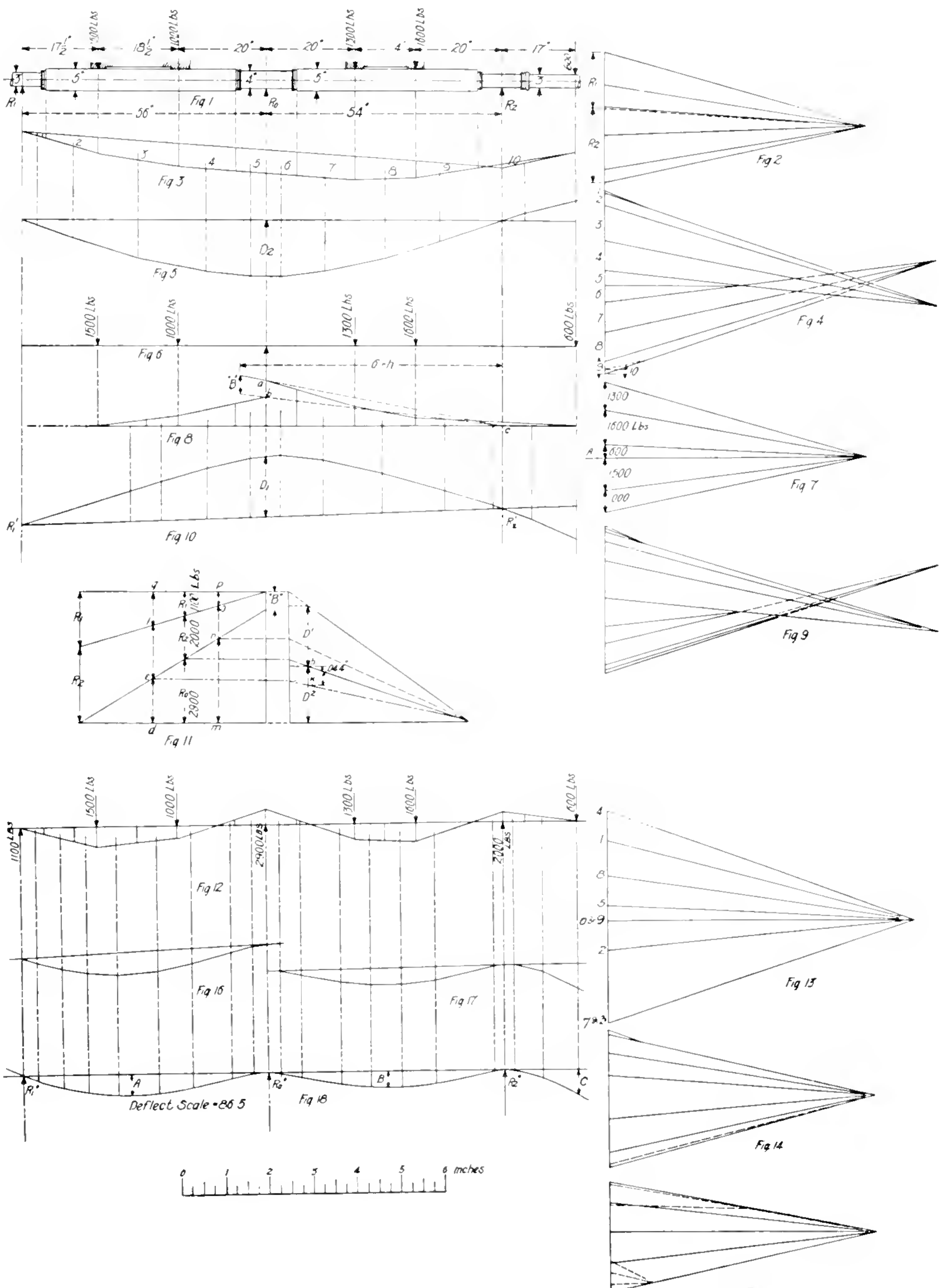


Fig 1
Fig 2
Fig 3
Fig 4
Fig 5
Fig 6
Fig 7
Fig 8
Fig 9
Fig 10
Fig 11
Fig 12
Fig 13
Fig 14
Fig 15
Fig 16
Fig 17
Fig 18
1500 Lbs
1000 Lbs
1300 Lbs
1600 Lbs
600 Lbs
1100 Lbs
2400 Lbs
2000 Lbs
2000
2900
56"
54"
Deflect. Scale = 86.5
inches

Reactions R_1 and R_2 are obtained after Fig. 3 is completed.

Figure 3. The bending moment diagram is drawn as described in Case 4.

Figure 4. From Fig. 3 plot the areas 1, 2, 3........9 down, and area 10 up, to a scale of $a=1$. Assume a value for $\frac{I}{H}=4$. Then

for 3 in. diam., $I=3.976$; $H=0.994$ in.
for 4 in. diam., $I=12.57$; $H=3.142$ in.
for 5 in. diam., $I=30.68$; $H=7.670$ in.

Complete the vector polygon.

Figure 5. Draw the deflection curve and mark D_2 under the center bearing.

$$\text{Deflection scale}=\frac{E}{S^3\times W\times h\times a}\times\frac{I}{H}$$
$$=\frac{29{,}000{,}000}{10^3\times 2000\times 6\times 1}\times 4$$
$$=9.68$$

$$\text{Deflection}=\frac{D_2}{\text{scale}}=\frac{1.28}{9.68}=0.132 \text{ in.}$$

i.e., the shaft would deflect to that amount if the center bearing were removed.

Figure 6. On the horizontal line, locate the acting loads as in Fig. 1.

Figure 7. Keeping the same scale as in Fig. 2, plot the loads (as described in Case 5).

Figure 8. The bending moment diagram is then drawn. The unbalancing B can be found as explained in Case 5; or the method plainly shown in the figure may be employed.

Figure 10. Draw the deflection curve. Connect R_1' and R_2'. Then D_1 is the deflection of the shaft if supported at the center bearing only.

Figure 11. If the three bearings are on one level, then the reactions on the bearings are:

$R_0=2900$ lb.,
$R_1=1100$ lb.,
$R_2=2000$ lb.;

and the specific pressures are

$$R_0=\frac{2900}{4\times 12}=61 \text{ lb. per sq. in.}$$

$$R_1=\frac{1100}{3\times 9}=41 \text{ lb. per sq. in.}$$

$$R_2=\frac{2000}{3\times 9}=74 \text{ lb. per sq. in.}$$

If the center bearing were lowered 0.044 in. our reactions would be:

$R_0=de=2000$ lb.
$R_1=fg=1550$ lb.
$R_2=ef=2450$ lb.

The above values are obtained by making $kh=0.044\times 9.68=0.425$ in. (as the deflection scale is $=9.68$. If the center bearing were raised by the same amount (or 0.044 in.) then the reactions would be: $R_0=mn=3800$ lb.
$R_1=po=700$ lb.
$R_2=on=1500$ lb.

In many cases it is necessary to lower the center bearing to a certain extent, in order to diminish the bending stresses and also the pressure on the center bearing.

Figure 12. The bending moment diagram is completed after finishing Fig. 13. The diagram is correct if the bending moments under the reaction R_1 and the last load, 600 lb., are zero.

The bending moment is figured as in the first 4 cases, or,

$$M=L\times S\times W\times h$$

For W and h use the same values as were employed in Fig. 13. L is the ordinate from the bending moment diagram at the point in question.

Figure 13. Here the loads are plotted in the same way as was described in Case 5. The weight scale is $W=600$ and $h=7$. From 0 to 1 is 1000 lb., from 1 to 2 = 1500 lb., 2 to 3 = 1000 lb., 3 to 4 = 2900 lb., and so on.

Figure 14. The areas between R_1 and R_0 are plotted to a scale of 1 sq. in. = 2.5 in., or $a=0.4$. The ratio $I:H=5$.

Figure 15. The areas between R_0 and the last load are plotted to the same scale as in Fig. 14. $a=0.4$ and $I:H=5$.

Figures 16 and 17 are the deflections of each half of the shaft.

The deflection scale (for Fig. 16, 17 or 18) is

$$\text{Scale}=\frac{E}{S^3\times W\times h\times a}\times\frac{I}{H}$$
$$=\frac{29{,}000{,}000}{10^3\times 600\times 7\times 0.4}\times 5=86.5;$$

or maximum deflections at

$$A=\frac{0.5}{86.5}=0.00578 \text{ in.},$$

$$B=\frac{0.375}{86.5}=0.00433 \text{ in.},$$

$$C=\frac{0.58}{86.5}=0.00672 \text{ in.}$$

Forces in Different Planes

If the forces upon the shaft are acting in different planes, e g., vertical and horizontal, then:

(1) For a shaft supported in two bearings, the bending moment diagrams for the vertical and horizontal forces should be plotted separately. The combined bending moment diagram (the resultant of the two) should then be drawn out and the deflection obtained.

(2) For a shaft supported in three bearings, vertical and horizontal bending moment diagrams must also be worked out separately. As pointed out earlier in this article, the assumption has first to be made that the shaft is supported at the two end bearings only, and next that it is supported only at the center bearing. This necessitates drawing out the vertical bending moment diagram for the two-bearing assumption and again for the center-bearing assumption, and thus finding the combined diagram for vertical forces only; then drawing out the horizontal bending moment diagram for the two-bearing assumption and the center-bearing assumption, and finding the combined diagram for horizontal forces only. From these two combined diagrams, vertical and horizontal, the resultant diagram for the whole shaft is obtained, from which the deflection is calculated.

ELECTRIC POWER IN BUILDING THE WORLD'S GREATEST AQUEDUCT

By J. M. Matthews

Advertising Department, General Electric Company

Last month we published an article, "Electricity in Excavation Work," in which was outlined some of the principal reasons why contractors had not, until recently, adopted electric power for the performance of the greater part of the work involved in their undertakings. It was shown, from descriptions of several installations and the work accomplished, that it is admirably suited for all of the usual operations and offers many advantages over steam and compressed air. The present article shows conclusively that electricity has become an almost indispensable factor to the contractor engaged in such projects as the construction of the Catskill Aqueduct and the Panama Canal; while for smaller developments it is still the most desirable form of power, because of its cleanliness, flexibility and economy.—Editor.

New York City adds another big city's population to itself every year. In this way an Albany, a Bridgeport, a New Haven, or a Grand Rapids is annexed every twelve months; in two years a Jersey City is gained and in five years a Boston, a Cleveland or a Baltimore. In order to provide an adequate supply of water for this growth of approximately 125,000 a year, a plan was approved to obtain from the foothills of the Catskill Mountains 500,000,000 gallons daily. The comprehensive plan includes the development of the watersheds of the Esopus, Rondout, Schoharie and Catskill creeks, but at the present time only the Esopus watershed is being developed with its available 250,000,000 gallons of water daily.

Starting at the 130,000,000,000 gallon Ashokan reservoir, which will hold enough water to cover Manhattan to a depth of 28 ft. and whose area is equal to all of Manhattan below 116th St., an aqueduct 127 miles long is being constructed which will pass under deep valleys, the Hudson, Bronx and East rivers, and The Narrows to Staten Island, supplying New York's boroughs known as The Bronx, Manhattan, Brooklyn, Queens, and Richmond. Near Valhalla, N. Y., and 30 miles from the City Hall, the aqueduct is interrupted by the Kensico reservoir, which acts as an emergency storage reservoir to prevent interruption of supply during the unwatering periods necessary for inspection between Ashokan and Kensico reservoirs. This reservoir will have the largest dam in the world, containing over 1,000,000 yards of masonry, and will store 40,000,000,000 gals. of water, which is sufficient to supply New York for 75 days, or cover Manhattan Island to a depth of 9 feet. Its shore line is 30.2 miles long.

The Hill View Reservoir at Yonkers will hold 900,000,000 gals. and will equalize the difference between the use of water in the city as it varies from hour to hour and the steady flow in the aqueduct. It will also furnish large quantities of water for emergencies, as in the case of a great conflagration.

The total estimated cost of building the 500,000,000 gallon aqueduct was $176,857,000 of which about 100,000,000 has been spent to date (March, 1912), with the prospect of getting water into Croton Lake in about 10 months.

A quotation from the October, 1911, Budget of the Board of Water Supply Exhibit will be of general interest and show the magnitude of this work, rated by some engineers as the second greatest engineering feat ever undertaken by man, ranking next to the

Panama Canal. In reading the quotation, bear in mind the fact that the largest Roman aqueduct was only five by three feet.

"There are four distinct types of aqueduct, cut-and-cover, grade tunnel, pressure tunnel and steel-pipe siphon, north of the City line.

"The cut-and-cover type will form 55 miles of the aqueduct, will be of horseshoe shape, 17 feet high by 17 feet 6 inches wide inside, and will be constructed of concrete When completed it will be covered by an earth embankment. This is the least expensive type and so is used wherever the elevation

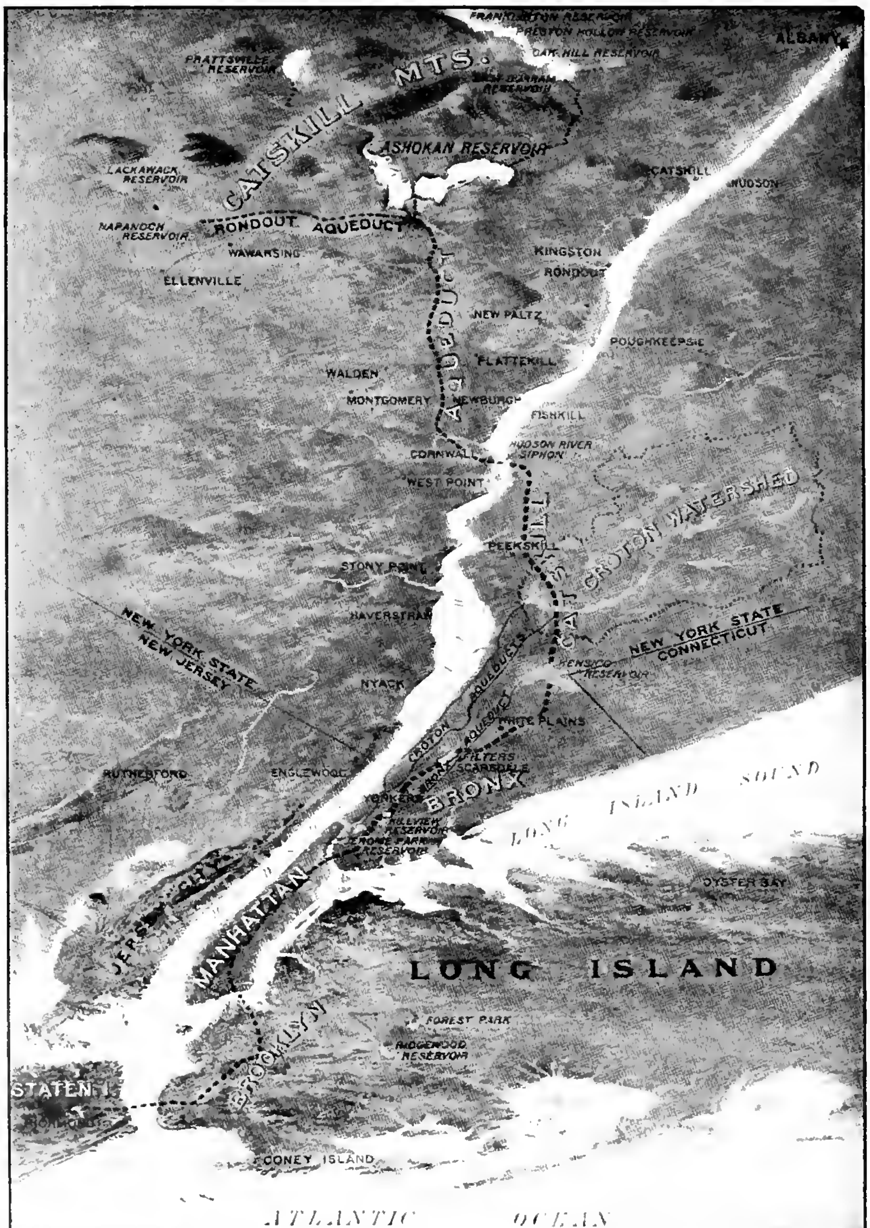


Fig. 1. Catskill Watersheds and Route of Aqueduct

and nature of the land permit. Of this type 36 miles have been built.

"Where hills or mountains cross the line and it would be impracticable to circumvent them, tunnels at the natural elevation of the aqueduct are driven through them. There are 24 of these grade tunnels, aggregating 14 miles. They, also, are horseshoe shape 17 feet high by 13 feet 4 inches wide, and lined throughout with concrete. Of these tunnels 11 miles are excavated.

"Where deep and broad valleys must be crossed and there is suitable rock beneath them, circular tunnels are driven deep in the rock and lined with concrete. There are 7 pressure tunnels, totaling 17 miles, with a diameter of about 14 feet. A shaft at each extremity connects each pressure tunnel with the adjacent portions of the aqueduct. To date, over 16 miles have been excavated, including all shafts, of the total of 29 shafts.

"Steel-pipe siphons are used in valleys where the rock is not sound or where for other reasons pressure tunnels would be impracticable. These steel pipes are made of plates riveted together, from $\frac{7}{16}$ inch to $\frac{3}{4}$ inch in thickness, and are 9 feet and 11 feet in diameter. They will be lined with 2 inches of cement mortar, embedded in concrete and covered with an earth embankment. There are 14 of these siphons, aggregating 6 miles. Three pipes are required in each siphon for the full capacity of the aqueduct, but only one is now being laid. Almost 5 miles of pipe have been laid."

Electricity plays a very prominent part in constructing this great aqueduct, and has proved to be both a saver of time and money. The whole work is divided into over a hundred contracts, on practically every one of which electric power and light are extensively used, and telephones are in frequent evidence. Air compressors, ventilating fans, pumps, car pullers, hoists, derricks, cableways, drills, clam shell diggers, mine locomotives, crushers, screens, elevators and concrete mixers are operated by electric motors, as are also the carpenter and machine shops. In every case the motors have given unqualified satisfaction and proven a paying investment. A few of the more important applications of electric power to the work involved will be described, beginning at the site of the Ashokan reservoir in the Catskills.

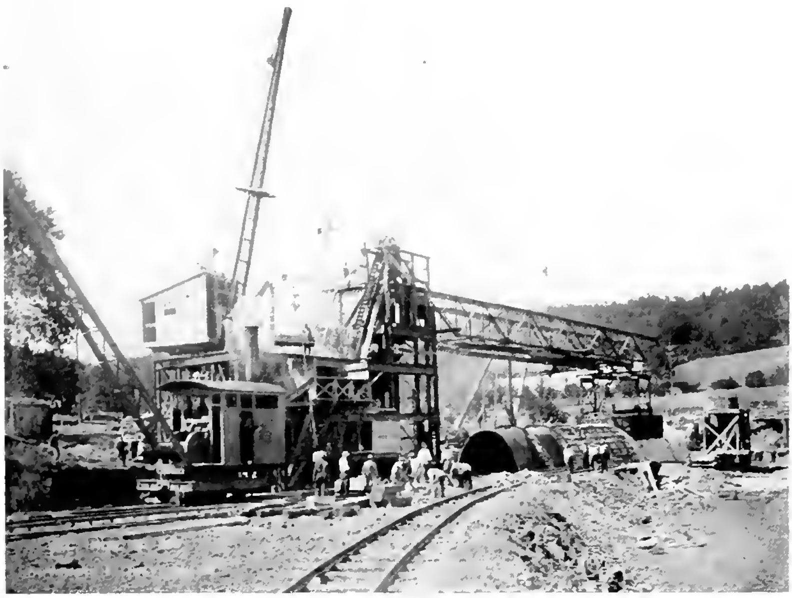


Fig. 2. Travelling Concrete Plant, the Principal Apparatus of which is Operated by Electric Motors

Esopus Cut, Cover Work and Peak Tunnel

The first contract along the course of the aqueduct, let to Stewart-Kerbaugh-Shanley Company, and consisting of Esopus cut, cover work and Peak tunnel, was completed by electric power purchased from the Newburgh Light, Heat & Power Company, at a rate which effected a saving of at least 50 per cent. over the cost of steam operation, with its watchmen, firemen and coal. About six miles of 33,000 volt high tension transmission line supplied two substations, one of which contained three 300 kw. transformers to reduce the voltage to 2300 for the motors, and the other, three 200 kw. transformers of the same voltage and ratio. These transformers are oil insulated and water cooled and are controlled through panels equipped with oil switches and meters.

To supply air for the drills, two 300 horse power 2300 volt induction motors were belted to air compressors located at a compressor plant inside the south portal of Peak tunnel.

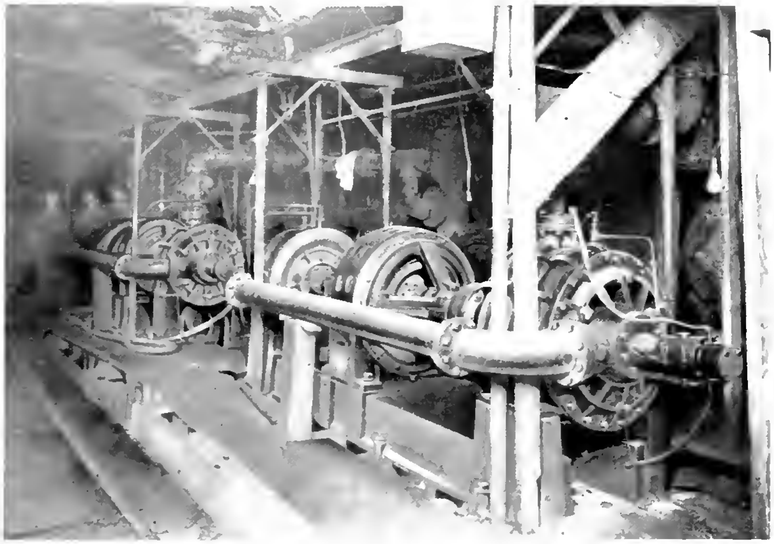


Fig. 3. Induction Motor-Driven Pumps

The tunnel was ventilated during the construction period by two fans supplying air through a 14 in. pipe and driven by 30 horse power, 220 volt induction motors. Two 2 h.p. motors of the same type were used to drive centrifugal pumps.

A travelling concrete plant was employed for mixing and laying the concrete; it consisted of a three-deck structural steel traveller 140 ft. long by 24 ft. wide, moving on the finished invert and supporting a pillar derrick, two gyratory stone crushers, sand rolls, sand and stone bins and a mixer, all of which were operated by electric motors. Three 15 horse power, 220 volt induction motors were used for handling steel forms, two 50 horse power motors of the same type for driving Hains' concrete mixers, and one 200 horse power 2300 volt and one 100 horse power 220 volt induction motor to drive the crushers, screens and elevators. A 140 ft. bridge extended from the traveller and rested on the finished arch, spanning the forms in which concrete was to be placed. Concrete was carried out on the bridge from the mixer in 1-yd. buckets and deposited. This plant is shown in Fig. 2.

Between July 28 and December 22, 1910, starting with 1150 feet of invert laid, 1275 feet of arch of the loose earth type, and 875 feet of the firm earth type had been placed, and most of the completed arch had been covered with back filling. The plan of operation was to build the aqueduct continuously by joining the work of one day to that of the preceding, but late in the season, 45 foot sections were placed on every other day against 30 foot sections every day attempted earlier in the season.

T. A. Gillespie Co. Contract

Next to the Stewart-Kerbaugh-Shanley Co. contract just described, we find the T. A. Gillespie contract for Rondout pressure tunnel and the north half of Bonticou tunnel, Ulster County, N. Y.

At High Falls a large central compressor plant was built. It contained, in addition to the compressing apparatus, two 100 kw., 3600 r.p.m. 150 lb. condensing Curtis steam turbines, furnishing power for lighting the job and running the carpenter shop. This plant was built to obtain a large amount of compressed air from one central station instead of having small separately attended plants at the several shafts.

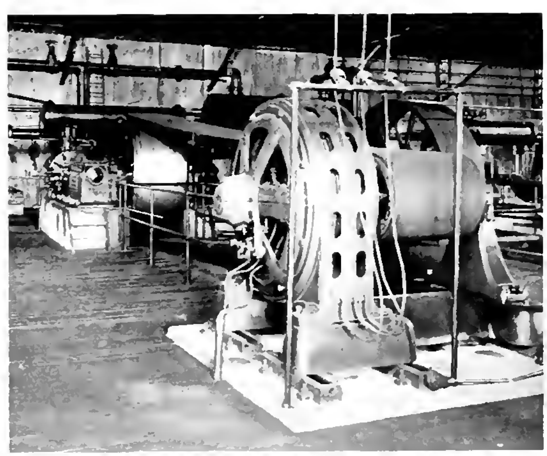


Fig. 4. Air Compressors Driven by 500 H.P. Induction Motor

The frequent increase of water leakage, which rose to over 2000 gals. per minute at one time, made the air pumps inadequate; therefore, three 600 gals. per minute Worthington pumps were installed, which pumps against a 500 ft. head and are driven by 150 h.p., 1200 r.p.m. induction motors. These pumps were operated at 175 per cent. overload for three weeks, and for a long period in tunnel air heavily charged with sulphuretted hydrogen which corroded air pipes to a mere shell. The motor-driven pumps operated satisfactorily, and are now used in preference to those driven by any other power. They were frequently covered over with rock dust from tunnel blasting when the heading was near the shaft. Power for operating the pumps was obtained from the Newburgh Light, Heat & Power Company at 33,000 volts and transformed to 440 volts.

This installation conclusively demonstrates the superiority of electric pumps, which, unlike air pumps, do not make a demand upon the air supply when it is required for drilling.

The totally enclosed motor was also proven to be the best for tunnel operation, as more or less water is likely to flow up around the pumps, and is sure to be sprayed around while the pumps are being primed. Leaky packing has also been known to spray motors which were direct connected to pumps.

Grade and Pressure Tunnels

Adjoining the Gillespie contract we have that of the Degnon Contracting Company, which includes the southerly half of the Bonticou grade tunnel, the Mohonk grade tunnel, and the Wallkill pressure tunnel, together with about 4 miles of cut and cover aqueduct south of the Bonticou tunnel.

A short transmission line was built to the New Paltz substation of the Newburgh Light, Heat & Power Company, over which current was furnished to Bonticou and Forest Glen. The lines of this company connect with a hydro-electric station at Honk Falls, N. Y., 13 miles northwest of Forest Glen, and with the steam generating station of the Poughkeepsie Light, Heat & Power Company at Poughkeepsie, N. Y., as well as with its own steam generating plant at Newburgh; therefore all these sources were available for furnishing electric energy as required.

A steel frame building cased with corrugated iron was built near Forest Glen, and five compressors with a combined capacity of 6700 cu. ft. of free air per minute were installed. These are driven by 300 and 500 horse power induction motors, Fig. 4, receiving power from the six water-cooled 33,000/1185-2370-2170 volt transformers shown in Fig. 5. A 600 kv-a. 2200 volt synchronous motor with direct connected exciter is used to improve the power-factor and at times when this motor is not operating, a drop of 80 volts is evident at the Forest Glen board. The station is protected by aluminum cell lightning arresters.

At each of the six shafts is a mine hoist operated by a 150 horse power induction motor equipped with a magnetic brake, which automatically sets if current fails, and overwinding devices which prevent the cage from being hoisted too high. The hoist drum is 66 in. in diameter with 1⅛ in. Hazard steel cable operating balanced cages of 4 tons capacity at the usual speed of 400 feet per minute. Several small rock crushing, screening and elevating plants that are in operation at the shafts are also driven by electric motors.

At four of the shafts motor-generator sets are used for lighting the tunnels and supplying current for mining locomotives which are used to haul muck and concrete cars. Such a set at shaft No. 5 consists of a 35 horse power, 220 volt induction motor direct connected to a 20 kilowatt, 220 volt direct current generator.

The electric mining locomotive is used extensively in this service; it is much faster than mules, and the cost of upkeep is less, as the loss of animals through accident in this class of work is considerable, and in many cases unavoidable, as the mules break through flooring into holes and the cars run over them.

The crushed stone for the Degnon Contract is furnished by the Bonticou Stone Company from a point about four miles from New Paltz, N. Y., where they have a compressor plant containing three 33,000 to 2200 volt transformers and two induction motors belted to compressors. The one shown at the left in Fig. 7 is rated at 100 horse power and runs a 300 cu. ft. per min. compressor; while the one on the right is a 60 horse power motor running a 200 cu. ft. per min. compressor. The control board may be seen in the center of the picture and the aluminum cell lightning protective devices in the background.

A large stone crushing plant is located on the hillside about a quarter of a mile from this station. Each motor is enclosed in a small room and connected by belt to its load. The screens and elevators are also driven by electric motors, while the crushed stone is lowered down the hillside by an incline hoist operated by a 37 horse power induction motor.

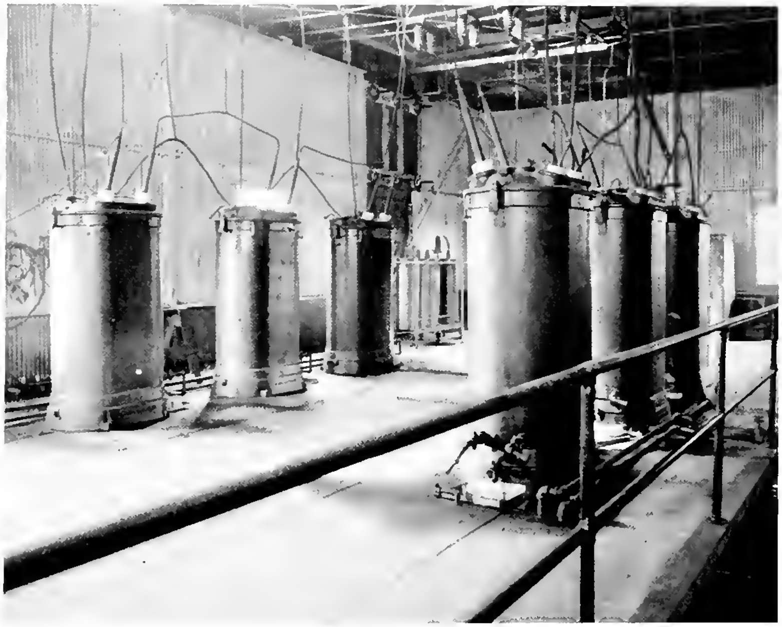


Fig. 5. Transformers for Supplying Power to Induction Motors, one of which is shown in Fig. 4

For several hundred feet back of working faces the tunnel is hung with cables having a lamp socket for a screened 16 c-p. lamp every 25 feet. The lamp globes are removed when firing the blast. The cut as well as other bench holes are wired in series and fired from a distance of 500 feet back of the heading. The shoot wires are strung on the opposite side of the tunnel from the lighting circuit.

This contract has established what are believed to be American records for driving hard rock tunnels, an average advance of $11\frac{1}{2}$ feet a day having been maintained during September, 1910.

Moodna Pressure Tunnel

The next tunnel contract is that of the Mason & Hanger Company for the Moodna pressure tunnel, where electric mining locomotives and electric lighting were used in the tunnel, with motor-generator sets at the shafts; power was purchased from the Newburgh Light, Heat & Power Co., a 600 kw. generator furnishing the power for lighting and for driving a ventilating blower at the south portal.

Tunneling the Hudson

Next to the Mason & Hanger contract is that of the T. A. Gillespie Company for constructing the siphon under the Hudson River. This tunnel, which extends under the Hudson from Storm King to Breakneck mountain, gives the aqueduct its rank as the second greatest engineering project ever undertaken,

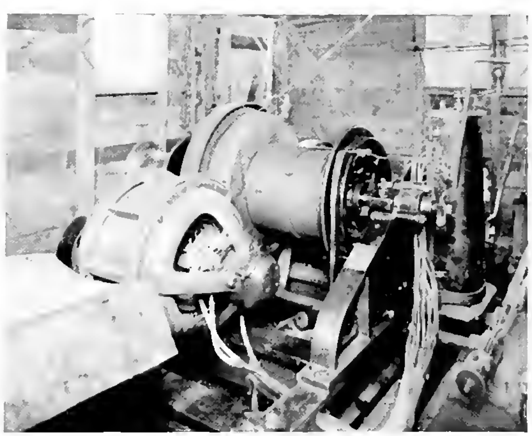


Fig. 6. Induction Motor Geared to Clam Shell Digger

and its construction has attracted the attention of engineers the world over. Engineers from Europe and Japan have come over just to study the work, and recently *Le Matin* of

Paris sent a special representative to write up the work and its progress.

Before the tunnel was decided upon, the question as to the type of crossing had to be settled.

Five possible methods were condsidered: First, a tunnel far down in the solid rock, connected by vertical shafts to the aqueduct on either side of the river, called an inverted siphon, or simply siphon; second, a bridge high above the river; third, a tunnel just under the river bottom similar to those of the subway and the Hudson and Manhattan Railroad under the East and North rivers; fourth, a tunnel constructed in sections, floated out and sunk in position like the railroad tunnel under the Detroit River; and fifth, metal pipes laid in a trench dredged in the river bottom.

Of these possible methods, the first, or the tunnel in the solid rock, was selected as the best and the cheapest to construct and maintain, even if it had to cross at a depth of 4000 feet. Had a bridge been selected, it would have had to be by far the heaviest bridge yet built, and by reason of its conspicuous location, would have been the mark for a cannon shot or dynamite; its destruction would have deprived New York City of its full supply of water for five years.

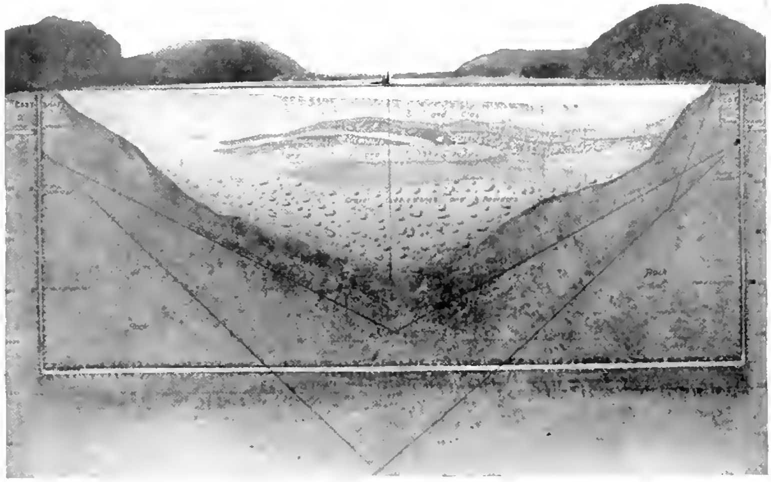


Fig. 8. Section of Hudson River at Storm King, showing Pressure Tunnel and Borings

The tunnel site was determined after a series of soundings and borings extending over two years, during which time hundreds of wash, shot and diamond drill holes were bored into the river bottom, until solid rock from shore to shore was located between Storm King and Breakneck mountains.

A shaft in either side of the river was sunk and a pump chamber excavated 250 feet down on the side toward the river. While the shaft sinking continued diamond drilling was started in the chambers. The holes sloped downward and after nine months of drilling crossed each other in solid rock 1500 feet under the river surface. Two other holes were then drilled, which crossed in solid rock at 960 feet. It was decided to drive the

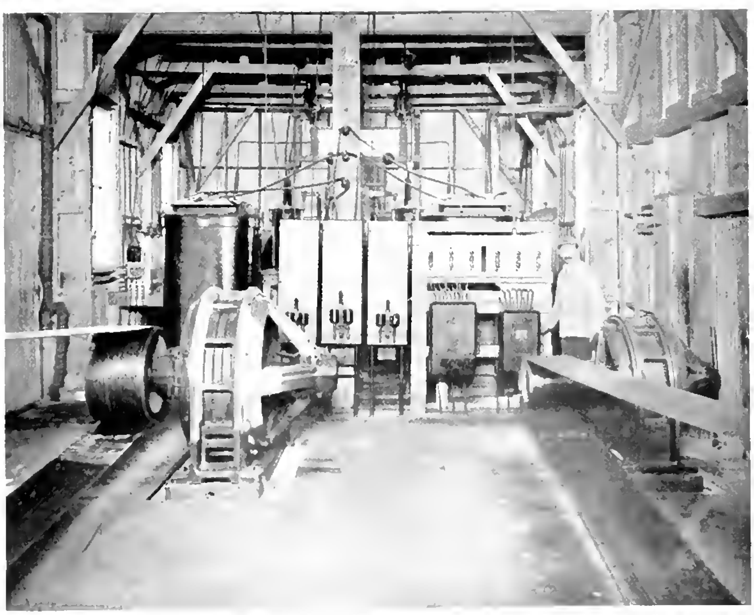


Fig. 7. Induction Motors Belted to Air Compressors

tunnel 1100 feet below the surface of the river.

When the tunneling was started and had advanced 160 feet a concrete bulkhead was built 12 feet thick and strongly reinforced by

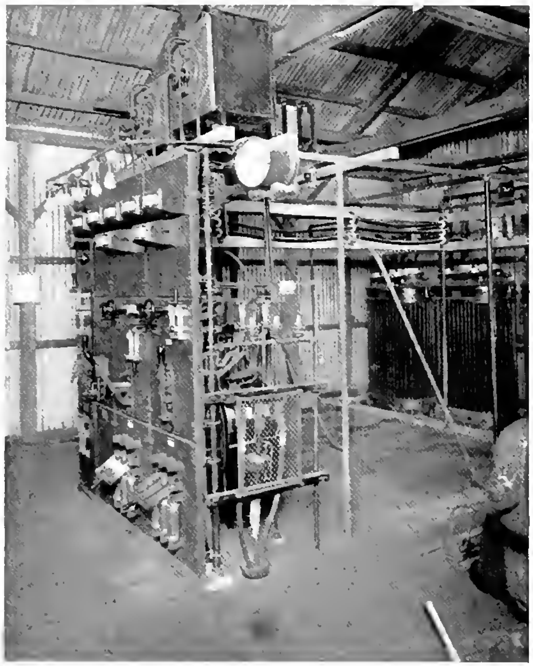


Fig. 9. Switchboard and Transformers in Power House at Storm King

steel rails driven into the rock. This unusual strength was necessary to withstand the great pressure to be expected if water from the river should leak in through a fissure. Valves were arranged in this bulkhead so that water could be admitted only as fast as it could be taken care of by electric motor-driven pumps located between the bulkhead and the bottom of the shaft.

A power plant was built at Storm King containing a 500 kw., 3600 r.p.m. Curtis turbine connected to a 500 kw., 480 volt alternator. The turbine operated condensing at 100 lb. steam pressure. A 25 kw. Curtis turbine exciter was also installed. The voltage is stepped up by three oil insulated and water cooled transformers, from 480 to 6600 volts and transmitted by submarine cable to the tunnel shaft on the west shore of the Hudson, where it is used to operate mining locomotives, pumps, ventilating fans, etc., after being again transformed to 480 volts.

In the east shaft the power is used at the voltage at which it is generated to operate two specially constructed pumps. These pumps, which are of a capacity of 500 gallons per minute (against a 1200 foot head), are operated by 275 horse power ball-bearing, water and air cooled, specially designed squirrel cage induction motors. These motors can be turned over with the little finger when disconnected from the pumps.

They are controlled from either the top of the shaft or near the pump by push buttons which operate the remote control contactor board enclosed in a watertight steel box, shown in Fig. 10. Should the pumps and their switchboard be flooded and under 15 feet of water, they would easily pump themselves dry. Although both air and water cooling is provided, only water cooling has been found necessary. The back of the remote control panel is seen through the door

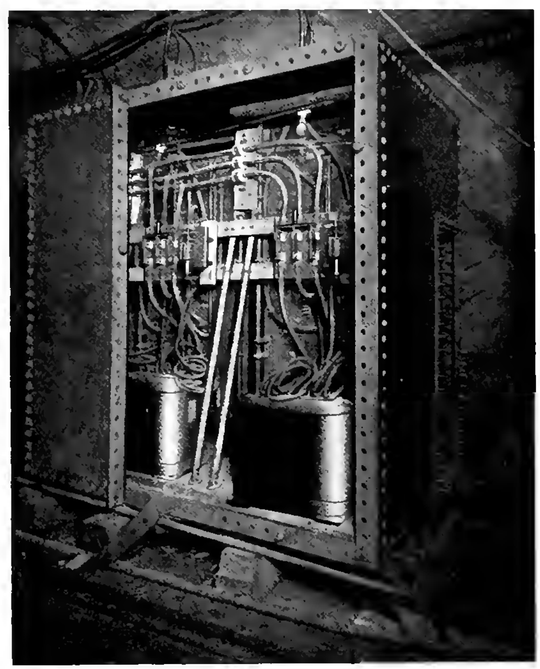


Fig. 10. Remote Control Contactor Panel Enclosed in Watertight Steel Box

in the watertight steel box. This pumping equipment is duplicated at the west shaft, with the exception that the contactor panel is in the transformer house above ground.

(To be Continued)

NOTES

OBITUARY

Many of our readers, and particularly those on the Coast who are old servants of the Company, will have already learned with profound grief of the sudden death of Mr. A. W. Ballard, which occurred at Phœnix, Arizona, on the 9th of February last.

Mr. Ballard was born in London, England, 43 years ago, and was brought by his parents to this country a year later. After an education in Canada, he went to San Francisco where he entered the employ of the General Electric Company. After several years' service, he was promoted to the managership of the Los Angeles office, a position which he filled with conspicuous success for a number of years. With twenty years of service for the Company to his credit, he resigned about two years ago to enter upon private enterprises; and at the time of his death was president of the Pacific Gas & Electric Company, the Alhambra Brick and Tile Company, the Phœnix Machine and Cold Storage Company, all of Phœnix, Arizona; and of the Santa Maria Gas and Electric Company. Mr. Ballard was a man of remarkable executive and business ability, of charming personality, and buoyant disposition; and enjoyed the friendship of a vast number of prominent men in San Francisco, Los Angeles, and many other cities on the Pacific Coast.

An impressive funeral service was held at the Bresee Chapel, among the floral tributes at which was a great wreath of Killarney roses and carnations from Mr. Ballard's old associates of the General Electric Company.

CORRESPONDENCE

To the Editor,
General Electric Review.

Dear Sir:

In the March issue you publish an editorial on the subject of economy and efficiency. The truth of the statements and the logic of the arguments in this able paper cannot be denied. Since, however, there are many individuals who sometimes err in a direction opposite to that referred to in the editorial, it would seem pertinent to carry the argument a step further and emphasize the fact that *real* and not apparent economy is the true desideratum.

To spend a large amount for telephone messages on a small and unimportant matter is, beyond doubt, a crime. Not to spend whatever necessary, when much is at stake, is no less an offense. To send heavy material by freight in order to save express charges is, in itself, laudable. But to leave a force of men drawing pay and incurring living expenses in idleness while waiting for some essential parts to come by freight, and while an anxious customer becomes more impatient, is folly. Such instances may perhaps be more rare than ones of extravagance; but they are, unfortunately, not purely hypothetical, and there seems to be room for a little sermon on the value of true perspective and proper comparison of values.

In the matter of writing letters too many words cannot be praised, but too few words is fatal. The business motto, "Be brief," is an excellent one; but to be so brief as to leave out some vital point is to fail entirely. Ask any man familiar with work in the central office of any large industrial concern how many letters are received which fail to give all the essential information, and how much lost time, wasted effort and loss in general efficiency result therefrom. Many times, of course, this is because the writer does not know what information is required; but often it is because the man is doing two men's work—another case of false economy, or because he dares not write a long letter from fear of censure, or because he thinks it will not receive attention. If he only knew how happy the man at the other end is to get a good, complete letter, setting forth in full every thing he needs to know!

A course in letter writing would be an excellent thing, and so would a complete education for every man who has to do business and write letters. But not all have, or can get, such training; and the point is that if one cannot make himself clear in a few words he should not stop until he has used enough to convey his meaning. So long as men are not perfect in development and not perfectly trained, so long must inefficiency and waste continue to some extent. The most efficient man is he who recognizes his own and others' inefficiency, and, by allowing for it, makes what he does accomplish as much as the limitations permit.

When we are more highly developed than now, a few written words will transmit from man to man a series of complete thoughts. Until that time, we shall have to waste the time of ourselves and others in dictating, writing and reading many pages, in order that mistakes may be minimized and business may go forward smoothly and, so far as may be, efficiently.

Very truly yours,
Edward J. Cheney

Schenectady, N. Y.
March 11, 1912.

ERRATA

March [Review, page 122, 25th line, should be $\frac{15000}{300} = 50$ ohms: page 123, 4th and 6th lines after eq. 25, should be $\frac{2}{\pi} l_1 L_0$ and $\frac{2}{\pi} l_1 C_0$ respectively.

GENERAL ELECTRIC REVIEW

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MAY, 1912

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GENERAL ELECTRIC REVIEW

THE NATURE AND EXTENT OF RECENT INDUSTRIAL CONTROL DEVELOPMENTS

By C. D. Knight

Engineer Industrial Control Engineering Department
General Electric Company

One has only to consider the enormous extent of the various applications of electric motors in order to realize what a variety of control apparatus must be required to meet the ever-increasing industrial demands. It seems only a few years ago since we had only one type of constant speed motor, belted generally to a line shaft running a large group of machines, and started up two or three times a day by an ordinary starting rheostat. With the advent of individual drive, it was found that by building adjustable speed motors, combined with suitable control, many economies could be introduced, not only in the amount of power required, but also in the saving of gears, clutches, belts, etc. It is safe to say that the greatest development of control apparatus has taken place during the last ten years, during which time all new steel mills and a large majority of the old ones have adopted electric drive. The same may be said of the mining, printing press and machine tool industries, all of which seem to be out-doing one another in the matter of exacting requirements, and varieties of motor control.

It was stated above that in the early days the average motor was started two or three times a day. Only seven years ago the A.I.E.E. set out to determine the proper service for starting-duty rheostats. At that time the standard was set at fifteen times an hour; or, in other words, starting up the motor once every four minutes was considered fairly heavy duty. It was only recently that the writer had occasion to see a table motor in a steel mill started up and reversed three times in five seconds. Many similar examples of heavy starting duty might be cited. In the case of the control of motor-driven planers, during each stroke of the planer it is necessary for the control to automatically accelerate the motor, slow it down at the end of the stroke, stop it by means of dynamic braking and reverse it for the return stroke. Now every time a motor starts or stops its line circuit must be closed or opened; the forward and return stroke of a planer will average five seconds; so that, figuring ten hours for a working day, and three hundred working days to the year, the control switch must operate over five million times a year.

In the early history of electricity experimenters were amazed and fascinated by the long electric arcs which they could produce. Today the control engineer has the problem put before him to eliminate the arcs with the least possible harm to the control apparatus. This can only be done by concentrating them as nearly as possible at one point and disrupting them as quickly as possible with powerful blow-out coils, at the same time making the arcing parts as accessible as possible for easy renewal. Considering, for the moment, only the planer service requirements, it can be readily understood how the demand has grown for rugged apparatus, which will last as long as the machines themselves.

In order to accomplish these results it has been clearly proved that a piece of apparatus consisting of electrically-operated contactors is the only one which will stand up under the severe service conditions. Apart from its ruggedness, its second outstanding virtue is the automatic acceleration of the motor which it renders possible. This means that the operator need simply close a master switch, the motor in turn accelerating its load without further attention on his part. This feature can be fully appreciated when one realizes what a large percentage of inefficient help is necessarily used in connection with this class of apparatus. The advent of automatic motor acceleration has naturally brought forth many different methods of obtaining this feature. They may be placed in three classes, viz., time limit, counter e.m.f., and current limit control.

The two principal types of time limit control may be briefly outlined. In one case the resistance in series with the motor is cut out by means of a solenoid-operated switch, whose action is retarded by means of an oil or air dashpot, the period of acceleration being accomplished by means of a valve, which allows the air or oil to flow more or less rapidly. In the second method the resistance is cut out by means of a motor-operated switch. By varying the speed of the small pilot motor the speed of the large motor may be varied at will. This type of apparatus is more fully described in the article on the control of electrically-driven printing presses. Each of these methods may be used in connection with direct and alternating current motors.

In counter e.m.f. control the contactors may be made to control the motor by arranging them so that each successive contactor requires a higher voltage to operate its coil. The contactors are then connected in multiple with the armature of the motor; and, as it comes up to speed, its counter e.m.f. meanwhile increases and causes the contactors to close in their proper sequence. This is the simplest operating control system possible. It is, however, subject to certain limitations, among which is the effect of abnormal voltage on the line. First, if the line voltage is high the contactors will close prematurely, while if it is low some of them will not close at all; secondly, the contactor coils, in order to operate satisfactorily, have to be designed with a very liberal amount of copper in their windings; thirdly, the system is not well suited to series motors without important modifications, for the reason that the counter e.m.f. of the series motor is a function of the current as well as the speed. The action of the counter e.m.f. control is liable to be interfered with by changes in the temperature of the operating coils. It should be noted that this type of control can be used with direct current motors only.

The other well known method of automatic acceleration is known as current limit control. The theory of its operation is dealt with in some detail in an article on page 272 of this issue and may be outlined briefly as follows: On each device there are a number of contactors and magnetic series relays, the coils of the latter being in series with the armature. The plungers, being connected to some form of contact, are held up by the load of the motor, the current inrush naturally being heavy at the start. As the motor speeds up the current diminishes. This, of course, weakens the field of relay No. 1 and allows the plunger to drop and make contact for the coil of contactor No. 2. The second contactor going in cuts out another step of armature resistance, which naturally produces an inrush of current; and as this value again becomes lower, due to acceleration of the motor, the plunger of another relay drops down, cutting in contactor No. 3. This cycle is followed until all the steps of resistance are cut out and the motor is up to speed. The same principle is used with both alternating and direct current but with different forms of relays.

Another simple form of current limit covers the combination of a contactor and series relay in one unit. This type is called series contactor control, the contactors being wound with heavy edgewise-wound operating coils in series with the motor, so designed to give a distribution of magnetic lines which prevents the contactor from closing when the current is high, and allows it to close when the current has fallen to some pre-determined value. Automatic accelerators of this type must necessarily be equipped with a switch, circuit-breaker or shunt contactor, to open or close the main line current. They are so connected that the contactors must close in proper sequence and this without the use of electric or mechanical interlocks, making an extremely simple and rugged piece of apparatus. Such apparatus is used at present on direct current motors only. With the ever-increasing advance in the art there is no doubt that a simpler form will also be obtained for alternating current motors.

The question has been asked how far the use of automatic control devices will go and to what extent they will supersede hand operation. The latest ruling of the Standardizing Committee of one of the largest steel companies calls for their application for all classes of service. One of the greatest arguments which influenced the committee was the question of safety for the operator; and there seems little doubt but that the precedent created by this corporation will be followed by other large users of the electric drive.

THE SELECTION OF CONTROL APPARATUS FOR STEEL PLANTS

By M. A. Whiting

Power and Mining Engineering Department, General Electric Company

A general classification is given of the various motor services in steel plants, under two main headings; and some general recommendations are made as to the type of control (hand, magnetic, or a combination of the two) appropriate for various operations. The article discusses the relative advantages of, and the suitable fields for, shunt and series contactors in direct current magnetic equipments, specifying the various automatic effects which each can accomplish. Later in the article a few instances are cited to illustrate some possibilities of special control arrangements in steel plants, and the conditions under which the use of such arrangements is warranted.—Editor.

General Classification of Service

In a complete steel plant the variety of motor applications is as great as the diversity of operations which these motors handle, from the unloading of the ore to the tapping of pipe couplings or shearing of merchant bars. Control applications, being intimately related to motor applications, are equally diverse, embracing many types of apparatus and many arrangements of apparatus of any one class. Various classifications may be made according to the point of view, covering the different kinds of service; but probably the commonest is that indicated by the term "mill service," which may be considered to include all applications directly concerned with the production of iron and steel, all other applications then falling into the miscellaneous class. For many reasons "mill service" is incomparably the more severe of the two.

Miscellaneous Applications

The motor drives not directly engaged in the process of making steel may logically be divided into two classes. In one class (including power station auxiliaries, air-compressors, roll shop lathes, machine tools in repair shops, etc.) the motors will run under as favorable conditions, and will be handled by about as intelligent a class of men, as in the case of similar applications in other industries; and in such cases there is usually no reason for deviating from ordinary standard practice. In the other class (such as coal-conveyors, gas-washers, pumps, clay-mixers, fans and other constant speed applications about the plant), conditions of operation, although nominally not very severe, will depend largely on the quality of common labor available, and on plant organization; and it is often found that to protect apparatus against the ignorance or carelessness of operators special precautions in the selection of control are required. In such cases it will sometimes be sufficient to use heavier apparatus consisting of standard apparatus rated down in capacity; but, if exceptionally careless handling of motors prevails, it may be necessary for this reason alone to use magnetic control with complete current limit protection.

Mill Service

The use of electric motors of 50 h.p. and above on reversing mill tables led inevitably to the adoption of magnetic control, as a means not only of increasing the life and reliability of the control, but also of decreasing the severity of the service on motors and driven apparatus. Early experience with this class of apparatus, however, soon led to the appreciation of other advantages of magnetic control, such as the ease of control of a large number of motors by one operator and the possibility of obtaining practically any desired combination of remote control, automatic limit features, interlocking between separate equipments, etc. These latter advantages permit an elaboration and co-ordination of the equipment in the mills, by which the number of men engaged in handling the steel may be greatly reduced, and the production maintained at a higher average rate. In order to obtain to the highest possible degree this perfection of detail and high degree of organization of equipment and operating force, which is necessary for economical production, it is becoming general practice in new mills to equip all intermittent duty stationary motors with magnetic control, even down to sizes as small as 10 h.p.

For cranes, charging-machines and similar moving machinery the choice of control is influenced not only by service conditions, but also by considerations of space and weight. Ladle cranes, by reason of the large size motors used, and the comparatively severe nature of the service, require magnetic control in almost every case on the main hoist and usually also on the bridge motion; but with the large majority of cranes about a steel plant, in which individual motions are equipped with motors under 100 h.p. both magnetic and manually-operated control may be considered feasible. In this connection a general distinction may be made with regard to cranes, etc., of moderate capacities (using motors up to 75 h.p.), according to the degree of continuity of operation of the machine as a whole.

One class includes charging-machines, soaking-pit cranes, strippers (and in some cases loading cranes and lifting-magnet cranes), which are directly engaged in production and are almost continuously in service for considerable periods of time, operating nearly at maximum speed. In this class of apparatus the duty is very severe and requires the most reliable type of electrical equipment. Earlier practice was to use manually-operated controllers throughout, on account of their smaller dimensions and weight, and on account of unfamiliarity with the characteristics of magnetic control; but the present tendency is strongly toward the use of magnetic control for all except the smallest motors, due provision being made in the design of the crane, if necessary, to accommodate the magnetic control.

A second class includes what may be termed "general utility" cranes, having no direct relation to production except now and then, as in changing rolls, repairing breakdowns, or removing "cobbled" steel. This class of crane meets with severe work only occasionally, and is used principally for construction, general repairs, and cleaning up, and most of the time lies entirely idle. It is evident, therefore, that magnetic control is not indispensable in this lighter class of work; and in many cases the advantages to be gained by its use will not be sufficient to warrant its additional bulk and weight.

There is, however, an alternative in the nature of a compromise which will be of advantage for some crane work, viz., combined manual and magnetic control. "Combined manual and magnetic control" may be either one of two very different things, between which it is necessary to discriminate. In some classes of work the combination consists of a contactor, or contactors, for closing and opening the circuit, actuated by a manually-operated starter or controller which serves also to cut out the resistance. In some cases (particularly where a comparatively large constant speed motor is to be started by a reasonably careful operator), this arrangement is an advantage, as it relieves the manually-operated device of the duty of closing and opening the circuit. However, if a similar arrangement is applied to reversing work in which a manually-operated controller provided with line contactors is thrown rapidly from full forward to full reverse, the resistance will be nearly or quite cut out during the time that one pair of contactors is opening and the other pair is closing, so that the motor will be thrown directly across the line. For fast reversing work, therefore, the use of auxiliary contactors for the line circuit is actually detrimental, and is not at all to be recommended.

An entirely different method of combining contactors with a manually-operated controller is to use the controller for making and breaking the forward and reverse circuits, and series type contactors (or shunt contactors with relays) for cutting out part or all of the resistance by current limit. The function of the contactors in this case is to protect the motors from extreme overloads, thereby incidentally decreasing the severity of the service on the controller. The acceleration may be made entirely automatic, cutting out the entire rheostat by contactors; or some degree of hand control may be obtained by cutting out the first part of the resistance on the controller and the remainder by the contactors. Such an equipment, consisting of a standard drum controller and two or three series contactors, is simple and inexpensive, and will be found serviceable for bridge and trolley motions of small cranes.

Ore Handling Machinery

In the electric operation of ore unloaders and bridges on an up-to-date dock, the service on the motors and control equipment is no less severe than on the reversing auxiliary machinery of a fast, two-high blooming mill, so that all the reasons for using magnetic control in the mills apply equally to ore-handling machinery. Moreover, the large size of some of the motors, and the necessity for precise and easy remote control of several motions by one operator, render magnetic control absolutely indispensable for the successful operation of an up-to-date ore dock.

On the bridge traverse (motion along the length of the dock—used relatively infrequently) it is entirely feasible, as far as the motor and controller are concerned, to use a manually-operated controller, although even in this case the advantage of uniformity of method and ease of handling make it desirable to use magnetic control. For the other motions, however, even as small as a 25 h.p. rotating motor, manually-operated control is practically out of the question.

Current Limit

In an article dealing with steel mill practice it is, of course, unnecessary to go into detail regarding the purpose of the current limit system in connection with magnetic control equipments. It is worthy of note, however, that the current limit systems described elsewhere in this issue are based on sound engineering principles, and the positive action of the current limit feature is not dependent upon any delicate adjustment. In the systems (both direct current and alternating current) using shunt wound contactors and current limit relays, each relay is held by independent means in the open position during the closing of the contactor preceding the contactor which this relay is to govern. When the preceding contactor closes, the relay is released mechanically so that it is then held open entirely by the current peak, the decrease of which, to the calibrated value of the relay, allows the relay to drop and close the next contactor. In the series contactor system, in which the contactor itself contains the current limit function, an equally positive current limit action is secured by the system of connections used.

More detailed information as to the method of operation of the current limit systems for alternating current and direct current contactors is contained in the article on page 272. In this connection the essential thing to bear in mind is that current limit systems can be obtained in which the current limit *acts every time on every point*, whenever the current peaks during acceleration rise above the current limit settings of the relays. In other words the current limit relays never "slip a point." When the acceleration is very rapid, the motor coming up to speed in about a second, it is difficult to determine positively by any kind of observations whether or not the current limit is functioning correctly, or whether the natural time elements of the contactors or relays are the only limiting features. In such a case, however, if the load can be increased very nearly to the setting of the relays, or if the relays can be set very low, the action of the current limit can be observed; under these conditions there should be a distinct interval between the closing of any two successive contactors.

In order to give satisfactory service, the current limit adjustment should be obtained without simultaneous or mutually dependent adjustments of two or more elements (e.g., two air-gaps, or an air-gap and spring pressure) on the same relay. Also, a change in the adjustment (e.g., by changing the length of the air-gap) should not affect the reliability of operation of a relay, but should merely change the value of current at which the relay operates.

Various methods of obtaining current limit will occur to anyone engaged in the design of control apparatus, some of the more obvious of which do not meet the requirements discussed in the foregoing. It is therefore important in selecting control equipments to examine carefully the current limit system proposed, to determine whether it meets these requirements.

Series versus Shunt Contactors

In selecting direct current control apparatus, it is necessary to distinguish between two general systems, and to make a selection according to the conditions governing the particular application. One system is that in which shunt wound contactors are used throughout and current limit protection obtained by individual relays. The other is the system using shunt contactors (or equivalent devices) for making and breaking the circuit, and series wound contactors for cutting out the resistance, the current limit characteristics being inherent in the series contactors.

Merely in order to obtain a suitable current limit characteristic there is no reason for preferring either system over the other, and the selection should be made on the basis of the relative simplicity of the two systems for the work in hand. The ideal conditions under which to apply the series contactors are those which do not require any elaborations, but only automatic acceleration (reversing or non-reversing). For these cases the series contactor system is simpler by reason of the elimination of the relay coils and interlock contacts. To obtain partial speed, however, requires auxiliary magnets (or in some cases extra shunt contactors), whereby the extreme simplicity of the series system is impaired; while in the case of the shunt contactor system, partial speed control and certain other more or less special results are attained very simply, without any additions whatever to the magnetic parts, by using merely additional fingers in the master controller. On the other hand, there are cases where special devices can be added to the series contactor system without complicating either the contactors themselves or the method of obtaining current limit acceleration. It is evident, therefore, that in using series contactors in special applications, it is necessary to consider each case on its merits. Whenever the application of series contactors to a particular problem requires the use of so many auxiliary magnets, extra shunt contactors, etc., as to result in a greater elaboration of circuits and amount of apparatus than the corresponding shunt contactor equipment, it is advisable to use the latter system.

In the following, a few typical cases are discussed briefly with reference to the relative suitability of the series contactor and shunt contactor systems.

Overload relays, shunt field relays (for protection in case of broken shunt field), or *contactor type circuit-breakers* may be applied to a series contactor system in a simple manner. The relay coils are connected in the line circuit (or shunt field circuit as the case may be), and the contacts of the relays connected in the actuating circuits of the (shunt wound) line contactors.

For dynamic braking with a shunt or compound wound motor for stopping an inertia load, the shunt contactors may be arranged for disconnecting the armature from the line and connecting it across the accelerating rheostat, allowing the series contactors to cut out the successive steps of the rheostat, as the motor slows down. This arrangement does not introduce any complications into the series contactor system, and the equipment is simpler than the corresponding equipment using shunt contactors throughout, to about the same extent as in the case of a straight reversing equipment.

Dynamic brake slow-down by a shunted armature requires, with series contactors, the introduction of extra shunt contactors and it is therefore simpler as a rule to use shunt contactors throughout.

On widely varying loads, the series contactor might be expected to give trouble from the fact that it is energized by the load current. The limitations, however, are far less serious than is often supposed, and are not prohibitive except in special cases. The unfavorable effects to be anticipated are of course those occasioned by the dropping out of contactors on light loads; and are, *first*, burning of the tips, *second*, overheating of rheostats, and *third*, slowing down of motor. Now the series contactors will hold in at currents equal to 10 per cent. of their continuous capacity, and will close on any current between 30 per cent. of continuous capacity and the current-limit setting, or "lock-out" current, as it is sometimes called. (Another thing to note is that solid copper contacts are used, so arranged that if required, a series magnetic blow-out can be provided.) It follows, therefore, that, *first*, the small fractional loads which the series contactors may have to open will cause only slight arcing, which will not appreciably affect the life or current capacity of the tips; *second*, a rheostat for ordinary starting duty or for reversing service will have ample capacity to run for a considerable time at 10 to 30 per cent. of full load; *third*, cutting the entire rheostat into circuit will, of course, reduce the speed, but at the small loads at which the series contactors drop out the speed reduction will be small.

As a rule, therefore, the effect of a widely varying load will not be noticed, except as the contactors may be observed to drop out and notch up. On a mill table, for example, where speeds are never very accurately predetermined or closely adjusted (as is evident from the fact that series motors are chiefly used), an occasional reduction of the normally high free-running speed will be entirely negligible. It must be borne in mind, of course, that in some classes of work, such as a small finishing mill or a cold saw, for example, the gauge or finish of material may be seriously affected even by relatively small variations in speed, and in such a case the load characteristic of a series contactor may be a limiting feature in the application.

The most extreme case is one in which a shunt or compound wound motor is running on a circuit the voltage fluctuations of which are so violent as to cause the motor to "pump back." Under these conditions, if the opening of the series contactors and consequent slowing down of the motor is detrimental to the work, it is advisable to use the shunt contactor system throughout.

As the minimum holding current of a series contactor is approximately proportional to its continuous capacity, it follows that the use of series contactors much larger than necessary will introduce this effect of cutting in the resistance at a much higher percentage of normal running load than would be the case if contactors were applied closer to their limit of capacity. It is therefore advisable not to "play safe" to any great extent where the load is comparatively uniform. In cases where series contactors are in other respects highly desirable, it is necessary to determine carefully the load conditions and apply series contactors which will not have excessive capacity, and which, if necessary, are wound with a special number of turns.

Alternating Current Control

For controlling induction motors, or for any purpose for which contactors can be used on an alternating current circuit, there is, of course, no difficulty in using direct current contactors (i.e., contactors whose operating magnets are actuated by direct current). However, the alternating current contactors (with operating magnets energized by one phase of the a-c. circuit) have been developed to a point where they have practically as long life and are as free from trouble as the best d-c. contactors. The use of d-c. contactors with a-c. motors introduces an additional element of delay, since a failure of the d-c. circuit will shut down an a-c. motor which would otherwise be undisturbed. Furthermore, unless an extra device is provided, (viz., an a-c. no-voltage release), a failure of the a-c. voltage will not drop out the d-c. operated contactors; and, on the return of the a-c. power, the motor will be thrown directly across the line without the benefit of the starting points of the control. It is advisable, therefore, in view of reliability of service as well as on account of the greater simplicity of a single system, to use only a-c. contactors for a-c. motors.

There are, of course, certain forms of dynamic braking which are readily obtained with d-c. motors but which can not be obtained with induction motors, or must be obtained in a different manner. *But, aside from cases involving differences in motor characteristics*, there are no results attainable by d-c. operated control which are not equally attainable with a-c. operated control.

The best practice with induction motors is to use double pole (or multiple pole) contactors throughout. In any case the secondary rheostat should be cut out in balanced steps, using either a double pole or two single pole contactors for each step.

Special Systems of Interlocking

It is a matter of common knowledge that it is possible to obtain by the use of magnetic control, automatic stopping or slow-down by means of limit switches, control of one equipment from several remote points, and many forms of protective arrangements and interlocking. Theoretically it is possible to obtain any form of protection, or any interlocked sequence of events which may be desired (so long as the control equipment is not required to exercise free-will). Practically considered, however, there are certain results which may be so easily attained that the additional complication which they entail is almost negligible; while some other results require for their accomplishment a bewildering number and arrangement of contactors, relays master controllers, and limit switches.

For example, on a traverse motion in which it is not necessary to stop automatically at the desired point on every trip, but where it is necessary merely to prevent over-travelling so far as would cause damage, the limit switch may be of a very simple type, connected in circuit with the forward and reverse actuating wires of the contactor control. If an accurate stop by means of a limit switch is required, a more highly developed form of limit switch is required. In case the load or free running speed is very variable and an accurate stop is required, it is necessary to slow down to a definite speed (by cutting resistance in series, or by cutting resistance in series and shunting the armature), just before applying the final stop. This requires additional circuits on the limit switch and additional contactors and control wiring, but not to an unreasonable extent.

Suppose, however, that it is desired to stop accurately and automatically in any one of ten positions distributed over the traverse, the master controller being simply moved and left at a position corresponding to the desired stopping point. The method of obtaining this result will be only slightly more complicated than the method of obtaining a single accurate stop; but a very large number of control wires and segments on the master controller and limit switch will be required, and the actual complication of wires, segments, etc., will be very great. This kind of automatic operation should therefore be provided only where conditions of production urgently require it. On the bridge traverse of an open-hearth charging machine, for example, a system of predetermined automatic stops in front of the various furnaces would be ridiculously out of place. But for an ingot buggy in connection with a large group of soaking-pits, such an arrangement is worthy of consideration, because by its use it may be possible (without taking on an extra man to run the ingot buggy exclusively), to economize sufficiently the time of the soaking pit-cranes to enable one less crane to handle the work.

The possible arrangements of special control equipments are numberless, and it is difficult to make even a comprehensive classification. Enough has been said, however, to indicate that the demand for the highly special interlocking systems should as a rule originate in the conditions of production; and that the adoption of such systems should be determined according to the "rule of reason," after making a comparison between the operating or mechanical advantages obtained, and the electrical disadvantages incurred.

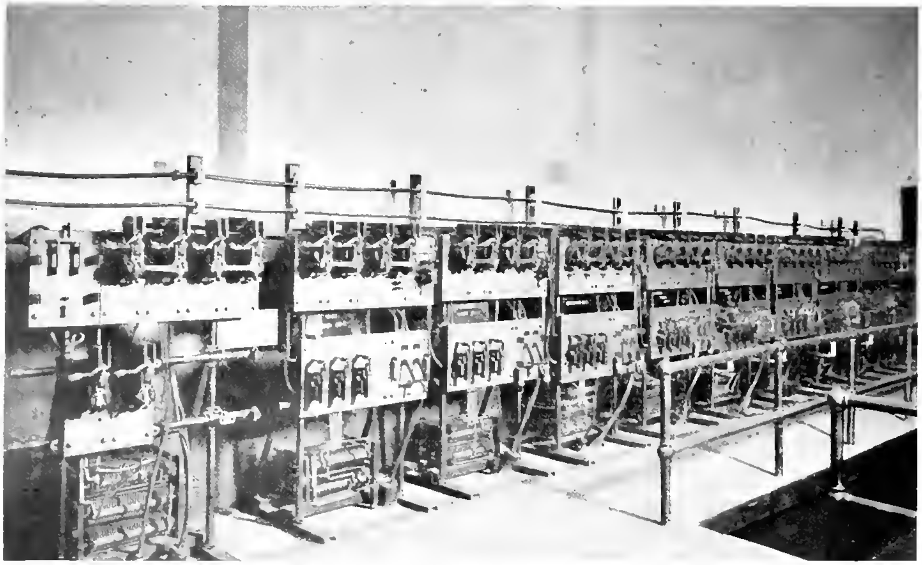
Main Roll Drive

The foregoing discussion has been confined to control for auxiliary machinery and has not touched directly on equipments for driving the main rolls. The various advantages of magnetic control are nowhere more in evidence than in the control of main roll motors. With the exception of large reversing direct current motors, which as a rule are run from flywheel sets with generator field control, the present practice is to use magnetic control with all motors driving main rolls. For 2300-volt or 6600-volt induction motors the practice, at the present time, is to use oil-switches for the primary circuit and contactors for cutting the rheostat in and out of the secondary circuit; while for induction motors at voltages of 550 and less, and for direct current motors of any standard voltage, the connections to the line are also made by contactors. Complete current limit acceleration is always provided, and various other devices may be readily applied, as required by the nature of the individual case. So many considerations enter into the selection of control apparatus for main roll drive that complete treatment would require an entire article, and a full discussion of this subject will therefore appear at a later date.

Details of Apparatus

This article contains practically no details regarding the mechanical design of the various devices which go to make up magnetic control equipments, as it would have been impossible to have included these details without curtailing the discussion and recommendations on applications. The writer recognizes, however, that owing to the exacting nature of steel mill service, engineers in this line of work are interested in details to an extent entirely unknown in most other applications. For such detailed descriptions reference should be made to other articles in this issue of the REVIEW, to the standard bulletins issued by the manufacturers, and to a paper before the Association of Iron and Steel Electrical Engineers.*

*New Developments in Control Apparatus for Steel Mills, by M. A. Whiting, presented before the Association of Iron and Steel Electrical Engineers, Sept. 26, 1911.



Series Contactor Panels Controlling Induction Motors in Steel Mill Service

THE CONTROL OF ELECTRIC MINE HOISTS

By S. Haar

Power and Mining Engineering Department, General Electric Company

The author divides the subject into two broad classes, rheostatic control and control by voltage variation; the discussion of the first, which is the simpler, embracing the question of dynamic braking, location of the skits, fixed time and fixed torque acceleration, automatic stopping, reduced speed running, and safeguarding the hoist in case of accidents. The more precise method of control by voltage variation, as exemplified in the Ward Leonard system, is fully described and a number of diagrams are shown to assist in giving a clear understanding of its working principles. It is at once obvious that the latter system has been most carefully designed to insure complete control over the hoist at all times.—Editor.

Almost every type of electric motor has been used on a mine hoist and each kind requires somewhat different controlling apparatus. The tendency is toward an increasing elaboration of these equipments, on account of the success with which automatic safety devices have been applied to hoist motors.

Perhaps the subject will be rendered clearer by a brief statement of the conditions to be met. A mine hoist is the means of communication and transportation between the surface and the underground workings, and therein resembles other transportation systems, such as interurban and urban railroads. Similarly the hoist operates between permanent stations and on a schedule of definite starting, running, stopping and loading periods, which may recur regularly for a considerable time. In the operation of the mine hoist there is the important difference, however, that the operator is not stationed on the moving car, and in fact, does not see it except at one end of its trip. Furthermore, different speeds are desired or specified by law for different classes of service, such as hoisting material, hoisting men, rope or shaft inspection, etc. The features to be included, if possible, in any system of control are then: absolute control of the hoisting speed at all times; knowledge of the precise location of the skips at all times, together with precautions against their passing the customary termini of operation; limitation of acceleration and retardation to safe values, yet entire freedom to use lower values if desired; provision against likely contingencies; and finally, of less importance, the protection of the electrical equipment against overloads.

An examination of the various methods proposed for the control of hoist motors establishes the existence of two broad classes, rheostatic and varying voltage control, the former being simpler and the latter more precise. The action of the hoist motor during the period of acceleration is the same with either method.

Rheostatic Control

Any motor can be governed with rheostatic control, as, in its simplest form, it merely reduces the starting current and reverses the direction of rotation of the motor; dynamic braking is possible as a result of more complication. Small hoists, more especially sinking and contractors' hoists, if equipped with direct current motors, usually have series wound motors. After the acceleration, the speed is entirely beyond the operators' control and is likely to vary considerably. In order to stop the hoist, the usual practice is to open the line circuit and allow the motor to coast until near the end of the trip, the final stop being made by the brakes. A drum controller usually gives satisfactory service, and the whole electrical equipment consists of line switch, circuit-breaker, controller, motor and rheostat.

If dynamic braking is desired, alternative methods are available. The more efficient way is to excite the motor field separately and connect the armature across the rheostat; the energy to be absorbed in braking being wasted in the rheostat, but none being drawn from the line. A simpler way is to reverse the motor and connect it to the line, in which case the armature voltage is added to the line voltage. No extra points on the controller are needed and positive braking practically to standstill can be realized; but the rheostat must absorb the energy of the moving masses, and additional energy which is drawn from the line. If two motors instead of one are employed, it is possible to return power above half speed by connecting the motors in series across the line. The necessary conditions being rarely at hand, this arrangement is seldom or never used. Contactor control panels are also used with series motors; but it is usually possible (and it is always advisable) to provide some shunt excitation for a motor large enough to require contactors, in order to limit the maximum speed to a safe value. If the hoist motor (direct current) has essentially shunt characteristics, its action is as above described, except that the full speed is nearly constant.

The polyphase induction hoist motor also has shunt characteristics, and its action conforms to that of the direct current shunt motor. As is well known, the motor is reversed by interchanging two primary leads, and the speed is controlled by resistance in the secondary circuit. Controllers designed for direct current motors can be adapted so as to make these connections, and this arrangement is therefore quite general. When the size of the motor increases sufficiently to warrant a contactor panel, it is becoming customary, especially in foreign countries, to require that all three lines be opened at reversal. This could be done with contactors aggregating five poles, but there would be practically no saving in cost over two triple-pole contactors, the safety is less, and the wiring is more complicated. Figure 1 illustrates a six-point equipment with triple-pole reversing contactors and double-pole accelerating contactors. For the sake of general application, current and potential transformers are included. The diagram is drawn to cover a case in which few partial speed running points are desired. It is possible to run with all resistance in, with 4, 2, and no sections of resistance in each phase. Dynamic braking by reversing the motor can be practised with the equipment shown; but if the other method described above is preferred, it is usual to excite the stator from a direct current source, such as a small motor-generator set. There is no commercial method of regenerative braking with an induction motor. The term "regenerative braking" may be extended to include the condition corresponding to lowering a load at full speed. The direct current shunt motor and the induction motor perform this function automatically, but the series motor cannot do so. The location of the skips is given by an indicator usually furnished by the hoist builder, which removes this problem from the motor builder's province. Prevention of overwinding is attained by means of limit switches driven from the depth indicator just mentioned, or from the hoist drum, or mounted in the shaft. Switches in the mine shaft are for emergency use only, as they are tripped by the skip striking them, but the other type can be utilized also to introduce automatic features into regular operation. For strictly emergency use the shaft type is safer. The limit switch of the drum type is driven from

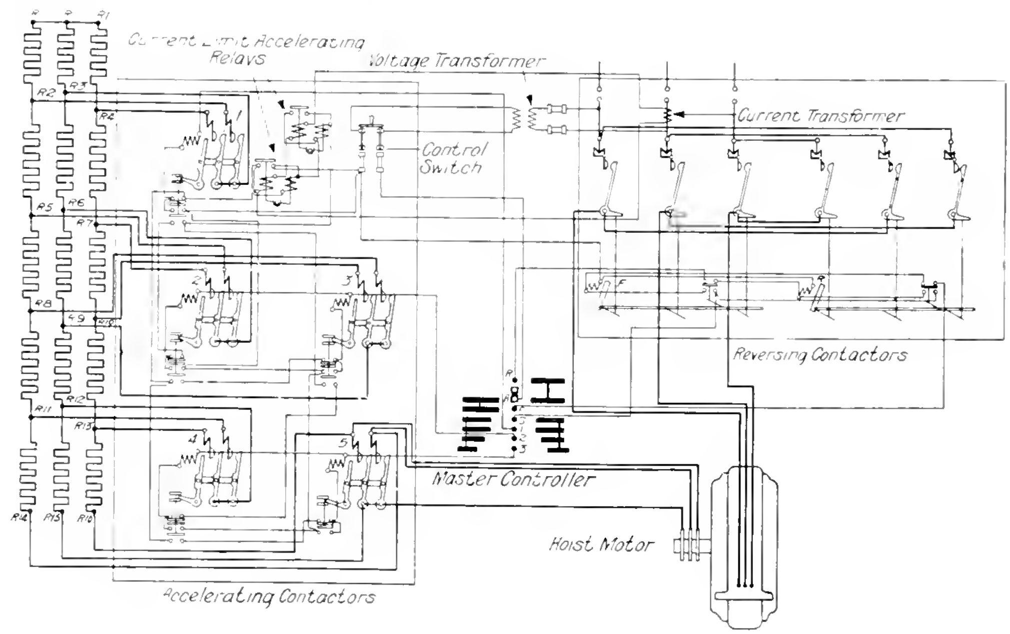


Fig. 1

the hoist, and arranged to perform its operation in a predetermined number of revolutions. The device is really a small drum controller, and the management of control circuits attainable with such controllers is possible by its use. Development in Europe has been along the line of a strictly mechanical device. Although hoist operators are always skilful and are necessarily very careful, yet since they have a number of things to watch, any relief which can be afforded them by automatic control of the hoist motor will be appreciated.

The starting can be arranged for either a fixed time or a fixed torque. Time limit acceleration is obtained by interlocking the controller handle with the hoist drum, so that full speed cannot be reached in less than a predetermined number of revolutions; if a liquid rheostat is used, the throttle valve of the circulating pump performs this function. Where the hoist must stop at intermediate levels this interlocking is not easily arranged, except with the liquid controller, and foreign equipments with Ward Leonard control do not provide any such protection. Such a device, however, has been developed in this country. By its use the time of acceleration and retardation can be limited independently of each other every time the controller handle moves from or toward the off position.

Constant accelerating torque means practically constant current, a limitation which is invariably furnished with rheostatic control including magnetic contactors. This form of protection can be adjusted to the liquid rheostat, but there is at present no demand for it. The plain current limit applied to Leonard control produces a result the opposite of what is desired when the motor is used for braking, so that it is necessary instead to operate the controller by a small pilot motor. The current limitation will, of course, be just as effective in protecting a hoist operating from several levels.

The situation in regard to automatic stopping is somewhat different. There is no practical method of time limit retardation with rheostatic control, if we except dynamic braking with the liquid rheostat by reverse current. With Leonard control the retardation is accomplished in the same manner as the acceleration. Current limit retardation for rheostatic control depends upon the practicability of dynamic braking; for Leonard control, the motor-operated controller accomplishes the desired result. It is also practicable to furnish a set of controlling devices which will automatically repeat a given hoisting cycle indefinitely. This is useful for conditions such as those of water hoists. Where the water level changes gradually, attendance is required occasionally to adjust for the varying height of lift.

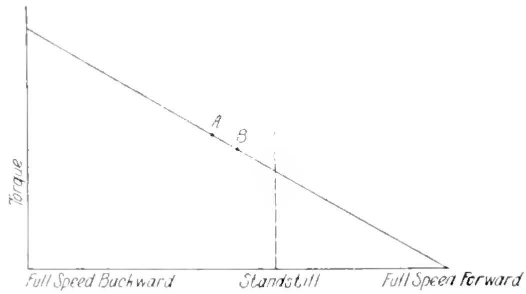


Fig. 2

Under the head of contingencies we understand reduced speed running and the safeguarding of the hoist in case of accidents. In considering the procedure to be adopted, we find that all that can be done with resistance control is to set the emergency brake or trip the line switch. Therefore, overwinding limit switches set the brakes either mechanically or through electro-magnets, and the resulting overload on the motor opens the line switch. Rope speeds for hoisting men are limited by law to about 600 ft. per minute with a maximum of 1000 ft. per minute (except when voltage control is used); if the hoist serves a deep shaft, this means about one-half to one-third normal speed. It is unnecessary to point out how wasteful of power such operation is, and how extensively the speed varies with the load. Rope and shaft inspection are carried on at about 100 ft. per minute. Since the load on the motor in such a case is light, the resistance required is high and the speed is unstable. It is now customary to lower the rope and inspector's car by allowing them to overhaul, all resistance being inserted in the circuit. If the stator leads are reversed, as for dynamic braking, the operation will be improved and the speed will be stable, as the lighter the load the less the speed. Reference to Fig. 2 will elucidate this statement. If the load decreases from A to B, the speed approaches more nearly to standstill, that is, decreases. A typical wiring diagram for an induction hoist motor with rheostatic control is given in Fig. 3, the rheostat being a liquid one, and the usual accessories being included.

The overload trip on the oil-switch is set as high as possible, so that advantage can be taken of the maximum braking torque of the motor. The brake magnet may be either a solenoid or a small motor (usually back geared.) The motor magnet is usually selected for large efforts and the solenoid type for smaller pulls, although in some cases the motor magnet is used for all purposes. There is not much choice for direct current or single-phase alternating current, but it is easier to build a polyphase motor magnet than a polyphase solenoid.

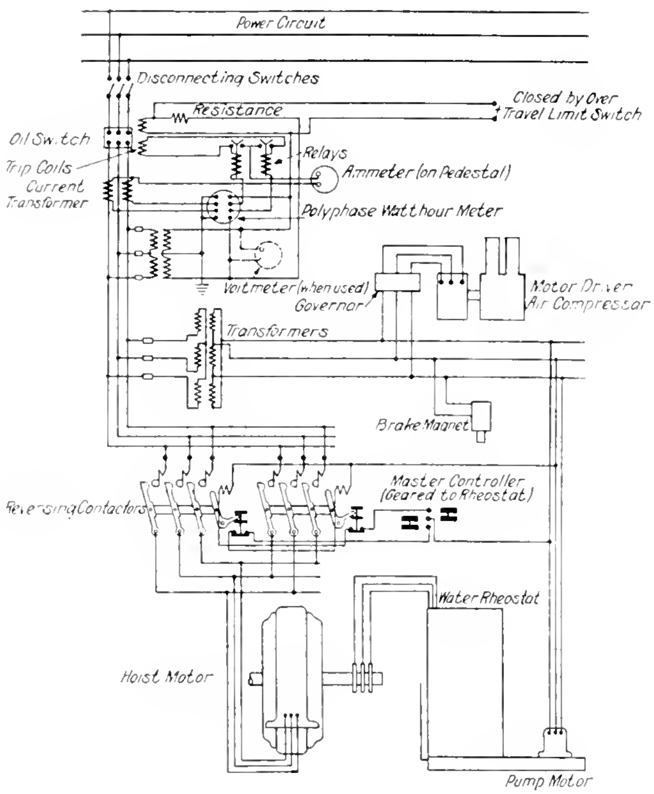


Fig. 3

Control by Voltage Variation

Turning now to voltage control, called Leonard control after its inventor, H. Ward Leonard, we find much greater scope for improving the operation of the hoist motor. As is well known, the hoist motor is a shunt wound separately excited direct current motor; power is supplied to it by a generator of variable voltage and reversible polarity, each motor having its own generator. The fact that practically independent of the load the speed of the motor corresponds in magnitude and sense to the voltage of the generator, renders possible a complete realization of the first characteristic specified above for an adequate control, namely, continuous control of the motor speed. For acceleration, the generator voltage is gradually increased to its normal value by a revolution of the controller cylinder in one direction; during full speed running the controller remains in this position, and when it is desired to stop the motor, the controller is returned again to the "off" position. A further advantage is that a light controller is sufficient for varying the generator field current and the generator voltage; while further it is unnecessary to interrupt the heavy current in the armature circuit for reversal.

Referring to Fig. 4, a diagram of Leonard control, we see that the armature of the hoist motor is connected directly to the generator, and the fields of both hoist motor and generator through the controller to the exciter. In the armature circuit there are the overload circuit-breaker and disconnecting switch, ammeter with zero point at the middle of the scale, and a contactor which opens at the "off" position of the controller. The circuit-breaker is set for extreme overload so that it will open the circuit only in case of damage to the machine, as breaking the armature circuit robs the operator of his control over the motor. For this reason the breaker is provided with an auxiliary switch which closes the circuit of a relay, which in turn short-circuits the brake magnet and sets the emergency brake, causing prompt stoppage of the motor. In certain European equipments the unwillingness to open the circuit results in using the circuit-breaker merely as a switch for short-circuiting a high resistance, the purpose of which is to reduce an excessive current. It is questionable if such an arrangement is as valuable as the arrangement shown in the diagram. It is necessary to have an ammeter with the zero in the middle of the scale, because the hoist motor is reversed by reversing the polarity of the generator voltage alone; this causes the motor current for successive trips to be opposite in direction. Furthermore, whenever the motor is reduced in speed by dynamic braking, the current reverses. With the line switch and the circuit-breaker, both sides of the circuit can be opened in case any work or cleaning around the motor is to be done. The contactor prevents the motor from creeping during the loading period on the residual voltage of the generator.

Mention has been made of the fact that the motor field goes through the controller. A moderate amount of speed adjustment by field control is useful if the voltage of the generator varies considerably, such as occurs voltage; but this would result in exceeding the legal limit of speed, and reducing the efficiency of hoisting by increasing the generator losses.

The field circuit of the motor includes, also, the brake magnet coil, so that any accident to the former automatically sets the emergency brake. This is an important provision, as the failure of the motor field nullifies the arrangements for speed control. It will be noted that the brake is also set if the skip passes a predetermined distance beyond the regular landing places, if the motor circuit-breaker opens, or if the main oil-switch is

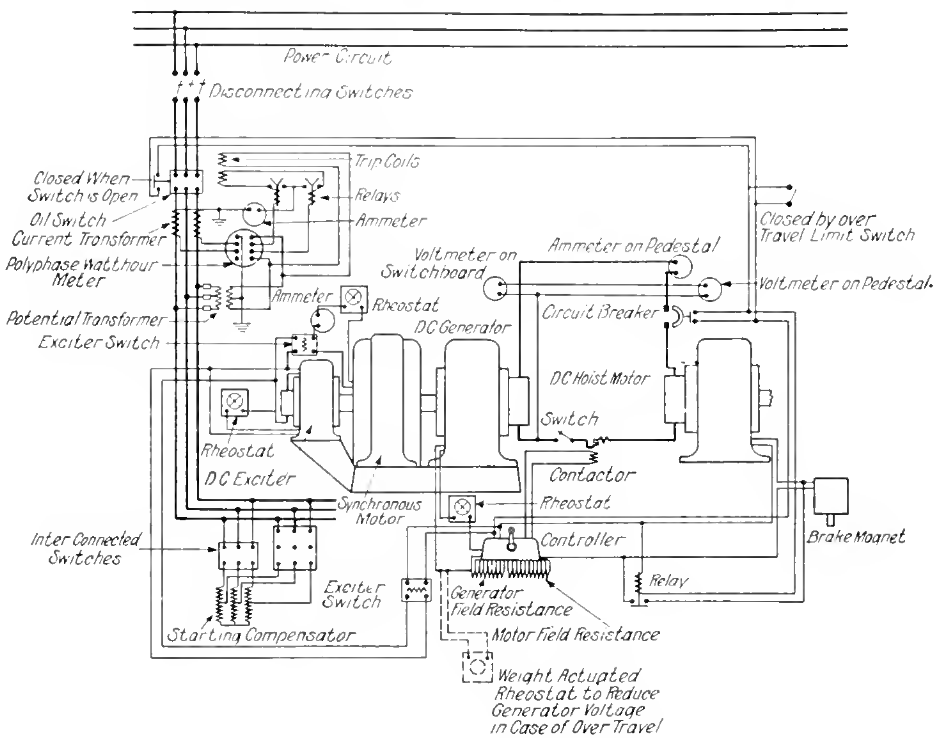


Fig. 4

when a flywheel motor-generator set is employed. No increase over the normal speed is sought, but the field of the motor is weakened just enough to maintain the speed with the decreased voltage. The resistance points for field control are not reached until the generator field has been strengthened to its full value, after which the armature current usually falls off so that the commutation of the motor is not affected by the weakening of its field. Of course, the same average speed might be attained by over-exciting the generator for a higher tripped. As has already been explained, the circuit-breaker will not open unless a dangerous current exists, and it is advisable in such a case to stop the hoist as quickly as is safe. The opening of the main oil-switch during retardation, or other form of regenerative braking, instantly terminates the braking effect and renders probable a rise in speed, so that it is necessary to interlock the oil-switch and the emergency brake.

Mention has been made of the action of the limit switch. A possible safeguard which may be connected thereto is an automatic rheostat in the circuit of the generator field so arranged either with a weight or a motor, or the equivalent, that the closing of the limit switch sets the apparatus in motion, thus gradually reducing the generator voltage by

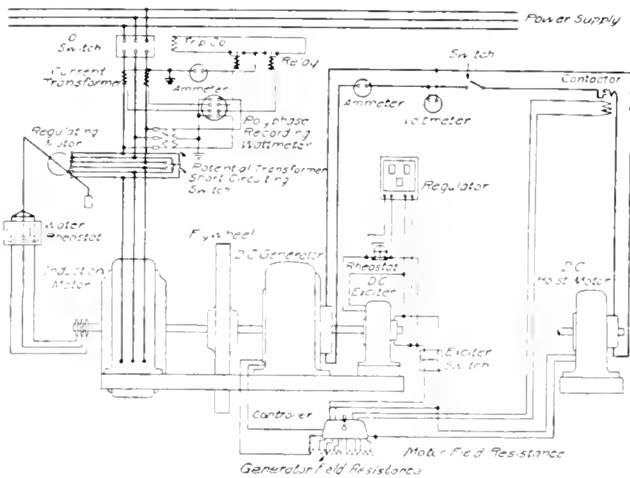


Fig. 5

inserting resistance into the field circuit. If the brake holds, this rheostat is unnecessary, and, besides, the stoppage of the motor will probably result in the opening of the circuit-breaker; while if the brake does not hold, the damage will be done before the voltage is reduced to zero by the rheostat. Failure of the line voltage, or trouble in the motor-generator set sufficient to cause abnormal current, will both open the main oil-switch and put into action the other safety devices. An over-speed trip might also be included; but, with a synchronous motor driving the generator, the effect of any dangerous speed would be a current large enough to trip the oil switch. Such a device should properly be included with an induction motor set having an automatic speed regulator, the essential connections of which are reproduced in Fig. 5.

A real objection to the Leonard control is the interposition of several machines between the main circuit and the hoist motor. This expedient is necessary because the generator and hoist motor operate in parallel, both with varying voltage. There is no essential reason why the variable voltage generator cannot be connected in series with the hoist motor if power is supplied by direct current, and this has been done in Europe. By the further feature of building the motor for twice the line voltage, the size of the extra generator can be reduced one half as will be explained later.

In Fig. 6 the armature of the generator, with a short-circuiting switch across it, is shown in series with that of the hoist motor *HM;* while the motor M_s driving this generator is connected across the line. All the fields are separately excited, the field circuit of the generator including also a reversing switch. The hoist motor is started from rest by connecting it to the line, with *G* fully excited, and with the proper polarity to neutralize all the applied voltage except enough to pass a suitable starting current through the machines. A slight weakening of the field of *G* sets *HM* in motion at a low speed; both machines are running as motors and the power absorbed by *G* is returned to the line by M_s acting as a generator (for this reason, M_s cannot be a waterwheel or steam engine, or other motive agent incapable of absorbing energy). The speed of the hoist motor rises in consequence of the progressive reduction of the voltage of *G*, until at half-speed this voltage reaches zero; the armature of *G* is then short circuited, its field reversed, the short-circuit removed, and the field regularly strengthened, the speed of the hoist motor rising correspondingly with the final result of full speed at twice the line voltage. For this part of a trip the hoist motor draws power from both the line and the motor-generator set. Weakening the field of *G* again causes retardation of the hoist motor,

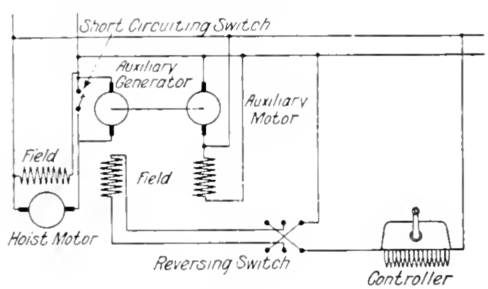


Fig. 6

Key to text: HM, hoist motor; M_S, auxiliary motor; G, auxiliary generator.

so that the cycle is completed by a process similar to that of acceleration but opposite in sense. During the loading period the motor-generator set may be left in circuit operated inverted, or the main circuit may be opened. It is evident that both the generator and the hoist motor should be designed for the same current; and, as the voltage of the generator is only half that of the motor, its capacity is half that of the motor, while with the ordinary connections the generator is of equal capacity. Since the machine *G* acts successively as generator and as motor, it lends itself well to power equalization; and, by connecting to it a fly-wheel, the motor M_s can be dispensed with as shown in Fig. 7. This arrangement is otherwise like that of Fig. 6.

In comparing the method of voltage control of Fig. 4 with that of Figs. 6 and 7, we immediately note one important difference, namely, that the series arrangement is available for direct current circuits only. Inasmuch as the ratio of direct to alternating current supply circuits is continually decreasing, this limitation alone is almost enough to exclude the series control. Its manipulation is more complicated and involved than the preferred method, and any accident to the auxiliary apparatus leaves the hoist motor as unmanageable in either case. There is, however, some saving in first cost. Another important advantage of the Leonard control is the ease with which fractional speeds are obtained. With the arrangement of Fig. 7, it would be hazardous to attempt any other than half-speed for any length of time. Using the machines of Fig. 5, the lower the speed, the heavier would be the load on the motor-generator set, while with the Leonard control the reverse is true. In comparing rheostatic with Leonard control, we find the principal advantages of the latter are the elimination of rheostat losses, the recovery of stored energy by regenerative braking, and the far superior speed control. This latter is most emphasized at partial speeds, the steadiness of any speed with varying load being conceded to be unapproachable by the other system. In regard to the question of efficiency, it may be said that busy main-shaft hoists operating under favorable conditions, will consume only about 85 per cent. of the energy required with rheostatic control in spite of the losses in the auxiliary machines. This statement has been framed to eliminate the case of the hoist operated infrequently, where the light-load losses of the motor-generator set for many hours would make its use prohibitive. The simple and effective speed control of the

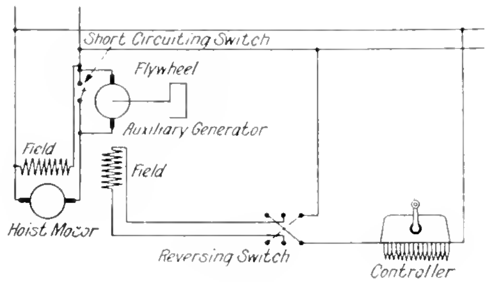


Fig. 7

Leonard system has fostered the development of safety devices, so that the reliability of this form of equipment is unattainable by other kinds of apparatus—a fact which has been recognized by certain government boards as evidenced by their permitting higher speeds for hoisting men.

The goal of an effective control without rheostats has also been sought by the use of alternating current commutator motors, and has been partially attained in Europe with motors of the repulsion type having provisions for shifting brushes. These motors start and run without rheostats, and are capable of regenerative braking. There are also possibilities in the concatenation of alternating current commutator motors and induction motors.

To sum up, we may say that for small hoists where the minimum of apparatus and investment and maximum of portability are of greater moment than saving of energy and precision of control, and where, moreover, the importance of the hoist is such that the operator with ordinary diligence and simple accessories can prevent disastrous accidents, rheostatic control will usually be selected. The larger the equipment, however, and the more the prosperity of the mine depends on the economy and reliability of the hoist under consideration, the more serious are the claims of the Leonard system of control.

THE CONTROL OF ELECTRICALLY-DRIVEN ROTARY NEWSPAPER PRESSES

By Carl F. Scott

Commercial Engineer, Sprague Electric Works

In commencing, the article classifies the various rotary presses, showing the work they will perform, and explaining the method of operation. The press is sometimes driven from counter-shafting, or a steam-engine, with a slow-motion gear for low speeds. A constant-speed or variable-speed electric motor may be substituted for this drive, the mechanical slow motion being retained; or the motor may be geared direct to the press and the slow motion provided in the control. The various steps in the development of the electric drive are clearly traced, preparatory to a detailed description of the completely automatic, two-motor equipment, with which it is possible to start, stop, accelerate or decelerate the press from any one of a number of push-button stations, located at various points about the press.—Editor.

The operation of rotary newspaper presses offers a very extensive and attractive field for the application of electric drive. Every city of any size in this country has its newspaper. Over 2000 daily papers with a circulation of 2000 or more are printed in the United States. A prime requisite in the publication of a daily newspaper is that the edition shall be made up, printed and distributed in the shortest possible time, and with absolute freedom from delays of any sort. To this end a type of drive must be selected by which the press can be "made ready" quickly and easily; driven at a rate of speed suited to the size of the edition, the number of copies desired, the quality of the paper, and the character of the work; stopped and started, speeded up or slowed down, always under the complete control of the operator.

For a better appreciation of the requirements of a motor equipment for a large newspaper press, a brief description of the press itself will be given. Rotary newspaper presses are classed by the work they do, as stereotype presses, color presses, electrotype presses, etc.; by the number of decks or webs, as 3-deck, 5-deck, two-web, etc.; or by the number of groups of which they are built, as quadruple, sextuple, octuple, etc. A modern high-speed sextuple press, to take as an example a size much used, has six plate cylinders, and three paper rolls. Each plate cylinder is four plates wide, and takes eight plates, as each plate is bent into a half cylinder, and fits on half the circumference of the cylinder to which it is secured. The plate cylinders revolve at a maximum speed of 300 r.p.m., and at this speed the press can produce papers of 24 pages each at the rate of 36,000 per hour. By a different arrangement of the folders at the end of the press, 18,000 32-page papers could be obtained. As the maximum speed is in practice required for only a short period, under great stress for time, the press will often be called on to operate at a speed of 30,000, 24,000, 18,000, or lower; so that a wide range of operating speeds must be provided on the controller.

When making the press ready for printing the control must provide for "inching along," that is, turning the cylinders through a small fraction of a revolution so as to bring them to the desired position for putting on plates or "blankets." The "blankets" are usually a paper coating of several layers wound on the impression cylinders, which press the web against the plate cylinders. For threading in the web the cylinders must be revolved at a very slow speed of about 10 r.p.m. When the paper is carried through to the folders, and everything is in readiness, the press must be accelerated smoothly and evenly to the desired producing speed. Preparatory to changing rolls, putting in new plates, or stopping the edition, the press must be smoothly decelerated or stopped. In case of emergency or accident, breaking of the web or clogging of the folders, the press must be brought immediately to rest.

In places where electric power is not available, newspaper presses are driven from counter-shafting or direct from a steam engine. The press is provided with tight and loose pulleys, and is started and stopped by shifting the belt. The usual practice of press manufacturers is to provide a slow-motion device, or back gear, which is thrown in by a lever for obtaining the slow speeds required for threading in the web.

The first step in the application of electric drive, and the simplest, is to replace the steam engine or counter-shaft with a constant speed electric motor, having a pulley with a wide flat face. The press is then started by shifting the belt, and the mechanical slow motion is retained in the press, just as with counter-shaft drive. This style of equipment can be installed very cheaply; and hundreds of presses all over the country are being driven by belted motors, some of the individual units exceeding 100 h.p. in capacity.

The next step is to use a variable speed belted motor with a hand-operated drum- or dial-type speed controller. The speed control is then used for obtaining different printing speeds, and the mechanical slow motion is retained. The use of variable speed motors is especially desirable on the new high speed presses, where the average everyday run is rarely at a rate corresponding to the maximum possible speed of the press.

The third step is to gear the motor directly to the press, and provide for the slow motion in the electrical control. With small and medium-sized direct current units this can readily be accomplished by shunting a resistance across the armature circuit, which in combination with the series resistance, gives

Fig. 1. Hand-operated Dial Controller used with direct current single motor semi-automatic printing press equipments. Push button jog; push button stop; no-voltage release; overload release; dynamic brake; slow speed; armature and shunt field regulation are provided.

the armature a fixed slow speed more or less independent of the load. A hand-operated control panel for this service is shown in Fig. 1. The features incorporated in this controller are armature and field regulation; slow speed (about 10 per cent. of normal speed); push-button jog and stop; dynamic brake; overload and no-voltage protection. A number of push-buttons are mounted at different points on the press, from any of which the press may be "inched along," run at slow speed, or stopped. Acceleration to printing speeds is accomplished by manipulation of the controller handle. This type of drive, with single geared motor, lends itself readily to full automatic control, by which it is possible to bring the speed of the motor to any point desired from any push-button station. A controller designed to accomplish these results is shown in Fig. 7. It is merely a simple modification of the full automatic double motor controller, described fully in the latter part of this article. The single motor control, with armature shunt for slow speeds, is not practicable in units larger than 30 or 35 h.p., on account of the comparatively great waste of the current in the shunt and series resistance.

Very satisfactory results have recently been obtained with semi-automatic single motor-geared equipments for alternating current circuits. The control consists essentially of a drum controller and contactor panel. Push-button jog and stop, from any point about the press, are provided. The press is accelerated to the desired speed by hand.

With large units the problem becomes more complex. One manufacturing company exploited for several years a double commutator motor; and obtained a very wide range of speeds, with good economy, including speeds low enough for threading the web, by a combination of series and parallel connections with resistance control. This system, however, has been abandoned in favor of the double-motor drive.

Full automatic control for rotary newspaper presses secures the best possible results, all things considered, and represents the highest development of the art of printing press control. In connection with full automatic control the double motor drive has been almost universally adopted on the larger presses. The essentials of full automatic control are the complete control of the press speed from any of a number of push-button stations located about the press, the complete protection of the equipment and operator against any emergency, and the production of an edition in the shortest possible time consistent with good results.

The full automatic equipment herein described has reached that degree of simplicity and reliability which is so essential to the successful operation of an automatic controller. One of the most important features of this controller is that essentially the same

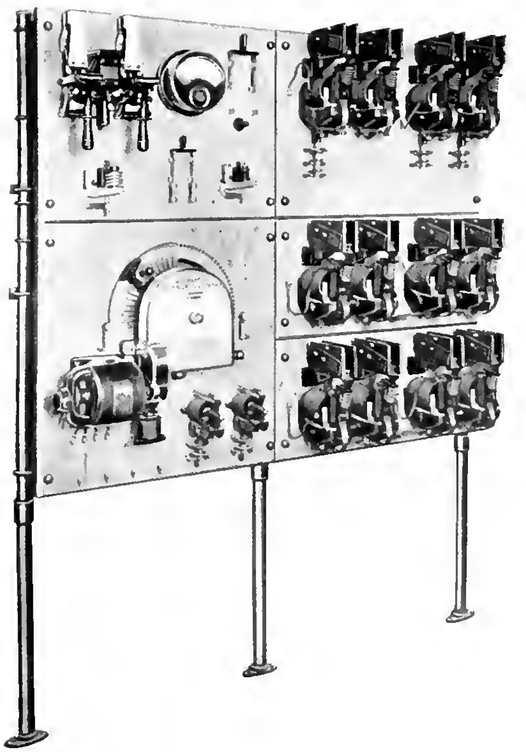


Fig. 2. 50 H.P. Control Panel used with direct current full automatic double motor printing press drive

type, with necessary modifications, is used for both direct and alternating current circuits. Fig. 2 illustrates a standard direct current panel, and Fig. 3 a panel for alternating current. A general view of a large newspaper press with a full automatic direct current equipment is shown in Fig. 4. The apparatus consists of six parts: the main driving motor; the slow motion motor; the bed-plate, gearing and pedestals; the automatic clutch; the control panel; and the push-button stations. The motors, gearing and automatic clutch are usually assembled on a common bed-plate and mounted in a pit as shown.

A typical direct current drive for a high-speed sextuple press consists of a 60 h.p. 500/1000 r.p.m. shunt wound commutating pole driving motor, and a 7½ or 10 h.p. constant speed slow motion motor. A corresponding alternating current drive consists of a 60 h.p., 900 r.p.m., slip-ring type driving motor, and a 7½ or 10 h.p. squirrel cage type slow motion motor.

The large motor is coupled to an auxiliary shaft carrying the main driving pinion. The small motor is connected to the auxiliary shaft through reduction gearing and an automatic ratchet-and-pawl clutch. During the process of plating the cylinders, putting on blankets, or threading in the web, the small motor only is connected in circuit, driving the press through the reduction gearing at a speed of about 10 r.p.m. of the cylinders. When the press is made ready the large motor is connected to the circuit and gradually accelerated. As it begins to drive the auxiliary shaft at a higher speed than it was being driven by the small motor through the reduction gearing, the pawls on the automatic clutch fly

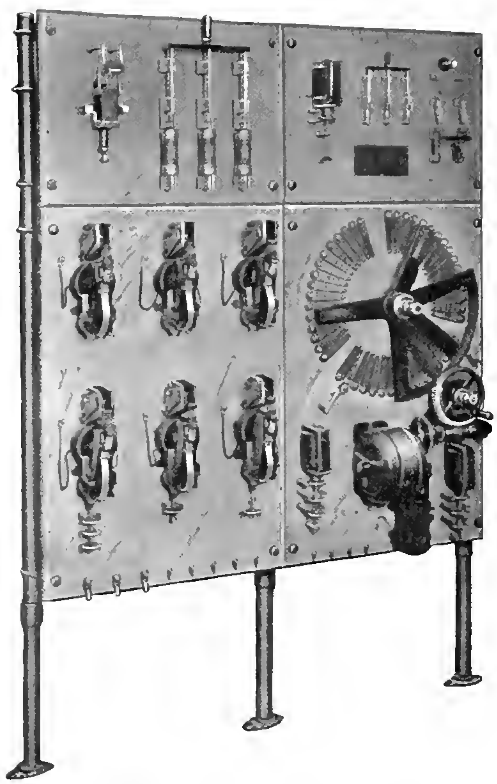


Fig. 3. 50 H.P. Control Panel used with alternating current full automatic double motor printing press drive at the Press Knickerbocker, Albany, N. Y., and the first full automatic alternating current controller installed on a newspaper press in the United States

out by centrifugal force, slip over the ratchet teeth, and finally leave it entirely, thus mechanically disconnecting the small motor. The small motor is shortly thereafter electrically disconnected at the controller as the large motor increases in speed.

With the driving equipment mounted in the pit as shown, the two motors will ordinarily be mounted on a common bed-plate and connected by spur gearing. Conditions often arise, however, which make it desirable for the motors to be mounted separately, as when the drive is within the press frame. Fig. 6 shows the small motor of an alternating current equipment mounted on an individual base, with worm gear reduction and automatic clutch assembled in a single casing. The reduction gearing and automatic clutch can be geared to any part of the drive shaft of the press or an auxiliary shaft, if desired.

The operation of the motors is entirely automatic, and is controlled by the push-buttons. The push-button stations are located, as many as desired, at different points about the press. From any station it is possible to start the press, increase or decrease the speed, or stop the press. A station is illustrated in Fig. 5 and contains five buttons, marked respectively "fast", "slow", "stop", "safe" and "run." Pressure on the "safe" button at any station opens the control circuit and renders the equipment inoperative, until the "run" button at that particular station is closed, releasing the "safe" button. A workman engaged about the press, plating the cylinders, or doing other work involving contact with the moving parts of the machinery, pushes the nearest "safe" button and thereby protects himself from injury. Pressure on the "fast" button causes the press to start, and to increase in speed as long as the button is held closed. When the button is released, the press will continue to run at the speed it has then attained. A slow speed for thread-

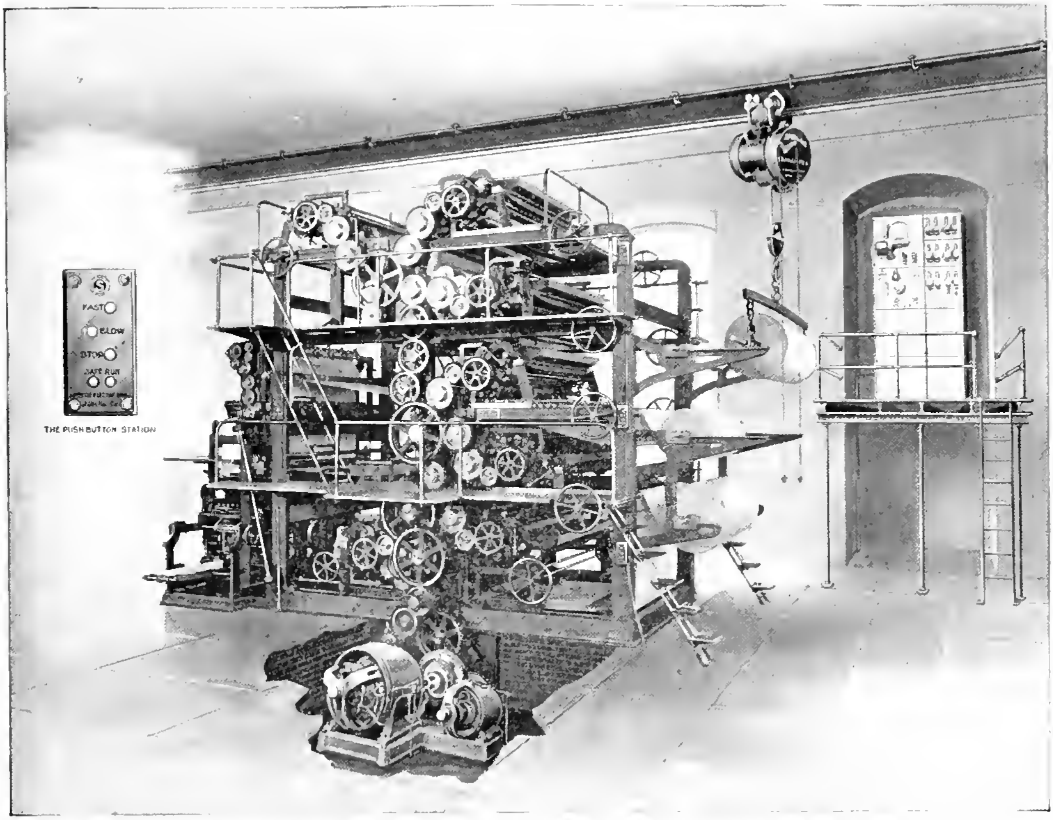


Fig. 4. Large rotary newspaper press with full automatic double motor control equipment. Large and small motors, slow-motion gearing, and automatic clutch located in a pit and geared directly to press driving shaft. The control panel is located on a platform well out of the way. The push button stations are secured at different points on the press frame. A large view of one of the stations is shown at the left

ing in the web is attained by releasing the "fast" button almost immediately after closing it, and before the large motor is

Fig. 5. Push Button Station Used with Full Automatic Printing Press Drive

connected to the circuit through the action of the controller, the press being driven through the reduction gearing and automatic clutch by the small motor.

A "jog" button is frequently incorporated in the push-button station, particularly on the alternating current equipments, for bringing the cylinders into any desired position for plating, by pressing a single button. When the "jog" button is released the press stops immediately.

Pressure on the "slow" button, while the press is running, will cause it to decrease in speed, as long as the button is held closed. When the button is released, it will continue to run at the speed it has then attained. Pressure on the "stop" button will cause the press to be stopped immediately, through operation of a dynamic brake on direct current equipments, or of a solenoid brake on alternating current equipments. When the press has been stopped, the controller handle returns automatically to the "off" position, so that the press cannot be restarted improperly. Besides the regular operating stations, an emergency station is provided, with its control circuits connected to the main control circuits through a double-throw switch. In the event of any failure of the operating circuits, due to grounds or other cause, the double-throw switch is put over and the emergency used, so that the press may be operated at once without delay. It is frequently desired to have control over the acceleration of the press from only one or two stations; and in this event the remaining stations may be provided with only "jog" "stop" "safe" and "run" buttons. This gives every operator control of the small motor, for plating etc., and complete protection against emergencies, while the important duty of acceleration is confined to the head pressman.

The panels consist of a motor-operated dial switch, with operating relays, the necessary contactors, line switch, overload relays, and reversing switch for small motor. The motor-operated dial switch is perhaps the most interesting feature of the controller. This system entirely eliminates dash-pots,

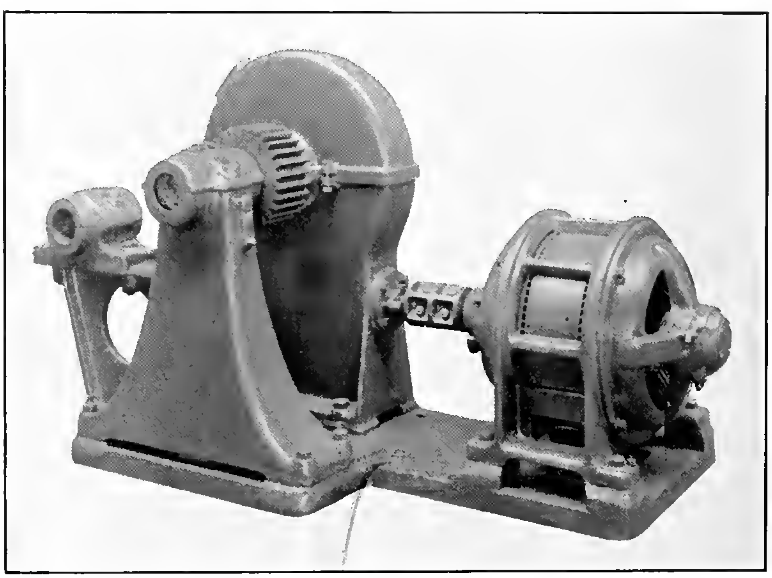


Fig. 6. Slow motion motor, with reduction gearing and automatic clutch, as used with double motor full automatic alternating current printing press equipment. Large and small motors mounted independently and geared to different parts of the press shaft. The worm gear reduction shown may be used instead of the spur gear reduction where the driving condition makes it more convenient or desirable.

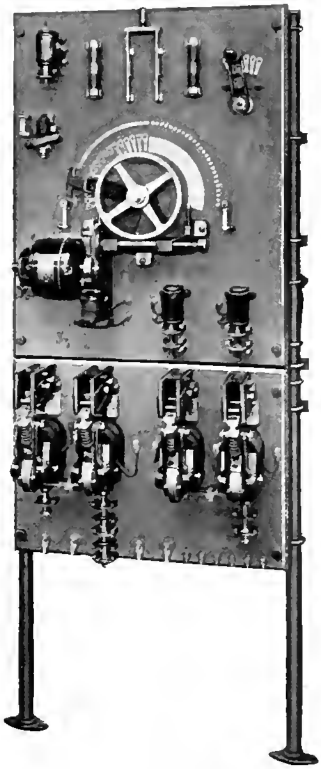


Fig. 7. Control Panel Used with Direct Current Full Automatic Single Motor Printing Press Drive

holding coils and other possible sources of trouble which are features of automatic controllers using long pull solenoids. The current consumed by the motor is about one-fourth of that required for a solenoid to accomplish the same results.

In the direct current controller the dial switch acts, in the forward direction, to successively cut out resistance from the small motor, close the series of contactors which short-circuit in due order the armature resistance of the large motor, and cut field resistance into its shunt field. It will be noted that all contactors, both the line contactors and the armature resistance contactors, are of the heavy "mill" type, with magnetic blow-outs, and that no heavy currents are carried on sliding contacts at the dial switch.

In the alternating current controller the dial switch acts to cut resistance in and out of the secondary of the large motor. The pilot motor is controlled in the forward and reverse directions by the operating relays, which are in turn controlled by the "fast" and "slow" buttons respectively. A solenoid brake on the pilot motor shaft prevents drifting of the switch arm. Limit switches prevent over-travel at either end of the dial. In the event of any damage to the pilot motor the dial switch may be at all times operated by hand.

Fig. 7 shows a panel for the control of a single motor-driven press. It is similar to the full automatic double motor equipments just described, except that only one motor is controlled. As this panel is built for a comparatively small motor—15-25 h.p.—the currents are carried on the dial switch directly. Contactors are provided for throwing a resistance in parallel with the armature for obtaining a slow threading speed, and for momentarily short-circuiting part of the series resistance at starting, to give the motor torque enough to turn over the press.

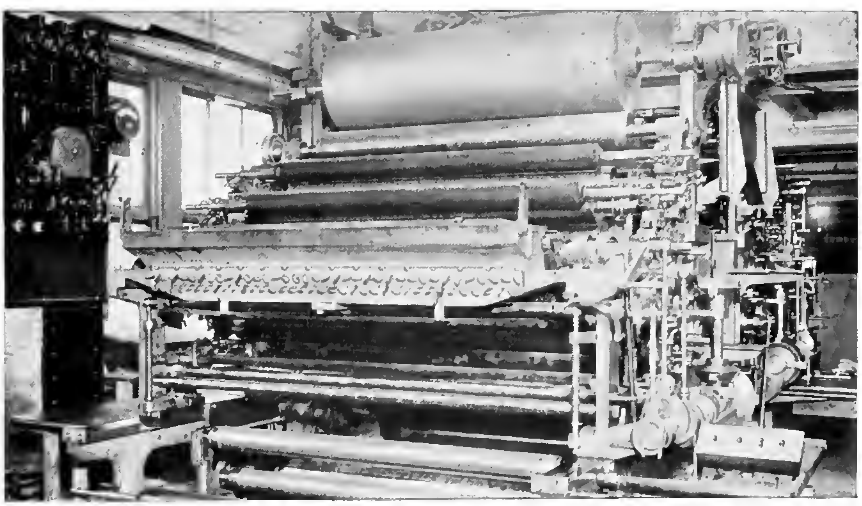


Fig. 8. Hoe Rotary Magazine Press Driven by 15 H.P. Direct Current Motor with Full Automatic Single Motor Controller

THE THEORY OF DYNAMIC BRAKING IN INDUSTRIAL MOTOR APPLICATIONS

By R. H. McLain

Power and Mining Engineering Department, General Electric Company

The ability of a motor to *absorb* power (as distinct from *exerting* power), has greatly enhanced its usefulness in many industries. This article explains the theory and the uses of this power absorption, or dynamic braking; and, with the aid of a few simple formulæ, shows the relation between back-torque, speed and rheostat ohms for a direct current motor, and how a knowledge of these relations is applied. The reasoning is extended to a-c. motors; and the limitations to the use of such motors for braking are pointed out. The article shows the extent to which the necessity for dynamic braking may sometimes reduce the rating of a motor for given duties; discusses the theory of a simple method of control for a shunt wound hoist motor; and concludes with a general summary of the advantages obtainable by the use of dynamic braking in hoisting and elevator service.—Editor.

As the field for application of electric motors increases, the variety of work imposed on the motor increases. The adaptability of a motor to exert power and thus replace steam engines and other prime movers was first to be recognized and used; while later motors began to be used to absorb power and thus to replace friction brakes. Strictly speaking, the motor neither exerts power nor absorbs power; it merely transmits power—in the first case from the electric power source to the mechanical apparatus, in the second case from the mechanical apparatus to the electric power source or to rheostats. The adaptability of the electric motor to absorb power, or to *brake dynamically*, has so extended its usefulness that it seems advantageous to discuss briefly some of the characteristics of a motor and its controller when used for this purpose.

The part that a motor plays in dynamic braking is so simple that its action can be explained in a few words to the ordinary electrical man. The method of controlling a motor, however, so as to employ its powers most usefully, is so large a subject and one so full of details, that only a few of the most practical applications can be discussed in a short paper.

If the fields of a direct current motor are excited from any source of current, and if the armature is driven from any source of power, the armature will generate a voltage just as any direct current generator does. If the armature terminals are connected to a rheostat, current will flow and this current will cause the motor to hold back against its driver. The amount of torque will depend upon the current, which in turn will depend on the ohms in the rheostat, and on the voltage of the armature. The equations representing torque, amperes and speed conditions are as follow, provided the field excitation is constant:

(1) $\text{Torque} = K \times \text{amperes armature}$

(2) $\text{Amperes armature} = \dfrac{\text{volts armature}}{\text{ohms rheostat}}$

(3) $\text{Volts armature} = K_1 \times \text{motor speed}$; therefore,

(4) $\text{Torque} = \dfrac{K \times K_1 \times \text{motor speed}}{\text{ohms rheostat}}$,

or,

(5) $\text{Torque} \times \text{ohms rheostat} = \text{constant} \times \text{motor speed}$.

As shown above in (5), if the torque and field excitation are constants the motor speed will vary directly with the ohms in the rheostat. Evidently the speed of the motor can be controlled accurately in such a case by varying the ohms in the rheostat. It is also easily proved that, if torque and ohms in the rheostat are constants, the speed of the motor can be governed by varying the field excitation. If the motor speed is a variable and it is desired to keep the torque constant, ohms in the rheostat must vary proportionally to the motor speed.

There are two general uses for the back torque produced by a motor. The first is to hold back against a falling weight, as in lowering with a hoist; and in this case the torque which the motor exerts is constant regardless of the speed. The second use for the back torque of the motor is to absorb stored energy in a system of moving weights. A motor which drives a trolley car, wheel lathe or similar apparatus, may be used to stop the same quickly and accurately; and in this case the back torque delivered by the motor may have any value. The greater the torque the quicker will be the stop. Since the motor speed is falling at all times the torque will decrease in proportion, unless the ohms in the rheostat are varied with the armature speed. In other words, in order to cause the armature to exert a uniform back torque while it slows down, it is necessary for the controller to decrease the ohms in the rheostat as the motor slows down.

The above remarks have been applied to a direct current motor, but the same reasoning is true with respect to an alternating current induction motor of the wound rotor type. In this case it is necessary to excite one portion of the primary winding with direct current in order to generate a voltage in the secondary winding. A rheostat can be connected to the secondary windings of the motor, and this rheostat will control the speed of the motor just as a rheostat across the armature of a direct current motor controls its speed. The speed can also be controlled, but not so effectively, by varying the field excitation.

There are, however, three important limitations in the use of an induction motor for braking. First, in practical applications the motor will not exert as much torque when braking as when motoring, for the reason that the available torque depends on the amount of direct current excitation, and if enough excitation is supplied to give the same torque when braking as when motoring, the motor will be abnormally heated. Second, the ordinary motor will not exert much torque when braking below a speed 25 per cent. of synchronous speed. Third, if on a hoist, while the motor is running at a high speed and delivering a large torque, the rheostat is suddenly changed so as to call for a much lower speed, the motor will lose its torque and let the load fall.

This action is illustrated in Fig. 1 (the figure is not correct as to actual proportion). T is the torque required to counter-balance the falling load; C_1 is a speed-torque curve of the motor when a high resistance is connected in the secondary winding; C_2 is a speed-torque curve of the motor when a medium resistance is connected in the secondary; C_3 when a low resistance is connected in the secondary. If the motor is running on curve C_1 at speed S_1, and the rheostat is suddenly changed so as to put the motor on curve C_3, the motor does not continue to deliver torque T and consequently slow down to speed S_3. Instead, the motor immediately exerts torque T_1 which is insufficient to sustain the load. Consequently the load over-hauls the motor at a higher and higher speed, until all torque is lost and the load falls freely. It is therefore necessary to change the rheostat slowly in properly-chosen steps. In the case of Fig. 1, if we wish to change the motor speed from S_1 to S_3, we must first adjust the rheostat

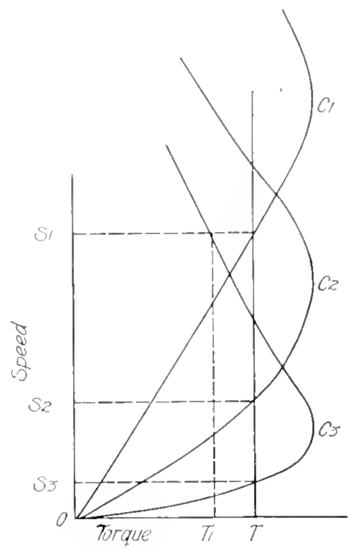


Fig. 1

to give curve C_2, and then after the speed has been reduced to S_2, again adjust the rheostat to produce curve C_3; whereupon the speed will be reduced to S_3 with the motor delivering torque T. This third limitation upon the use of an induction motor for dynamic braking does not cause danger when the motor is used only to absorb stored energy; because, if the motor does get on the "racing" end of a speed-torque curve, there is nothing to fall. The motor simply does not work so effectively or efficiently.

In order that an automatic controller of the current limit type may work properly with an alternating current hoist motor it is necessary that the current limit relays be so connected as to be effective when the motor is lowering, as well as when hoisting, and to be calibrated so that the contactors do not operate so rapidly that the motor "breaks down" when lowering.

One method of rendering an alternating current motor comparable with a direct current motor as regards torque, when braking dynamically, is to couple or gear the alternating current motor to a series wound, direct current generator which generates a comparatively low voltage. The direct current generator is used to excite the fields of the alternating current motor. Both machines hold back against the load, and the direct current machine can be made suitable in size to bring the total available torque up to any desired value. A very efficient system of controlling such an arrangement, when used to lower a load on a hoist, is to connect the alternating current motor to the alternating current power supply in such a manner that it runs as an induction generator. This connection is made by connecting the stator leads as if the motor had to pull its load downward. When so connected the motor will hold back against the load when the load tends to drive it at any speed above synchronism, and will return all surplus power to the line. For speeds below synchronism the two machines can be connected as described in the first part of this paragraph.

The question is often raised as to how much the size of a motor has to be increased when it is used for dynamic braking as well as for its usual work. For all such machines as printing presses, ordinary tools, etc., where a motor is used only to give a quick emergency stop, no increase is necessary in the size of the motor due to dynamic braking action, because such action is no more severe than the usual continuous running requirements on the motor. In some hoisting work and in some traction work the use of the motor to brake dynamically may increase the size of motor slightly over that which would be necessary if it were not so used. In many cases this may not be true. The following typical example of a hoist motor on a coal bridge will illustrate how dynamic braking frequently affects the size of a motor. We will take the case of a hoist motor which is used to close an automatic coal-bucket and to hoist it, then to open it by exerting power. The empty bucket is then to be lowered by the motor absorbing power. We assume the following data:

Time to close 8 seconds.
H.P. to close ½ hoisting h.p.
Weight of coal 10,000 lb.
Weight of bucket 15,000 lb.
Hoisting speed 4 ft. per second.
Lowering speed 5 ft. per second.
Hoisting efficiency 87½ per cent.

In considering such a case we must also consider the standard sizes of motors which are available for such work, and we will assume that we have, in this case, three sizes to choose from, viz., 180 h.p., 136 h.p. and 90 h.p., each rated on a continuous basis. The cycle when applied to a 136 h.p., 435 r.p.m. series wound motor will be as follows:

	Sec.	H.P.	Torque in lbs.-ft.
Close	8	104	1040
Accelerating	2	233	3420
Hoist full speed	11	208	2920
Open	5	50	320
Lower dynamically	9½	120	1330
Decelerate dynamically	1½	233	3420
Rest	13	0	0
Total	50		

For the particular motor which we had selected we find that the temperature rise, as calculated from test data, would be the same when the motor was working under the above duty cycle as if the motor were running continuously on a 136 h.p. load. If the dynamic braking part of the above cycle were omitted the motor would have the same temperature rise as if it were run on 97 h.p. continuously. This particular case shows that the motor has to be about 40 per cent. larger from a heating standpoint, on account of dynamic braking being used. It is found, however, that a smaller motor, next in size to the one we had selected, would be too small for the work, even if dynamic braking were omitted, since its rating is 90 h.p. continuously, and also because it could not be used conservatively on a peak load of 233 h.p. Consequently, so far as the motor is concerned, with the above duty cycle our first selection would be right whether dynamic braking were used or not, and the motor might just as well be used for dynamic braking as be idle part of the time. This example, it must be understood, is only one case. There are numerous cases where different conclusions would be obtained, and each must be considered by itself. For example, if the duty cycle above were just a little heavier, say equivalent to 145 h.p. continuous, the 136 h.p. motor would do the work if dynamic braking were not used; but if dynamic braking were used, a larger motor would be necessary.

The methods of controlling a motor are almost as numerous as the classes of work to be performed. Each machine must have a controller designed especially for it, and therefore no attempt will be made in this paper to describe all of the methods of control. Only one method of controlling a hoist motor will be described. Fig. 2 shows the connections of a shunt wound hoist motor, so arranged that the speed will be under control no matter whether the motor is required to drive a load downward, or is required to hold back against the load. The relations between voltage generated in the armature and the currents in the various circuits can be derived easily from the simple Ohm's law which holds in all direct current circuits. Referring to Fig. 2, e represents voltages, r resistances and c currents. c_1 is the current through r_1; c_2 is the current through r_2; and c_3 is the current through r_3. e_4 is the voltage generated in the armature, and r_4 is the internal resistance in the armature. Without burdening the reader with the simple algebraic solution of the equation of the circuits, it may be stated that all variables occur in the first power only, and consequently all curves are straight lines. Each curve can, therefore, be determined by two points:

Let $c_3 = 0$,

$$\text{then} \quad e_4 = \frac{r_2}{r_1 + r_2} \times e. \tag{6}$$

Let $e_4 = 0$,

$$\text{then} \quad c_3 = \frac{r_2 e}{r_1(r_2 + r_3 + r_4) + r_2(r_3 + r_4)} \tag{7}$$

When $c_3 = 0$ and $e_4 = \frac{r_2}{r_1 + r_2} \times e$

$$\text{then} \quad c_1 = c_2 = \frac{e}{r_1 + r_2} \tag{8}$$

When $e_4 = 0$,

$$\text{then} \quad c_1 = \frac{e}{r_1 + \dfrac{r_2(r_3 + r_4)}{r_2 + r_3 + r_4}} \tag{9}$$

$$\text{And} \quad c_2 = c_1 - c_3 \tag{10}$$

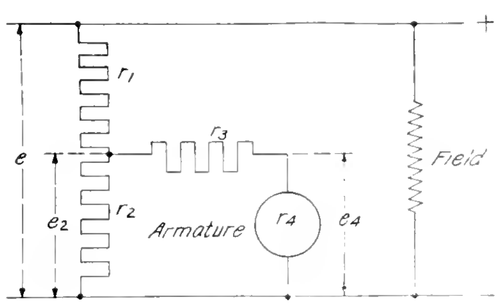


Fig. 2

Fig. 3 shows the relations of these values in graphic form. c_1, c_2 and c_3 are plotted as abscissæ against e_4 as ordinates.

Now if we assume that the motor speed is proportional to e_4 and the torque is proportional to c_3, we see from examination of curve c_3, Fig. 3, that the motor can be made to act very much like a shunt wound motor, whose speed regulation is poor, and that the

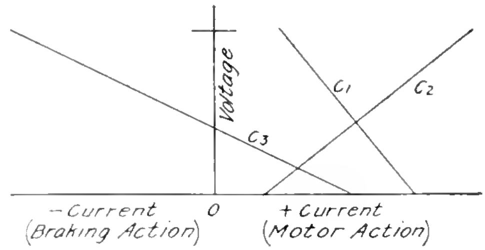


Fig. 3

no-load speed of the motor can be made to be any value below normal speed. From (6) it is seen that the no-load speed varies as the ratio of r_2 to $(r_1 + r_2)$. From (7) it is seen that the speed-torque curve is flat (i.e., the speed regulation is good) when $(r_3 + r_4)$ is small in value, and also when $(r_1 + r_2)$ is small in value. However, from (9) it is seen that c_1 is great in value, when $(r_1 + r_2)$ is small; and therefore, for a given application, it is necessary to make $(r_1 + r_2)$ as large as possible, in order to save current consumption from the line, and still make it small enough to produce the required speed regulation.

This method of controlling a motor is valuable in crane service where the operator desires to run at various speeds, whose values are *approximately* constant, regardless of whether the motor must drive or hold back against its load. In such a case the controller is used to regulate in various ways the values of resistance so as to obtain the desired speeds. This method of control is frequently used in elevator applications, where, although the load is variable, it is necessary to bring the cage to some definite slow speed just before a landing is reached, in order that an accurate stop may be made at the landing.

Fig. 4 shows a graphic record of the current in the armature of a series wound direct current motor which is used to accelerate a large mass, and is then used to decelerate the same mass. To accelerate the mass the motor is used as a series motor. To decelerate the mass the motor is used as a series generator. It will be noted that the current and the time required to decelerate are less than that required to accelerate. This difference is explained by the fact that the energy represented by the ampere-seconds used to accelerate, *minus* all of the friction losses, armature losses, etc. (both during the period of acceleration and of deceleration), is equal

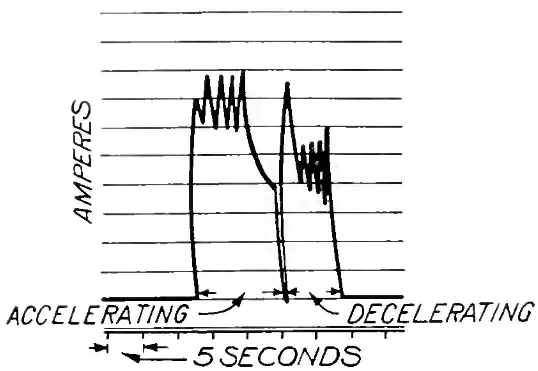


Fig. 4

to the energy represented by the ampere-seconds used to decelerate.

There are many advantages obtainable by the use of dynamic braking. One that is readily apparent in hoisting applications is that very often the motor required for hoisting the load has sufficient capacity to do all the lowering, without the use of friction brakes. This is especially valuable where large amounts of energy are to be absorbed, since large friction-brakes are hard to handle and expensive to build. Another valuable feature is the accuracy of control. If a load is being lowered the speed of the motor will, as has been shown above, depend only on the ohms of the rheostat; that is, there will be a definite speed according to each "point" of the controller. If a moving mass is to be stopped, it can be stopped at a uniform rate by the use of automatic current limit control, (such as was used in getting the record of Fig. 4). When dynamic braking is used all such operations can be performed with a greater degree of precision than is ever to be expected from friction braking. Dynamic braking also offers a system of braking which is conveniently and easily controlled, either by men or by automatic devices; and on account of this fact many machines perform, automatically, feats which would not be possible were electric motors not used in such a manner. Familiar examples of this are seen in the high-speed electric passenger elevators, and in skip hoists on blast furnaces.

METHODS OF CURRENT LIMIT CONTROL

Contributed

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Methods of current limit control are now extensively applied in many industrial motor services, and are several times referred to elsewhere in this issue. The following short article describes, with line diagrams, a method of automatic control in which series relays are connected in the main circuit and govern the operation of the several contactors, and in which an independent method is provided for lifting each current limit relay in advance of the time at which it is to be held up by the load. Considerable elaboration of the method is sometimes resorted to, but the essential principle remains always as outlined below.—Editor.

With the exception of the series contactor system, current limit control systems generally make use of series relays in the main circuit which govern the closing of the contactors. Series relays, however, may easily be applied in such a way that the current limit effect is only imperfectly realized. In the earlier systems it was required that each rush of accelerating current must lift a series relay and hold it up until the current had fallen to the value for which the relay was set. In any such system the closing of any contactor, and consequent rush of accelerating current, will be simultaneous with the closing of the interlock disc on this contactor, by which the actuating circuit is extended to the next contactor. Immediately on the closing of one contactor, therefore, the following contactor will close unless the relay lifts more rapidly than the contactor can close. The result is that under service conditions the relays will act irregularly, as a rule failing to limit the current as intended.

This characteristic has been eliminated, not by means of excessive refinement of design and accuracy of adjustment of the relays; but by providing an independent method of lifting each current limit relay in advance of the time at which it is to be held up by the load current. The details by which this is accomplished are different for the alternating current and direct current systems, and must be described separately.

Direct Current System

This system uses "current limit interlocks," which consist of current relays (with disc contacts) mounted on, and mechanically interlocked with, the respective contactors. This mechanical interlocking is such that when any contactor is open its interlock is held up; and when the contactor closes the interlock is released mechanically, so that it will either continue to be held up or will be dropped, according as the motor current is high or low.

The system of interlocking and current limit for either a series, shunt or compound wound motor is shown in Fig. 1, in which the armature, rheostat, contactors for forward operation and two of the resistance contactors are shown, but omitting the two contactors for reverse operation. The action of the current limit on the first point is as follows: (See Fig. 1.) The energizing of wire *f* by means of the master controller closes contactor *F1*. As this contactor closes it makes circuit through disc *a* and thereby closes contactor *F2*. When *F1* closes and before *F2* closes, the shunt wound current limit coil *b* is directly across the line, and holds the relay up magnetically while contactor *F2* closes. After *F2* closes the voltage across the coil *b* will consist of the drop in the rheostat, thus giving the effect of series current in this coil. As the speed increases and the current decreases on the first point, the coil *b* will drop its plunger which will close the circuit at *c*. This will allow contactor *3* to close, cutting out the first step of resistance.

On the resistance contactors the same form of current limit interlock is used as on contactor *F2*, except that a series coil *d* is used in place of the shunt coil *b*. After *F2* closes and before *3* closes, the motor current passes through the entire number of turns of coil *d*. The value of current which allows interlock *c* to drop is sufficient, when acting through the entire number of turns of coil *d*, to hold up plunger *e* while contactor *3* is closing. After contactor *3* is closed, the motor current no longer passes through the entire coil *d* but enters at the middle point of the coil. The holding power of coil *d* for any given current is therefore cut in two; and when the current (which increased considerably when *3* closed) again falls off sufficiently, the plunger *e* will be dropped, closing the control circuit at *e*. This will close contactor *4* and the operation of its current limit interlock will be entirely similar to that of interlock *e* on contactor *3*.

The magnetic parts of the interlocks are so proportioned that the current required to lift the plunger is three or four times the current required to hold them up. Moreover, as each contactor closes, it cuts out all preceding current limits, so that no possible subsequent overload can lift the plunger up. After the contactors have closed and their respective plungers have dropped, these

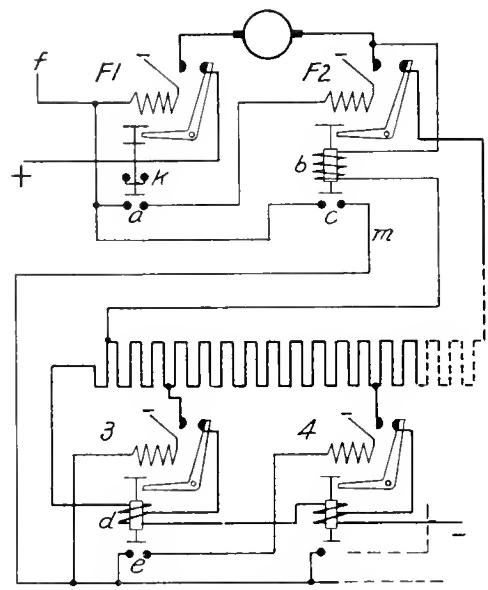

Fig. 1. Current Limit System with Shunt Wound Contactors for Direct Current Motors

plungers will, therefore, stay down until the master controller is thrown off; after which the contactors will open, and in so doing will lift their respective plungers to the open position ready for another acceleration.

Fig. 1 and the foregoing explanation cover all the essential features of the current limit system for direct current motors. For reversing service one contactor with plain interlock is added, like *F1*, and one contactor with current limit interlock like *F2*. In this case the control line for both reverse contactors passes through disc *k* on *F1*, and control line *f* passes through a disc located similarly to *k* on one of the reverse contactors. This provides electrical interlocking between forward and reverse, and is supplemented by mechanical interlocks. The current limit interlocks are adjustable (separately on each point) over a wide range. This adjustment is made by changing the air gap of the magnetic portion of the plunger.

The system described in the foregoing is capable of elaboration to meet a wide variety of conditions, but the current limit remains essentially the same. Attention is called to the extreme simplicity of this current limit system when used for starting or reversing duty. A shunt contactor equipment without any current limit at all, relying entirely on the time element of the contactors, would require a disc interlock on every contactor except

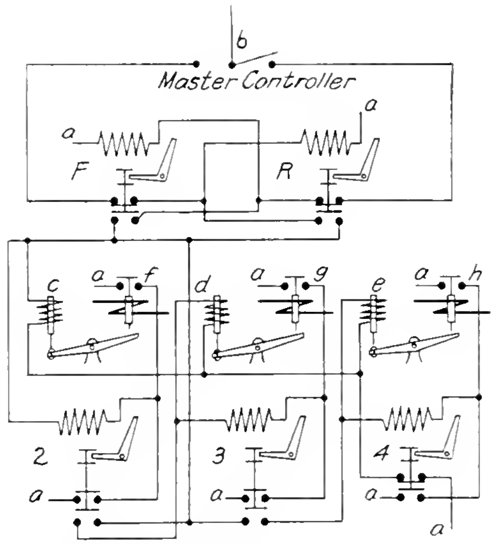

Fig. 2. Current Limit System for Alternating Current Motors, with Small Number of Points, for Heavy Reversing Service

the last resistance contactor. This current limit system, it has been noted, requires, for a reversing equipment, only two additional discs on the whole equipment. The current limit feature is thus obtained without any material increase in the amount of control wiring or interlock trouble.

Alternating Current System

As applied to equipments with a small number of points, for heavy intermittent duty, the current limit system for alternating current is illustrated by Fig. 2, in which *F* and *R* are double-pole contactors governing respectively the forward and reverse connections of an induction motor; and contactors *2*, *3* and *4* are double-pole contactors each of which cuts out a balanced step of resistance in the secondary circuit. Separate current limit relays are used for the various points, one less relay being required than the total number of points.

Looking at the left hand relay (Fig. 2) the arrangement is as follows: Coil *c* is wound so as to operate (intermittently) directly across the line, and its plunger is attached to the lever by a pin joint. The other plunger *f* is influenced by a series coil in the primary circuit of the motor. This plunger *f* is not attached to the lever but is normally held up by it. When the coil *c* is energized and lifts its plunger, the lever is pulled away from plunger *f*, which is then free to hold up or drop according as the motor current is above or below the value for which the relay is set.

The operation of the contactors and relays during acceleration is as follows: Closing the master controller to the right closes the circuit from line *b* through the upper disc on contactor *R* through the operating coil of contactor *F* and to line *a*. (Phase *a-b* is the phase from which all the control circuits are energized.) This closes contactor *F*, which starts the motor. When contactor *F* closes, its lower interlock disc is closed, which extends the circuit from line *b* to coil *c*, and thence through the upper disc on contactor *4* to line *a*. When coil *c* is thus energized its plunger is lifted and releases the series plunger *f*. The motor circuit has already been made by the closing of contactor *F*, and the plunger *f* is, therefore, held up until the motor current drops below the value for which it is adjusted. When *f* is released by the motor current it drops and closes a circuit from *a* to the operating coil of contactor *2*, the lower disc on contactor, *F*, the upper disc on contactor *R*, the master controller, and line *b*. As soon as contactor *2* closes it makes a holding circuit through its upper disc to line *a*, by which the contactor, after once closing, is held closed independently of plunger *f*. At the same time the lower disc on contactor *2* completes the circuit through coil *d*, which in turn releases plunger *g*. When plunger *g* is released by plunger *d*, it will still be held up until the motor current falls to the value for which the relay is set; after which the dropping of plunger *g* will cause contactor *3* to close.

Acceleration proceeds in this manner until, when the last contactor (No. 4) closes, the upper disc on this contactor opens the circuit of coils *c*, *d* and *e*. This lifts plungers *f*, *g* and *h* but the contactors *2*, *3* and *4* remain closed through their respective holding discs. The current limit relays may be adjusted over a wide range by adjusting the air gap in the magnetic part of the plungers *f*, *g* and *h*. It is obvious that the accelerating value of current may be adjusted independently for each point.

For equipments containing a considerable number of points and starting less frequently, the number of current limit relays may be reduced to two. In this case one of the relays governs alternate contactors, and the other relay governs the intervening alternate contactors, the arrangement of control circuits being different from that shown in Fig. 2, and requiring three interlock discs per contactor. The current limit relay itself is the same as shown, and is used, moreover, in accordance with the same general principles; that is to say, the series portion of the relay is held in the open position on any one point by independent means, until the instant when its current limit effect is to come into action. This insures that no current limit points are lost, in the manner possible with the cruder forms of current limit control discussed in the opening paragraph of this article.

AUTOMATIC ELECTRIC CONTROL AS EXEMPLIFIED IN THE BATCHELLOR PNEUMATIC TUBE SYSTEM

By C. H. Williams

Philadelphia Office, General Electric Company

In many instances automatic control of motors is to be recommended primarily because it lightens the service on the electrical apparatus employed and renders mistakes impossible by eliminating the human element. In other cases, the outstanding advantage which it possesses is the enormous economies which it is able to effect. The Batchellor pneumatic tube system for the conveyance of the Philadelphia mails provides a striking example of this. After the installation of the automatic electric control equipment, the net saving in the first year was 45 per cent. including installation cost. The following describes the pneumatic system and gives some details of the automatic control equipment by which these economies were rendered possible.—Editor.

Most people know what is meant by the pneumatic tube system, but probably few realize its extent and importance, and still fewer appreciate the number and the difficulty of the engineering problems involved in its development. The utilization of air in motion has made possible a revolution in mail transportation, which is now an accomplished fact in most of the large cities in America. Mails are rushed across seas and continents at speeds ranging from 20 to 60 miles an hour; but, having reached the cities, they are often compelled to crawl along at six, five, four and even less miles per hour unless the pneumatic tube system is employed. This is why the old delivery system is known as the anachronism of the Post Office.

The Batchellor pneumatic tube system is by no means new, as the first carrier (containing a Bible wrapped in the *Stars and Stripes*) was despatched through Philadelphia tubes on February 11, 1893. From that day steady progress has been made in its development, the last and greatest improvement being the automatic electric control of the pumps which furnish the air for despatching the carriers. It is practically impossible to give a full and precise explanation of this system without elaborate models and diagrams, but the essence of the plan may be briefly outlined. At the central, or despatching, station there is a 25 h.p. air-compressor for each mile of tube, which maintains an approximate pressure in the tubes of six pounds per square inch. Connections between the various stations on each system comprise outgoing and returning tubes, which are bored on the interior to reduce the friction to a minimum. The ideal system would have its tubes laid straight and level; although this is not absolutely necessary, as the carrier can turn any corner or pass over or under any obstacle, provided the curve is one foot to every inch of the diameter of the tube. From the despatching station the air passes through the outgoing tube, expanding as it goes and moving the carriers at a rate varying from 35 to 60 miles an hour. The air then passes into the vacuum cylinder of the engine at the receiving end, the compression cylinders of the same engine furnishing air for the return circuit.

The size of the carriers varies in the different cities. Those used in Philadelphia are eight inches in diameter, weigh thirteen pounds when empty, and from twenty-five to thirty pounds when filled. They are thin steel cylinders, closed at the front end by convex discs of the same material, carrying a buffer of felt and leather. The rear end is closed by a hinged lid, secured by a lock. The lock is so designed that it is impossible for it to become undone while the carrier is in transit. The shell of the carrier is 24 in. long, and is surrounded by two bearings of woven cotton fabric, specially prepared and clamped between metal rings. When the carrier is new it fits the tube closely; but in service the bearings soon become worn, until they are a quarter of an inch smaller in diameter than the tubes. A carrier will run approximately 10,000 miles before these rings have to be renewed. Considerable air escapes past the carriers when the rings become smaller; but this affects the velocity of the carriers very little, and does not interfere with the proper working of the system.

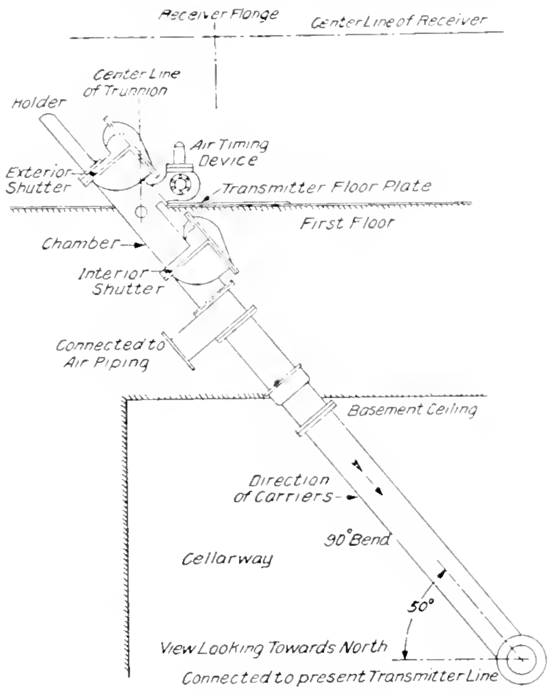

Fig. 1. Transmitter Used in Philadelphia Pneumatic Tube Mail Delivery System

The most complicated part of the system is the means by which the carriers are inserted and taken out of the tubes. The device which receives the carriers to be despatched is called the transmitter and is shown in detail in Figs. 1 and 2. This transmitter is composed of two sections, the outer one being merely a holder, while the inner one is a chamber closed by two swinging shutters. The carrier is placed in the outer section of the transmitter, resting against the exterior shutter; and as the pressure of the air in the inner section is the same as that of the outside atmosphere the weight of the carrier forces the shutter open, and the carrier enters the inner chamber. When the exterior shutter closes it sets a timing device which reverses the valve connections, thus cutting off the exhaust and admitting pressure from the tube through a by-pass. This firmly closes the exterior shutters; and at the same time allows the carrier to force open the interior shutter, as the pressures on both sides of this interior shutter are equal. Ten seconds after the carrier has gone the timing device re-sets itself, thereby changing the valve connections and allowing the compressed air in the inner section of the transmitter to exhaust. It is then possible for another carrier to enter the tube, without colliding with the carrier ahead. The device into which the carriers emerge from the tubes is known as the receiver. This consists of nothing more than the open end of the tube, arranged in such a manner that the main air circuit is cut off from it by means of a by-pass tube, leading to the vacuum cylinder of the pump. The carrier, upon entering the tube leading to the receiver, passes over the by-pass. This checks its speed; and it is carried up into the receiver by its own momentum, emerging on an oval table which has a spring at the farther end to absorb the shock and roll the carrier down to a lower section of the table, from which it can be removed without danger. This is clearly shown in Fig. 3.

The greatest commercial improvement was made to this system during the past year, when the old method of hand control was replaced by automatic electric control. This system eliminates the waste of power by shutting down the pumps when there are no carriers to be despatched. Comparatively few people realize the saving in operating expense which has been brought about through the introduction of automatic control. The operating records of the system under consideration show a saving in power of 60 per cent. on a bill of $45,000.00, while the cost of installation was only 16 per cent. of one year's power bill, or $7,500.00. The net saving in the first year was, therefore, approximately 45 per cent. During the past few years tre-

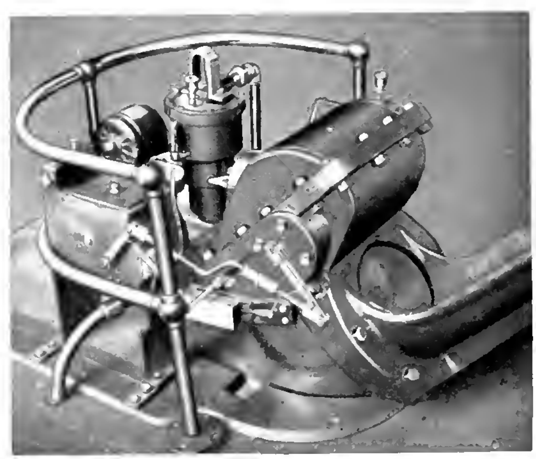

Fig. 2. Transmitter Used in Philadelphia Pneumatic Tube Mail Delivery System

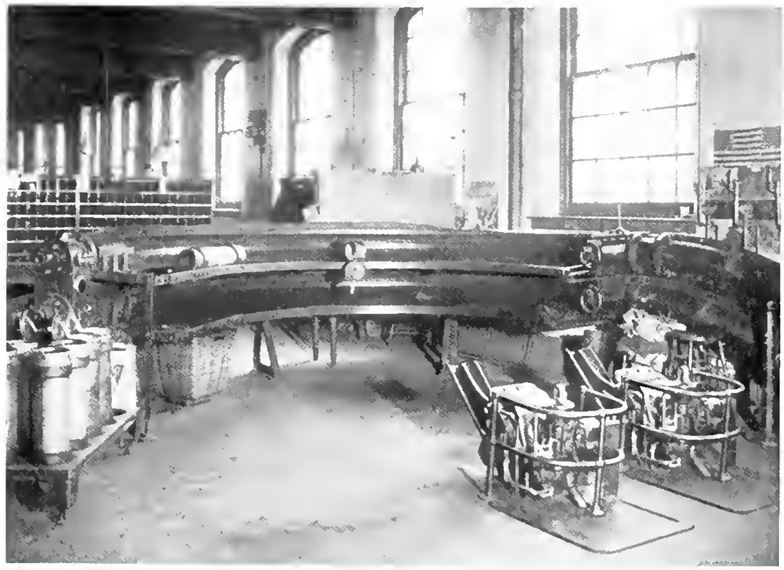

Fig. 3. Receiving Table Transmitter and Carriers Used in Pneumatic Tube System

mendous strides have been made in the development of automatic control for all kinds of work, and this installation stands out pre-eminently as an example of the economy which can be effected by its use.

While the actual starting and stopping of the motor is done from the automatic panel, which is located near it in the basement, the remote control originates at the point where the carrier opens the exterior shutter of the transmitter. The general outline of the control is as follows:

Remote Control. Attached to the transmitter is a motor-operated cut-out device. The motor drives through gears on to a friction clutch, the gear ratio being 10,000 to 1. This reduction is such that the arm, which is attached to one side of the friction clutch, takes three minutes to travel from "full on" to "full off" position, thereby insuring that the pump will not be shut down until the last carrier has reached its destination. A

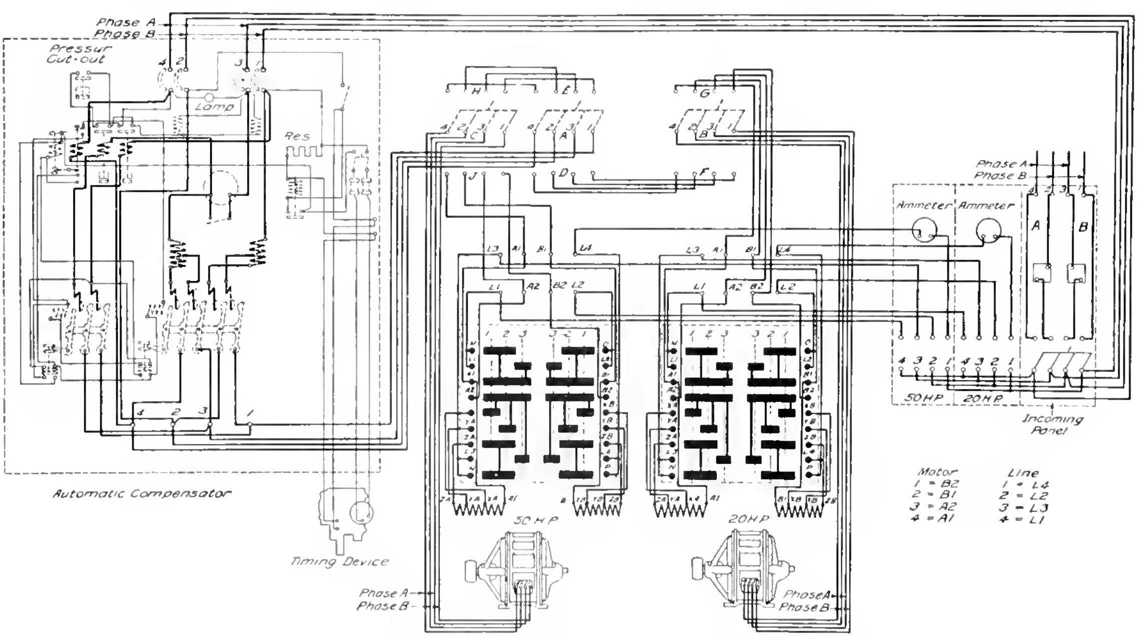

Fig. 4. Wiring Diagram of Station C Philadelphia Pneumatic Tube Mail Delivery System

copper segment mounted on the arm bridges two contact buttons when it reaches the "full off" position, thus shutting down the pumps automatically as soon as the demand

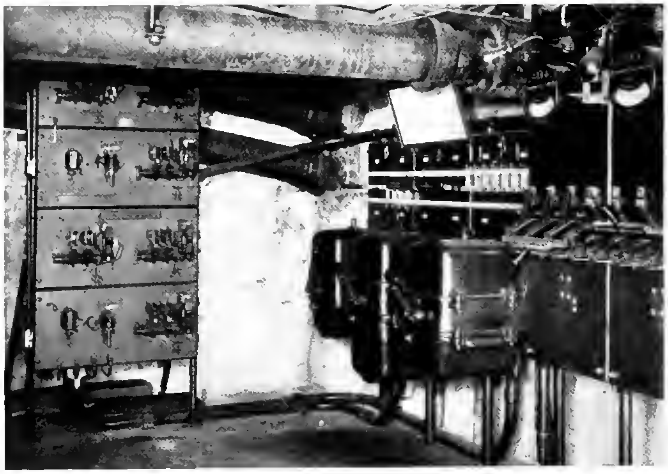

Fig. 5. Automatic Compensator Panel, Hand Compensators and Switchboard, Station C, Philadelphia

ceases. As each carrier passes through the exterior shutter of the transmitter, the friction clutch is opened by means of connecting rods, and the arm is returned to the "full on" position by a spring. By doing so the short-circuit across the contact buttons is opened, thus allowing the operating relay, which is connected across these buttons, to pick up and make the control circuit for the automatic compensator, at the same time starting the motor of the timing device, which, if the arm is not reset by another carrier, will drive it to the "full off" position in three minutes and shut down the pumps.

Current Limit Automatic Compensator: This panel is to perform the same function as a hand compensator, doing it at the psychological moment as determined by the current in the motor, which will be in proportion to the speed. The starter consists of a four-pole contactor for connecting the compensator coils across the line, and the motor across the reduced voltage taps of the compensator coils; and a current limit relay in the starting circuit, which, when the current reaches a predetermined value, opens the circuit of the four-pole contactor, thus opening the compensator circuit, and making the circuit of the two-pole contactor, which connects the motor across the line. On the panels furnished for this equipment, the four-pole and two-pole contactors are mechanically interlocked, but on standard panels these contactors are electrically interlocked. In this case there are two sources of overload protection; *first*, overload relays which, when they operate, protect the electrical circuit by energizing the tripping-out coil of the circuit-breaker, completely cutting off the motor and starter from the line; ***second***, the pressure cut-out which, when it opens, completes the circuit of the trip-coil of the circuit-breaker. This device is to protect the tubes in case a carrier gets jammed.

Fig. 4 shows the wiring of Post Office Station C at Philadelphia, while Fig. 5 is an illustration of the station equipment. Besides the two automatic panels are shown the hand compensators, switchboard and throw over switches. These latter make it possible to start the motors from either the automatic or hand compensators. In each station there is one spare motor, which is used not only as a substitute in case of a break-down; but also in case of an emergency, for forcing a jammed carrier out of a tube. For this reason the motor is rated at twice the horse-power necessary for operation.

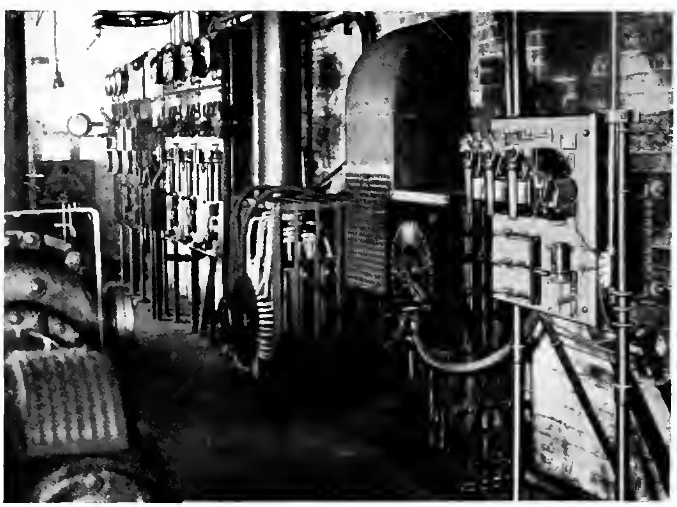

Fig. 6. Interior of Southwark Station, Philadelphia, showing series contactor panel in foreground

OPERATING NOTES ON RELAYS, CONTACTORS AND OTHER BASIC AUTOMATIC DEVICES

By W. C. Yates

New York Office, General Electric Company

This article has been written primarily for the instruction of those responsible for the good performance of automatic controlling apparatus. More important than a set of hard-and-fast rules for operation and adjustment is a clear understanding of the function of the various basic devices employed in such equipments. The following article explains simply the function of some of these elemental devices, protective relays, current limit relays, contactors, and so on; the author making notes where necessary on adjustments which may be made to secure the best operation.—Editor.

The general tendency in the application of motor control is to make the controlling equipment self-governing. The demand is growing for automatic controllers which will protect the motor and the machine it drives from mishandling by a careless operator, or which will insure the doing of a certain thing in a certain time. The ever-broadening field of application of the electric motor makes necessary the development of controlling devices to meet the new conditions; or rather—it might be more truly said—the new developments in the art of controlling devices have made possible many new applications of electric motors.

This tendency takes responsibility from the operator—in many cases eliminates him—and places it upon the electrician who installs the equipment and has to take care of it. From the nature of things an automatic controller is less simple than hand-operated apparatus, and the average electrician is sometimes finding it a problem to completely understand the device which is set down before him to install, adjust or take care of. The purpose of this article is to give him a brief description of some of the latest types of protective and governing apparatus as used in automatic controlling equipments, explaining the function of each and giving some suggestions as to proper care and adjustment. Each device is adjusted for certain average conditions when the equipment is tested at the factory; but, when the controller is put into service, it is frequently necessary to change the adjustment in order to meet the special conditions of the particular installation. Furthermore, between the time the equipment is tested at the factory and the time it is erected, there are opportunities for the adjustment to become changed by reason of rough handling.

We have referred to these devices as "protective" and "governing." Under the former term are those which provide for no-voltage and overload release. All automatic controlling equipments, which are operated by magnets or solenoids, inherently possess the no-voltage release feature, as all the switching devices drop out when the power is off. They can be connected either to start the machinery automatically when the power returns, or to make necessary the closing of a switch or a push-button by the operator. The simplest method of accomplishing the latter is to attach an auxiliary contact to the contactor which first closes, the said contact bridging a normally open switch or push-button, which is closed for an instant to start the equipment. The auxiliary contact maintains the control circuit of the various magnetically-operated devices as long as the contactor referred to remains closed. The auxiliary switch is usually in the form of a metal disc bridging two contact posts. These interlock discs are also used to insure the proper sequence of closing of the contactors, to guard against the closing of one device before another has opened, etc. It is essential to see that these auxiliary contacts are made or broken properly, as the case may be, when the contactor to which they are attached closes or opens; and it is quite important to maintain the discs, contacts, and the springs behind the discs, free from accumulation of dirt or corrosion.

The protection against overload is taken care of by a relay, the coil of which is in the main circuit. When the core of the relay is lifted, contacts in series with the control or pilot circuit of the equipment are opened and the contactors drop out, opening the motor circuit. A typical overload relay is shown in Fig. 1. This possesses a shunt coil by means of which the relay can be electrically re-set from any point. The two contact-making arms will be noted: the one at the left makes and breaks the pilot circuit, while the one at the right is in series with the shunt coil of the relay. When one contact is closed the other is opened and *vice versa*.

The object of the right contact is to open the circuit of the shunt coil immediately it re-sets the relay, as well as to make it unnecessary for the push-button, used to

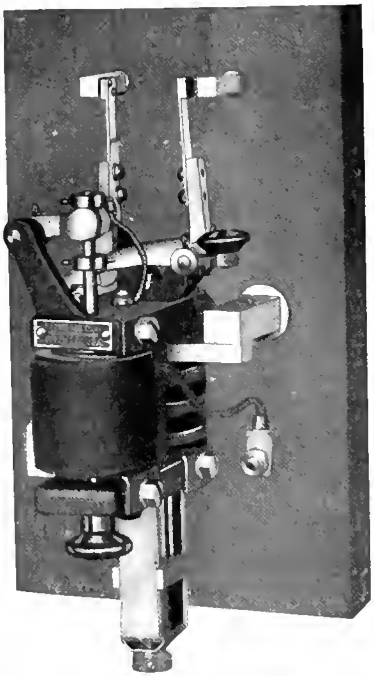

Fig. 1. Electrically Reset Overload Relay

close the shunt coil circuit, to open the same. The knurl-headed screw at the bottom of the relay provides for its adjustment. Turning the screw to the right raises the relay core and lowers the value of current at which the relay will trip. A graduated scale on the front of the relay indicates the current values within the range of the particular series coil used.

Overload relays used on alternating current control equipments are usually provided with a time limit attachment, so that the relays can be set at a current value below the initial rush of current taken by the motor in starting (Fig. 2). The attachment consists of a dashpot or a bellows; and in either case a time adjustment is possible by means of screws, the setting of which can be readily changed to increase or decrease the air inlet. No definite rules can be offered to cover the proper setting of overload relays. The use of an automatic control equipment usually pre-supposes an intermittent cycle of duty; and the motor can, therefore, safely undergo higher overload currents than are permissible for constant running. The percentage overload current allowable depends upon the frequency of the high currents, the proportion of time the motor is running, the accelerating period, and other factors. The proper point at which to set the overload relay can only be determined after the equipment is in operation and observations have been made of the current peaks attained. The relay should be adjusted to trip just above the highest current reached under normal operation.

Under the head of "governing" devices come those which limit the current taken by the motor while it is being brought up to speed. The alternating current forms are somewhat different from the direct current devices. One method of direct current limit control is by means of a series relay attached to a shunt wound contactor (see Fig. 3). All the accelerating contactors, which serve to cut out the successive steps of starting resistance, are provided with the relay, except the last one to close, and each contactor, when open, mechanically holds the relay core up so that the disc does not make contact. When the pilot circuit of the controlling equipment is closed,

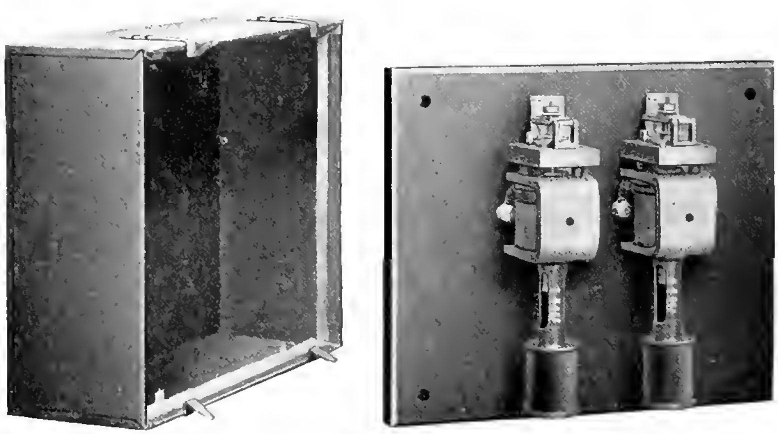

Fig. 2. Overload Relay Panel

the shunt coil of the first contactor is energized, and that contactor closes the motor circuit through the starting resistance and the coils of all the series relays. The relay coil of the first contactor is shunt wound, and is connected across the terminals of the starting resistance. When the current through the starting resistance falls by reason of the motor coming to speed, the drop across the shunt relay coil diminishes, until its core falls; and the contact disc thereupon completes the circuit through the shunt coil of the next succeeding contactor. This contactor cuts out a step of the starting resistance, causing a jump in current, and when the current diminishes, the series relay falls, and its contact disc causes the third contactor to close and so on. The number of contactors depends upon the size of the motor and the load it is called upon to get under way. The theory of current limit control, with connection diagrams, is discussed at greater length in an article appearing on page 272.

The current limit relay is adjusted by turning the knurled nut to send the core up or down, which will respectively decrease or increase the value of current at which the core will drop. It frequently happens that the original setting of the relays either causes the motor to come to speed too quickly, or prevents their falling at all by reason of the heavy load on the motor. Adjustments to

Fig. 3. Shunt Contactor with Series Relay for Current Limit Control

remedy either condition can be readily made as explained above.

Another method of direct current limit control involves the use of the series wound contactor which embodies the current limit feature with no accessory relay (Fig. 4). This device has the magnetic paths through its frame so arranged that it will not close

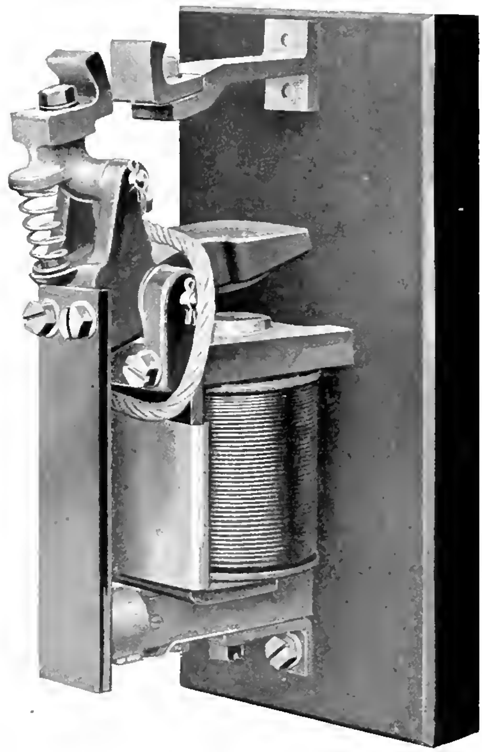

Fig. 4. Direct Current Series Contactor

when a current is passing through the coil of a value higher than that at which the contactor is set. When the current falls to this predetermined point the flux through the outer magnetic path is not sufficient to oppose the pull at the top, and the contactor closes. A number of series contactors can be used to accelerate a motor by cutting out successive resistance steps. As each contactor goes in the current immediately rises and closes the circuit through the coil of the next succeeding contactor. The current value at which each contactor is set can be varied by turning the thumb-nut at the bottom, to increase or decrease the magnetic gap at that point. Turning the nut clockwise increases the gap and increases the current value at which the device will close. After changing the adjustment care should be taken to tighten the set-screw which holds the nut.

Alternating current limit control is accomplished by self-contained relays, of which a typical one is shown in Fig. 5. This relay has a shunt coil and a series coil, the core of the former being heavy enough to lift the core of the latter, which carries the contact

Fig. 5. Relay Used with A-C. Contactor Control for Obtaining Automatic Current Limit Acceleration

disc. This relay operates in conjunction with two or more alternating contactors for accelerating a slip ring induction motor, in the following manner: When the pilot circuit is closed the first contactor, which closes the motor circuit, goes in, and, by means of an auxiliary disc contact, makes the circuit through the shunt coil of the relay. The core in the shunt coil is immediately lifted, leaving the core of the series coil free to drop as soon as the motor current falls to the pre-determined point. As soon as the disc makes contact the coil of the second contactor is energized. For a third contactor an additional relay must be employed; but no more than two relays are needed for any additional number of contactors, as they can be so connected in relation to auxiliary contact discs on the various contactors as to operate reciprocatingly for any number of starting points. The accelerating current limit relay can be adjusted by the nut, which can be turned to raise or lower the core of the series coil. Raising the core decreases the current value at which the relay will drop.

The type of relay used with automatic compensator starters for squirrel cage motors is the same as the one just described, except that it makes contact in both positions. When the relay falls it breaks the coil circuit of the starting contactor before it closes the coil circuit of the running contactor. This relay can be seen on the panel shown in Fig. 3 of the article on starting compensators, page 312.

All the current limit devices described in the foregoing are apt to need adjustment, after they are installed, to obtain the best results. Obviously, the ideal point to set them is just above the value to which the motor current will fall at each point; although there is no object in setting them below 25 per cent. overload current, unless it is desirable to start the motor slowly, even though lightly loaded. Extreme care should be taken not to set the relays below the value to which the motor current will always fall. A safe leeway is advisable, or else the starting resistance or the compensator is in danger of becoming damaged.

Another type of governing device is the shunt field relay (Fig. 6). This is employed on direct current equipments for use with adjustable speed motors, where it is desired to automatically accelerate the motor to a predetermined speed above normal. Adjustable

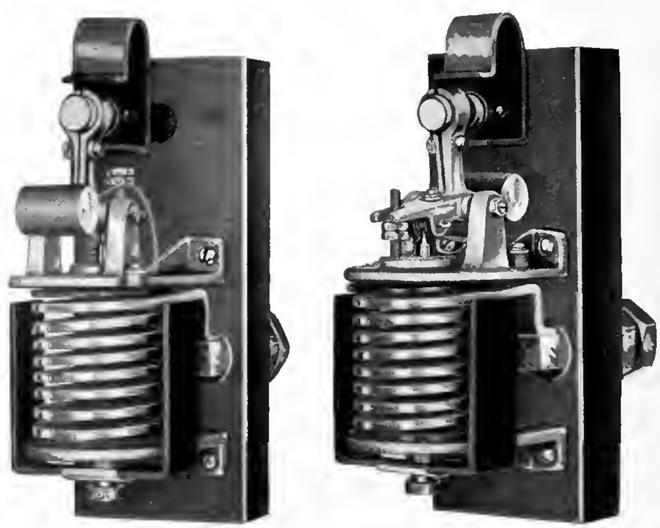

Fig. 6. Shunt Field Relays for Use with Adjustable Speed Motors

speed motors should not be accelerated with weakened field; and to prevent this the contacts of the relay are connected across the field rheostat, which is set for the desired ultimate speed. The relay is provided with a coil in series with the main motor circuit, and the core is so adjusted that the relay contacts maintain full field on the motor until the current has permanently dropped to a value at which it is safe to weaken the shunt field. In operation the relay tends to drop before its final fall, but the resulting rush of current closes it each time until the motor has come to a speed at which the final jump can be made without excess current. A knurl-headed screw provides for adjustment. Turning the screw to the right decreases the gap in the magnetic circuit and decreases the current value at which the relay will close.

The devices described in the foregoing are common to a large majority of the many types of automatic control equipments. Certain special equipments employ special devices; but those are outside the scope of the present article.

NOTES ON THE DESIGN OF CONTACTORS

By H. E. White

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It is the purpose of this article to call attention to some details in the design of direct current and alternating current contactors, to show generally the nature of the conditions which the designer has to meet, and the influence of these requirements on the various parts of standard contactors. Along these lines, a discussion is made of the function and design of the several parts, including general type (open or solenoid), switch contacts (carbon or copper), the blowout, the arc-chute, the pulling mechanism, the structure of the magnetic circuit, and so on.—Editor.

The most vital part of a magnetic switch, or contactor, is the solenoid whose function it is to furnish the power for operating the switch contacts. Not only must this part of the contactor be designed for economy in operating current, but the characteristics of the solenoid should be so modified as to give a pull suitable for this particular work. Solenoids which are suitable for other purposes may not be suitable for magnetic switches, as will be shown later. In designing this part of the apparatus knowledge must be had in advance of the variations in the voltage of the supply circuit, and, in the case of alternating current apparatus, of variations in the frequency also. On industrial circuits where the motors are of such capacities as to require magnetic control, it is usually found that the lowest voltage will be about 75 per cent. of the normal or nominal voltage, and that at times the voltage is liable to exceed the normal by about 15 per cent. Noting that the pull of an electromagnet varies as the square of the voltage, it will be seen that the effective pull at the low voltage falls to less than half what it is at the maximum. The difficulty of designing magnets for a greater voltage variation will be evident. The heating varies in a similar manner. Here the temptation is strong to use some device to reduce the current in the operating coil or after closure. Such devices if used for heavy and frequent duty will be found to be dangerous, in that it is necessary to open the current-reducing contacts at the very last part of closure of the switch. This requires that the mechanism used for the purpose shall have a nicety of adjustment which is not likely to continue long when the equipment is subjected to service. The various parts which go to make up a direct current contactor are shown in Fig. 1, while Fig. 2 illustrates the method of removing the solenoid or operating coil.

The designer in choosing between various electro-magnets will be confronted with two general types: the one in which the movable armature is in the interior of the magnet coil, the other in which there is no movable element in the interior of the coil. The first type will be found to be the more efficient, while the second will be found, when properly designed, a little less efficient but cheaper to build and much more accessible for replacement of parts. These conditions are generally true only of magnets for switching devices. If the magnets are required for lifting heavy weights through a considerable distance the first type is the better. The reason for this is that in magnetic switches the pull required increases greatly as the closure of the switch progresses. In the case of other applications, as for instance, solenoid brakes, a constant pull is better suited to the requirements.

Of equally great importance is the type of switch contacts used for closing and opening the main current. In the past it was usually considered necessary that the initial and final contact should be made on carbon contacts. Magnetic switches built on this principle have given excellent results, and have usually been provided with laminated copper brushes to carry the current after complete closure. In view of the liability to breakage of the carbon contacts, to their rather rapid wear, and also to the serious limitations of brush contacts, there has been a tendency to use solid copper contacts for making and breaking the main current, and for carrying the current after the switch is closed; and if some simple conditions are observed it is surprising how well such copper contacts will operate. Generally the switch will be required to open and close frequently, in which case durability rather than low contact resistance is required. This last consideration demands that the contacts should be liberally provided with copper, and that the magnets and springs should be such that the contacts may be worn to a considerable depth before they need to be replaced by new ones. Magnetic switches with copper contacts have operated, making and breaking their rated current at full voltage, over 500,000 times without any renewals or readjustments of any parts.

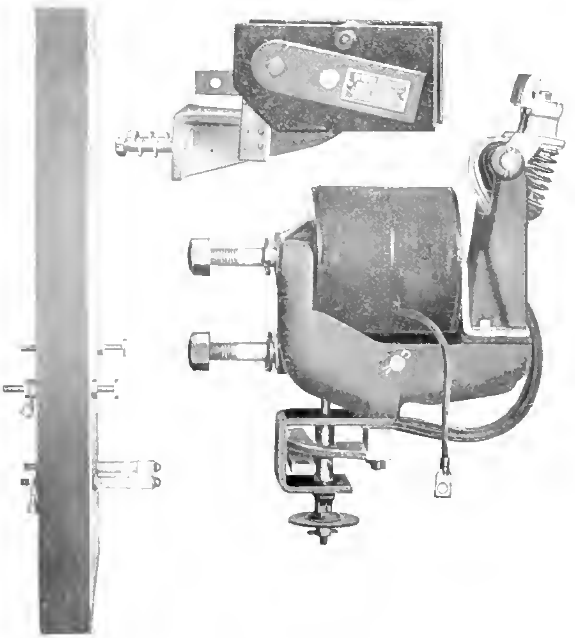

Fig. 1. Parts of Direct Current Contactor

A magnetic blow-out is essential to the satisfactory operation of a magnetic switch unless the capacity is very small. It is sometimes thought that the presence of a magnetic field at the point where the arc is broken is all that is necessary to ensure success. Such, however, is far from the truth. While it is impossible to give a clear idea of all the points that may be taken advantage of in this connection, one of the most important is the shape of the contacts which carry the current. It is well known that, when an arc is drawn between parallel conductors, the arc tends to travel away from the source of current. Since the parts of the conductors which lie nearest to the arc are the most effective in producing this result, the shaping of the contacts can be made such as to assist the magnetic blow-out, or even to direct the arc away from parts specially liable to injury by heat. Failure to take advantage of this will necessitate the use of a stronger magnetic field, or may even result in the arc being unduly prolonged; in which case the action

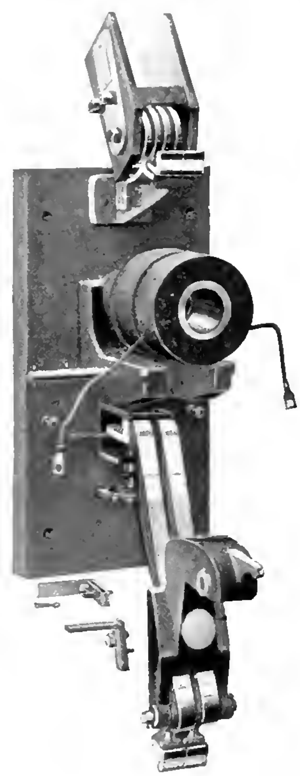

Fig. 2. Method of Removing Operating Coil of Contactor

can be recognized by its producing a tearing sound instead of a single sharp report.

A further detail of construction which assists the action of the blow-out is the shape of the arc chute, that is, of the insulating material surrounding the contacts. This may be made such that the expansion of the air caused by the heat of the arc will assist the expulsion of the arc. This means in general that the arc chute has to lie close to the hottest parts of the arc. It is therefore necessary that the material used shall be of a very refractory nature. At no point has there been a more noticeable improvement in control apparatus than in insulations for use in this and other similar places. A full account of the work done in this connection would be very interesting; but in this place it can only be said that materials practically as refractory as soapstone are available, which can be made to size in almost any form economically and accurately. Fig. 3 shows a direct current contactor, in which the arc chute can be clearly seen.

In the past many solenoid switches made use of toggle joints for increasing the pulling power of the magnet. For the most part these were used with alternating current switches. While at times it has seemed necessary to resort to this means, it should nevertheless be noted that in such apparatus the effect of a little wear in the bearings will result in a very large difference in the closure of the contacts. This is specially undesirable where toggles would seem to be most desirable, i.e., on switches of high capacity using laminated brushes. If this construction is used, means for shimming up the contacts and a very liberal bearing area on the toggle pins are necessary. In cases where toggles are used with magnets operated on alternating current, another undesirable result is liable to be introduced, which has its origin in a peculiarity of the alternating current magnet; viz., that there is no means inherent in the device for regulating the first inrush of current, as in the case of a shunt-wound direct current magnet. In order to understand this more fully it should be noted that in the case of the direct current magnet not only is the rise of current in the winding limited by the self-induction of the magnet, but there is also a reaction in the winding during the closure of the switches in the form of a counter e.m.f. directed against the external e.m.f., so that a distinct self-regulating effect is obtained, the magnet pulling less while in motion than if held at rest at any point; with the result that the switch closes with a slow motion which produces a minimum of shock on the operating parts. In the case of magnets suitable for operation on alternating current this effect

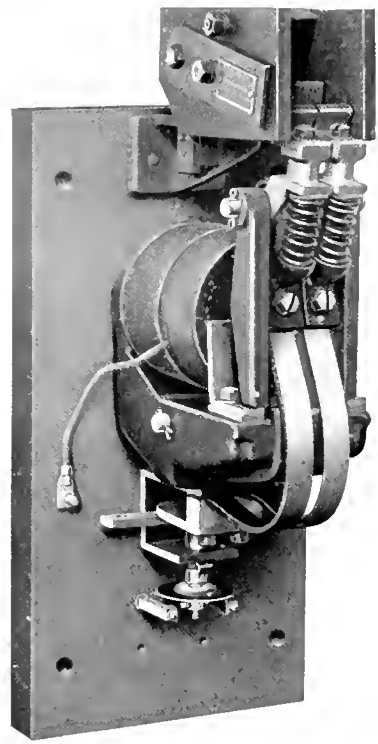

Fig. 3. Direct Current Contactor

is almost entirely lacking, unless the closure can be made so rapidly as to take place well within one half-cycle of current. It will therefore be seen that the moving parts, in the case of the closing of the direct current magnets, have practically no surplus momentum when operating over quite a wide range of voltage; while in the case of the alternating current magnet there is always, except at the minimum voltage at which the device will operate, a considerable amount of momentum of the moving parts which must be absorbed as mechanical shock. If a toggle-joint is used this momentum will be very great, since it will offer very little resistance at the instant preceding the closure of the magnet. In practically all cases where alternating current magnets have been fitted with toggles the continual hammering and wear have gradually carried the toggle farther and farther, until it passes the center, when the device will no longer open on de-energizing the magnets.

The writer has found, in comparing the advantages of "solenoid" *versus* "open-type" of electro-magnet for alternating current, that the latter, with no moving iron in the coil, more closely approximates in its pull-characteristics the requirements for closing switches; so that with the range in voltage liable to occur under service conditions there will be a smaller surplus of energy to be spent in the form of mechanical shock. With the armature hitting dead-flat on the pole faces of the magnet, the wear will be a minimum and the effect of the wear will be to maintain a good fit. This point can be appreciated from a study of the alternating current contactor shown in Fig. 4.

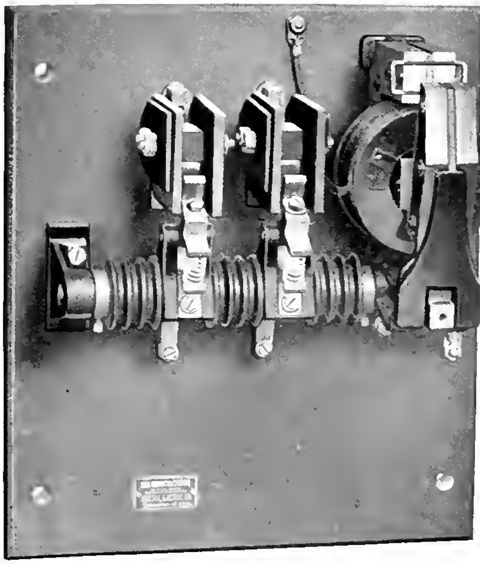

Fig. 4. Double Pole Alternating Current Contactor

The alternating current magnet possesses the peculiarity of automatically reducing its current during closure. This is due to the fact that the impedance of the coil changes during closure. It can be shown that the pull is a function of the rate of change of the impedance. It would be impossible to produce a simple electro-magnet which would have the same impedance after closure as before. This reduction, while very great, is not, however, sufficient to make the alternating current magnet as economical of power as a direct current magnet, for the reason that the hysteresis and eddy current losses are bound to be high in the former type.

In operating at different frequencies it will be found that the apparent power taken by the alternating current magnetic switches increases almost directly as the frequency. There are no compensating factors as there are in the operation of motors and transformers. A certain magnetic density is necessary in the magnets, and this can be obtained with increasing frequencies only by raising the voltage in the same ratio. The current will of course remain the same, as the ampere-turns need to be kept constant. Generally speaking it is easier to make a 25-cycle alternating current magnet than a 60-cycle magnet; while at lower frequencies the problem becomes even simpler.

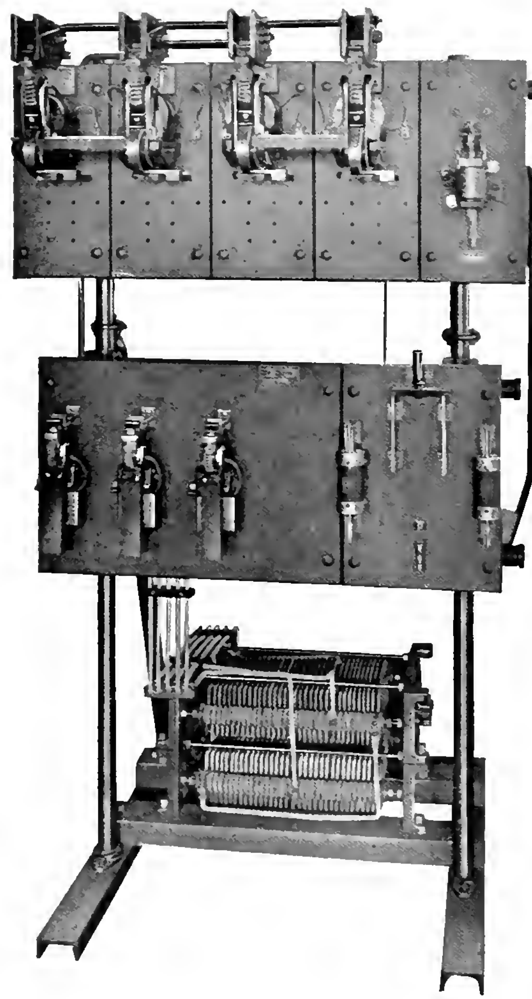

Fig. 5. Four Point Reversible Contactor Panel Using Series Contactors

With regard to the material to be used in the magnetic circuit of alternating current magnets, it has been found that for very small magnets cast-iron may be used in those parts where the density is not very great. For larger magnets it becomes necessary to use a laminated structure of sheet iron. In the case of magnets used on 60-cycle circuits it is also advisable to use special transformer iron with high specific resistance and low hysteresis losses. It will be found, however, that the latter kind of iron does not permit of running at so high a saturation. Leakage impedance is one of the serious problems in the design of the alternating current magnet. It has an effect here similar to that in induction motors. The leakage impedance will be a minimum on the solenoid type of magnet, but for reasons given above it is desirable to sacrifice efficiency for other advantages.

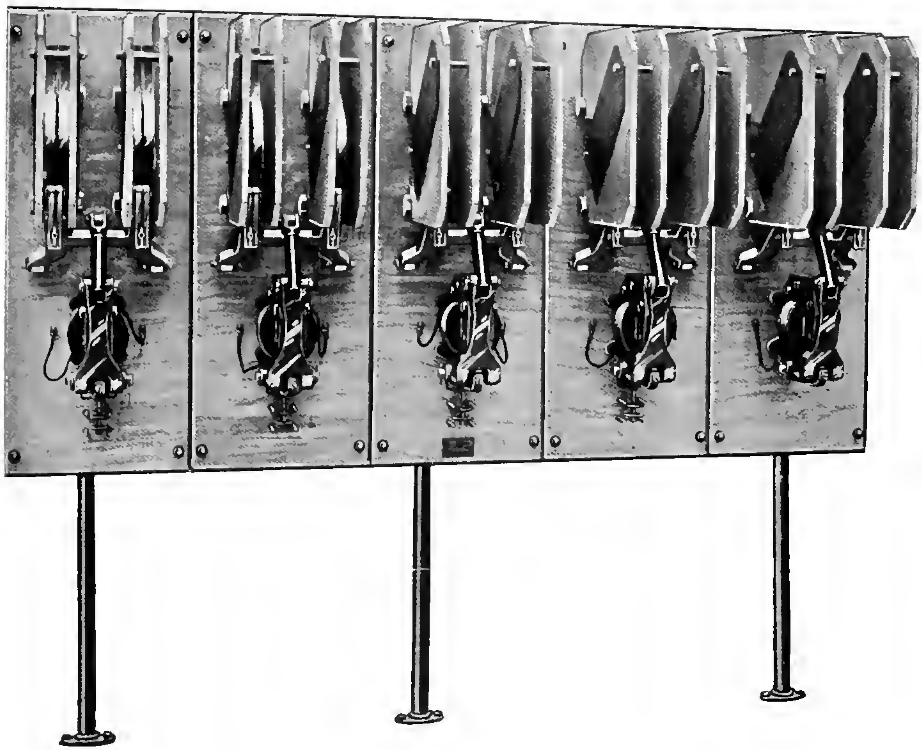

Fig. 6. Contactor Panel for 2300 Volt Induction Motors

THE CONTROL OF ELECTRIC MOTORS ON SHIPS

By C. L. Perry

Industrial Control Engineering Department, General Electric Company

Electrical apparatus on warships has to meet requirements far more stringent than those which usually obtain on land in industrial service, and this applies particularly to controlling apparatus. The following article describes some of the equipment used in U. S. naval vessels for controlling motors operating ammunition hoists, rammers, gun-turrets, boat-cranes, forced-draft blowers, and steering-gear. The paper necessarily contains much interesting matter on the operation of these various machines; while among the illustrations are included several views of modern U. S. warships which are equipped with various electrical power apparatus.—Editor.

The use of electric motors on shipboard in the United States, if we neglect certain equipments which were in the nature of experiments, began with the equipment of some eight-inch ammunition hoists on the battleships *Indiana*, *Massachusetts*, and *Oregon* about the year 1894. Since that time the use of electric equipments on naval vessels has steadily increased, until today they have almost supplanted steam for every purpose except engine-room auxiliaries and actual propulsion, and even the latter is being seriously considered. The number of installations on merchant vessels flying our flag has been insignificant compared with the number in the Navy, and in this article only the latter will be considered in detail.

Fig. 1. U. S. S. "Florida"

As a result of naval influence nearly all marine control equipments are of special character embodying features rarely called for in industrial practice, and in point of safety distinctly in advance of the latter. The two most important general requirements for continuously-running motors are, first, no-voltage protection for all sizes of motors; and, second, the requirement that unless starting rheostats are designed with practically continuous capacity, the control equipment must be such as to render it impossible to leave the motor running with resistance in circuit with it. Water-tight and flame-proof covers are also required in many places.

In order to meet the no-voltage and resistance requirements it has frequently been found better to use separate overload circuit-breaker panels with contactors mounted on them for no-voltage protection, connected with drum controllers having special contacts for the operation of the latter. The latest of these controllers have hinged handles which have a slight vertical movement as well as the usual rotary movement. The vertical movement operates a contact which closes the energizing circuit of the contactor, the main contacts of the latter being in circuit with the motor. In case the handle is released before the running point of the controller is reached, or in case of no-voltage, the contactor opens and cannot be closed until the handle is returned to either the "off" or first position.

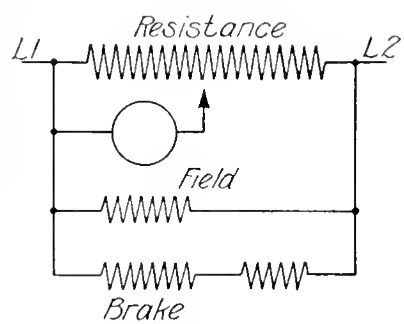

Fig. 2. Connection Diagram for Ammunition Hoist Motor

Aside from these general special requirements the many unique uses of motors, such as training and loading the guns, forced draft blowers, steering gears, etc., require special features. Some of these will now be considered in greater detail.

Turret and Ordnance Control Equipments

To understand the functions of the control apparatus for ordnance equipments an idea of the construction of a turret is necessary. The guns are controlled in a horizontal plane in pairs by the rotation of the turret, though their range may be separately adjusted by the elevating motors. In some of the turrets recently designed, the ammunition is first hoisted from the lower handling room in the magazine to an intermediate compartment; and there slid from the ammunition car of the lower hoist to the car of the upper hoist, which is then raised to the breech of the gun. This arrangement has been adopted on account of the danger of burning powder bags or other materials falling down into the magazine when a through passage-way exists; although this danger is sometimes avoided by having doors in the passage-way which close automatically. The turrets of U. S. S. *Florida* can be clearly seen in Fig. 1.

Three different methods of control have been used successfully for ammunition hoists, each being a step in the development of this class of apparatus. The first was a dial-type controller arranged for dynamic braking in lowering; and the second was a plain drum controller for a shunt motor arranged so as to give power as well as dynamic braking in lowering the car. In the system illustrated in Fig. 2, during lowering, a resistance—part of which is used during hoisting—is connected across the line, and the motor armature is then connected across sections of this resistance so as to gradually increase the potential across it. Such equipments are in use on a great many of the older vessels, which were furnished with a single hoist from the lower handling room to the gun. Their chief limitations were that the amount of current which could be handled greatly limited the speed of operation; and that it was difficult to locate a large drum controller beneath the gun-room deck, and still be able readily to operate it.

In the U. S. S. *Michigan*, *Florida*, and *Utah*, systems of automatic control with master controllers, magnetic switches and limit switches were developed. Figs. 3, 4 and 5 show the master controller, contactor box, and limit switch for ammunition hoist motor. The limit switches are so designed that the carriage is slowed down and stopped without any attention on the part of the operator. This is necessary on account of the extremely

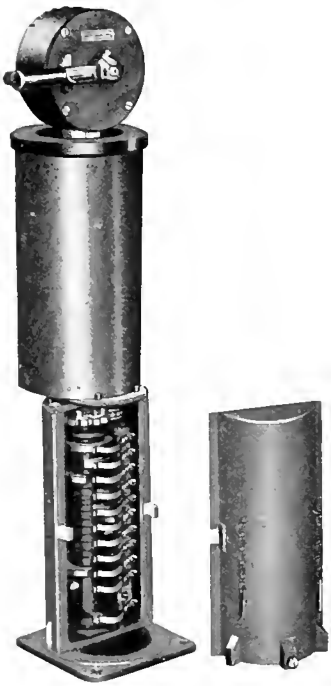

Fig. 3. Master Controller for Ammunition Hoist Motor

rapid operation required, the trip from the lower to the upper handling room usually taking from five to eight seconds according to the height of the turret, and the trip to the gun taking about seven seconds, the latter depending slightly on the elevation of the gun. On these ships it was considered desirable to retain current on the motor as long as the car was up, and compel it to follow the motions of the breech, which introduced several additional complications. On some of the latest ships automatic electric control has been abandoned in favor of clutches driven by electric motors, the change being made for sake of simplicity. This method also overcomes, to a considerable extent, the trouble sometimes experienced with the slacking of hoist cables caused by motor armatures not stopping quickly enough; as the latter, on account of their high momentum, are difficult to stop accurately in a short space of time.

The next apparatus to consider is the rammer. This may be either of the telescope or the chain type. The former, as the name indicates, consists of a series of concentric tubes which are extended by means of an arrangement of chains and pulleys.

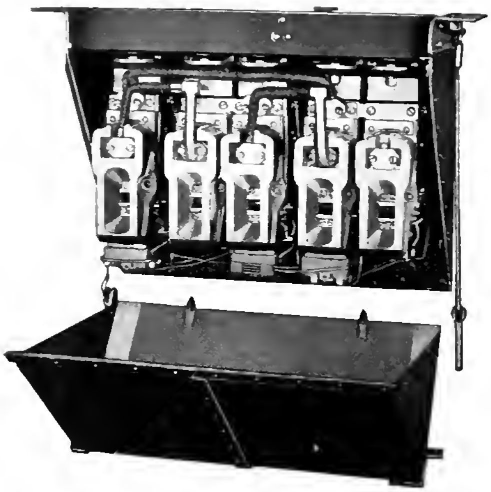

Fig. 4. Contactor Box for Ammunition Hoist Motor

The chain type consists chiefly of a large block chain, the links of which have square corners on one side so that they can bend in only one direction. Both types are usually driven by a compound wound motor, and except in a few recent ships no attempt at automatic control has been made, the operator being relied upon to check the speed as desired. Fig. 6 is an exploded view of a drum-type controller for rammer motor. In some special cases, however, automatic rammers have been used with very satisfactory results. In these a limit switch controlled through the agency of differential gearing jointly by the controller and the motor was used. The length of the rammer stroke could then be controlled by the position of the controller handle—a desirable feature when it is appreciated that the length of the stroke, for the shell, may be double that for the powder bags. Having loaded the gun the next step is to screw in the breech block, which in some cases is also done by a small motor.

During all these operations the men in charge of sighting the guns are busy. The electric range-finder has given the distance and the turret has been turned to the proper angle. The latter operation is an exceedingly delicate one, and a great many systems have been proposed for getting the necessary results. The first used on the older ships was a voltage control system, a separate generator or motor-generator set being employed for each turret. In its simplest form a single motor drove the turret throughout its entire range of speed, and was controlled by varying the field of its generator. The regulation was not entirely satisfactory, however, and this was superseded by what is known as the rotary compensator system. In this, two armatures having independent fields are mounted on one shaft and connected in series; and two motors, one of much larger capacity than the other, are connected across the terminals of the armatures of the rotary compensator. The speed of each motor is then regulated by varying the field of its counterpart in the compensator. These fields are connected in series across the feeders, their common middle connection being attached to the arm of a field rheostat, the resistance of which is also across the feeders.

With this arrangement, and the use of electric clutches for the small motor, the full speed range of both motors can be made use of; and it has the great advantage over the use of a single motor in that the slow speeds are far more stable and are accompanied by better torque. Nevertheless it does not give quite ideal results, as it has

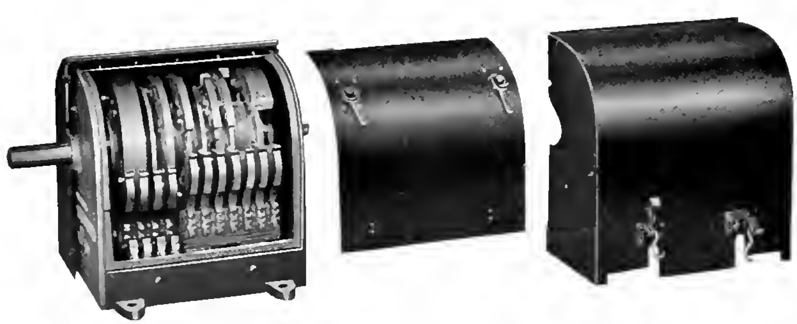

Fig. 5. Limit Switch for Ammunition Hoist Motor

been found impossible to obtain with it a straight line speed curve; for the reason that the speed changes of the large motor are too small at some points and too large at others. Another system in use consists of two motors driving a differential gear, the speed of the turret being obtained by varying the field strength of the two motors. This system has given good results; but the difficulty of electric control, due to the self-induction of the field magnets and the inertia of the armatures, has led to the preference for hydraulic speed gears, driven by constant speed motors.

The elevation of the guns is a simpler matter and is accomplished by a motor and hydraulic speed gear. The relative capacities of motors used in the turrets are of interest and are shown in the following table for the U. S. S. *Florida*.

Upper ammunition hoist	60	h.p.
Lower " "	25	h.p.
Rammer motor	7	h.p.
Elevating motor	15	h.p.
Breech-block motor	3.5	h.p.
Turret-turning motors for hydraulic gear	25	h.p.

Boat Crane Controllers

Boat crane controllers, since they must of necessity be exposed to the weather, are made water-tight. Each contains as a rule two cylinders, one for hoisting and one for swinging the boat over the side. They also contain magnetic blow-out circuit-breakers, which can be set by handles extending through the covers and tripped by push-rods passing through stuffing glands. The hoisting cylinders usually operate by rheostatic control, the load being held by a spring-operated magnetic disc brake when the controller is at the "off" position, or in case of failure of voltage; and an excessive speed in lowering is prevented by an automatic mechanical brake. In the latest types the lowering control is electrical rather than mechanical, and makes use of a principle similar to that in ammunition hoists. The cylinder for the rotating motor is generally arranged like the older ammunition hoists. Hoisting motors for boat cranes are usually of 50 h.p. capacity; while the rotating motors are usually about 30 h.p. to 40 h.p.

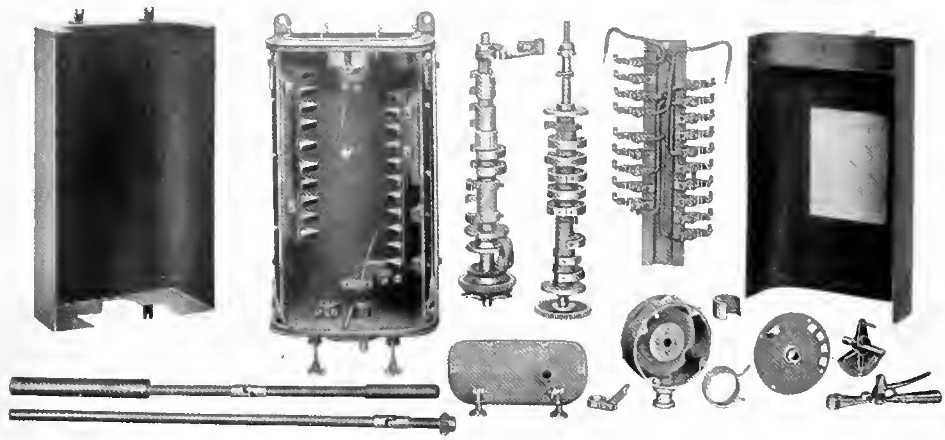

Fig. 6. Rammer Motor Controller

Forced Draft Blowers

The control of forced draft blowers would require no consideration here if only one blower were used for each boiler room, and the space for the motor and equipment were less limited than they are on shipboard. These two conditions, however, add certain elements of risk which must be taken care of by special means.

It is characteristic of two properly-designed blowers, of like capacity, acting together that they will divide the load equally; but that if either stops, the load on the other will at once increase. We must also remember that the blower motor speeds must be varied according to steaming conditions, and to do this economically the field strength of the motors are varied. If now, while two blowers are running at full speed, one of them is stopped, the other immediately becomes overloaded; but its load can be reduced by simply strengthening the

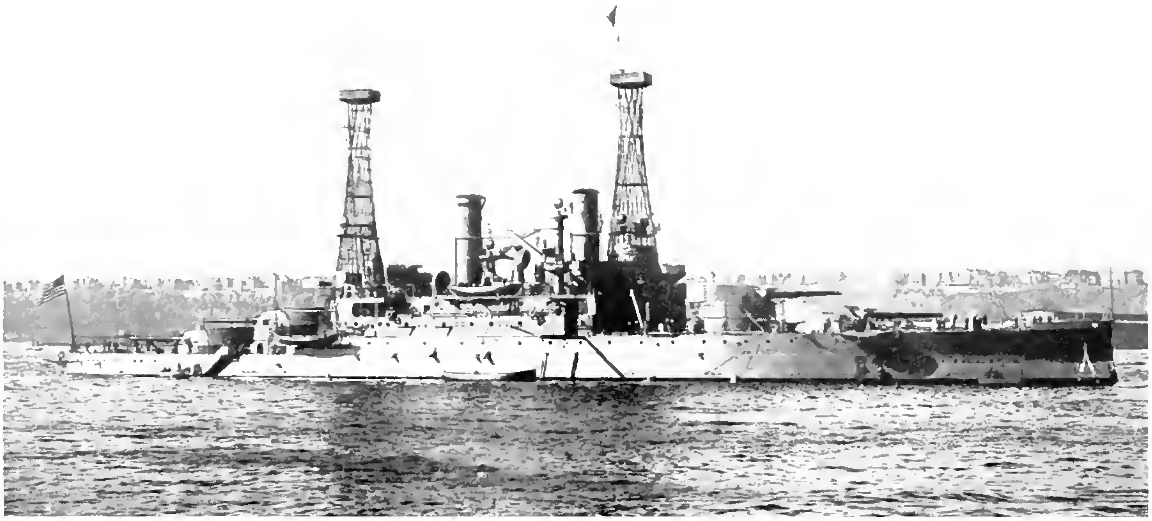

Fig. 7. U. S. S. "Michigan"

field of its motor. This is done by the use of an overload relay which short-circuits the field resistance. Controllers for forced draft blowers sometimes have a further complication on account of the necessity of operating them from more than one point. Under these circumstances, if it is also required that the special handle and contact, spoken of above, be employed, the circuits become quite complicated.

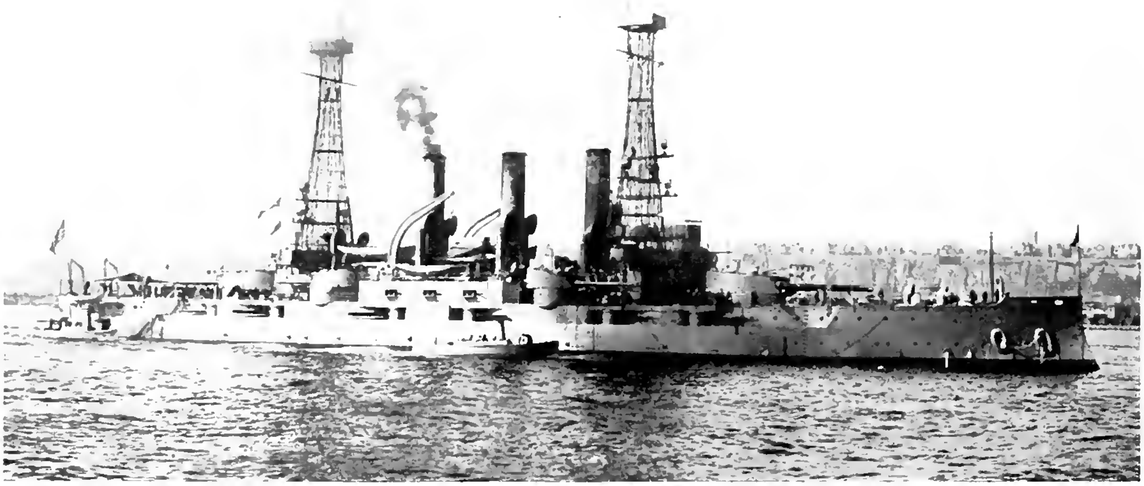

Fig. 8. U. S. S. "Connecticut"

Steering Gear Control

Electric control of steering gear has been studied almost from the beginning of the use of electricity on shipboard, but the necessity for absolute reliability combined with extremely severe service has, until recently, prevented its use except in a few experimental installations. The improvement in the reliability of control apparatus has of late, however, brought this matter again into prominence, and several recent ships are now being equipped with electric steering gears. In general, most systems include some form of follow-up device; i.e., a device so designed that as the rudder turns it will cut power off the motor which turns it. This feature in an analogous form has been almost universally applied to steam gears; and since the latter also will be installed as alternative means of steering on the ships which are to have electric gear, it is natural to insist that the same method shall be employed for control by either system. This can be accomplished by a wire rope transmission or by means of a device known as a telemotor. This consists of two cylinders containing pistons, and connected together by piping on both sides of the pistons. If one piston is moved the other will be forced to move also, and can be used to operate either a steam valve or a master controller. This arrangement eliminates all wiring between the steering stand and the electrical apparatus.

In other systems a pilot motor control is used between the steering-stand and the main

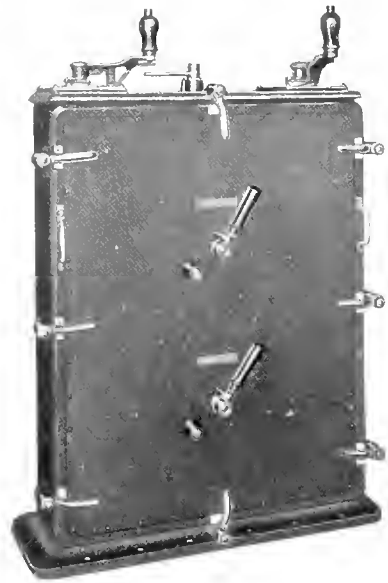

Fig. 9. Boat Crane Motor Controller

controller; while in others a Wheatstone bridge arrangement is employed for controlling the exciter of the special generator which fur-

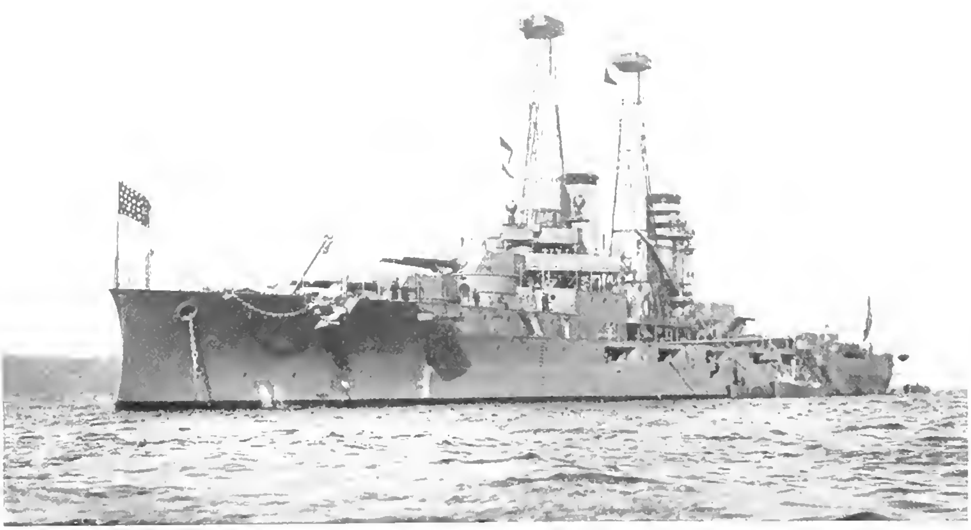

Fig. 10. U. S. S. "North Dakota"

nishes power to the rudder motor. In still others no follow-up device is used, depending on an indicator to show the position of the rudder. Aside from these features of remote control it is interesting to consider the

Fig. 11. Controller for Turret-turning Motor

mechanical characteristics of this problem. We must appreciate in the first place, that, to maintain even an approximately straight course, the rudder must be shifted constantly, seldom remaining in a fixed position for more than a few seconds. This necessitates constantly reversing the operating motor, which means the severest kind of service for the controlling apparatus. Another difficulty is the extremely variable load, which may change from a very small value to 100 per cent. overload an instant later. Fortunately the reversal of torque can be controlled to some extent by operating the rudder through the agency of a large screw having right and left threads at opposite ends, these threads carrying nuts to which links are attached which act on a cross-head on the rudder. The pitch of the threads is small enough to prevent the rudder from driving the screw, and consequently there will be but a very slight tendency to drive the motor even with the screw turning rapidly. Even with this arrangement a shunt around the motor armature can be employed to good advantage in order to stop the rudder quickly, when the pressure of the water and the momentum of the motor are tending to drive it.

Steering gears for large ships require as high as 300 h.p. for short periods; and since 120 volts is used on all American ships the current is very large and requires the use of magnetic switches. In the Argentine Navy 220 volts has been adopted, which has considerably lightened the equipments on the two ships now being furnished with electric gear.

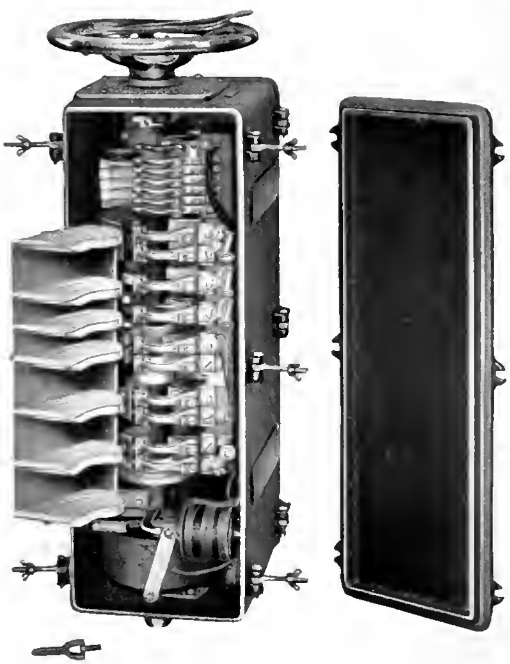

Fig. 12. Forced Draft Motor Controller

The future of electric control for marine service seems to have only the solution of the problems of propulsion to consider; and the day is probably not far distant when even this will be accomplished.

AUTOMATIC CONTROL APPARATUS FOR ELECTRIC FIRE-PUMP SERVICE

By G. T. Eagar

Industrial Control Engineering Department, General Electric Company

This article describes a new automatic control equipment, alternating or direct current, for controlling electric motors installed with fire-service centrifugal pumps, the latter being piped up to a tank on the roof of the building, to a high-pressure tank, or to a sprinkler-head system.—Editor.

The frequency with which the magnetic control switches, used in various industrial services, must necessarily operate, throughout the working day and year after year, has been cited as showing the degree of reliability which is imperatively required in the production of such apparatus. Although, from the point of view of wear-and-tear, this indeed presents the designer with a serious problem, it should be borne in mind that, given a good design, workmanship and materials, such constant repetition of the demand on the ability of the control apparatus in itself tends to keep the mechanism in smooth working order.

In some classes of service the reverse condition obtains. The apparatus may be left idle for long periods at a time, without inspection, and without attendance or adjustment; and yet when the demand appears, without a moment's warning the need may be one of the greatest urgency, and the possibility of failure too serious to contemplate. Electrically operated pumps for fire protection constitute a case in point. The excellence of the electric drive in pump service—whether reciprocating or centrifugal—has long been recognized, and its value for fire service is especially marked. Up-keep costs are reduced to a comparatively negligible value; while, upon the out-break of fire, the full water pressure becomes almost instantly available by the throwing of a switch.

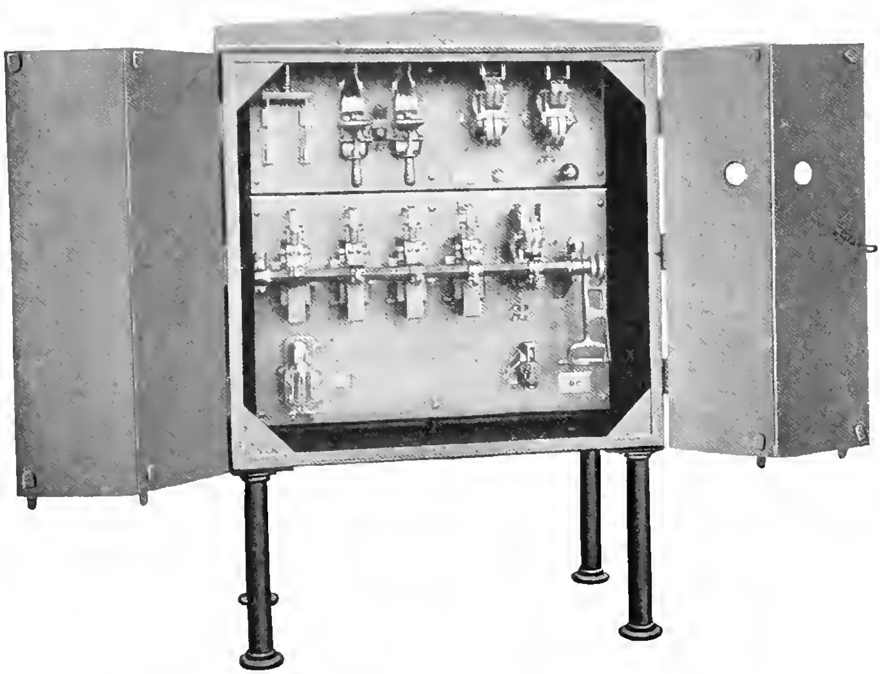

Fig. 1. Automatic Control Panel for 100 H.P. 220 Volt Shunt Wound Fire Pump Motor

The control equipment for this service must be capable of standing severe overloads, such as may be caused by stiffness of the bearings of the pump or motor through long dis-use; the apparatus itself must be rust-proof; while in its construction the use of all inflammable material must be eliminated, in order that it may operate successfully in excessively high temperatures. It is the

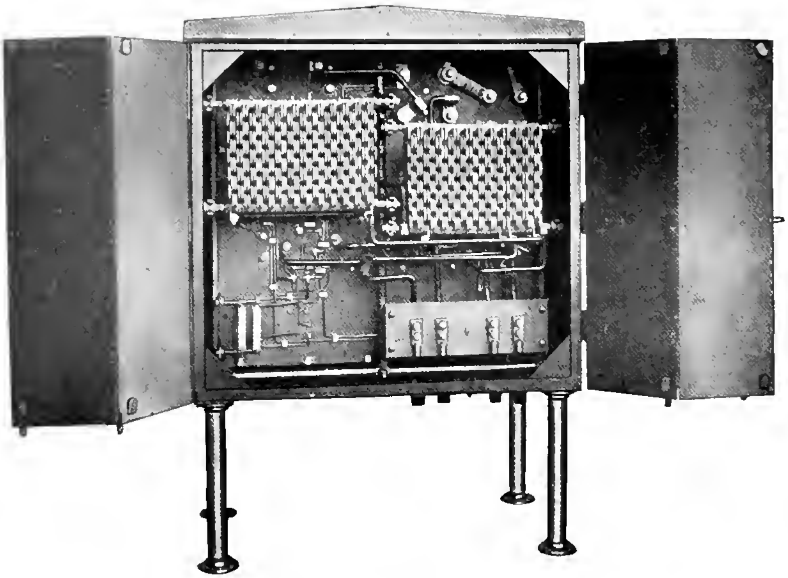

Fig. 2. Showing Connections of Fire Pump Panel in Fig. 1

All operating parts have bronze or brass bearings and pins, and there are no operating parts of iron-to-iron such as might rust and prevent operation. Hand control is obtained by a cam shaft, with cams arranged so that on raising the hand-lever the series contactors are closed in the proper sequence, cutting out the starting resistance. A separate shunt contactor is energized by the movement of the hand-lever, so that the hand operation is independent of the pressure governor. The hand-lever is returned to the "off" position by means of a spring, and cannot be left in the mid-position allowing the motor to run on resistance. Unless installed in a separate building a specially designed splash-proof case with proper ventilation is

present practice to make the control equipment for this service automatic in operation, by connecting a pressure governor to the stand-pipes; while provision for hand control in emergency cases is also provided. In many cases it is the custom to connect the pumps to a tank on the roof of the building or to a high-pressure tank located elsewhere, while in the others the method is adopted of piping the pumps up direct to the sprinkler-head system. An idea of the severity of the service may be gleaned when it is stated that, with the latter arrangement, an out-break of fire may result in the breaking of sprinkler heads in such a number that the equipment may be called upon to operate as frequently as two to three times a minute for several hours.

Fig. 1 shows a fire-pump panel for a 100 h.p. 220-volt shunt motor recently installed in Kansas City provided with line switch, circuit-breaker with high overload capacity, self-starter of the series contactor type, pressure governor, a small contactor and push-button switch for cutting in a section of field resistance to give an increase in speed, pilot lights (one to show when voltage is on panel, and one to show when all the starting resistance is cut out) and a lever for hand control. The starting resistance of the iron grid type is mounted in suitable insulated supports back of the panel, and the connections are run to a connection-board near the bottom of the panel, as seen in Fig. 2.

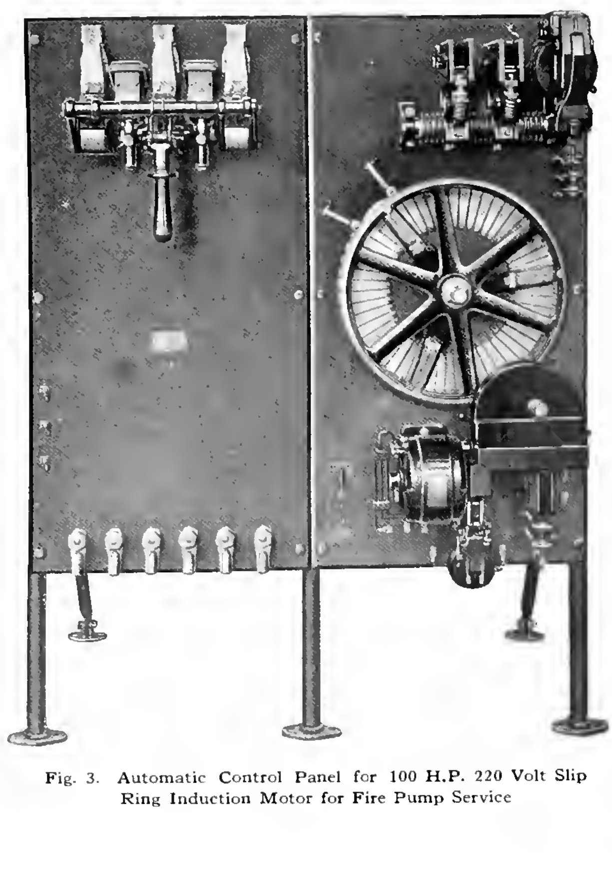

Fig. 3. Automatic Control Panel for 100 H.P. 220 Volt Slip Ring Induction Motor for Fire Pump Service

recommended. The case shown has doors both at the back and front with glass "bullseyes" so that the pilot lights may be seen.

Where alternating current is the source of power, the slip ring type of induction motor is the one generally adopted. Control panels for such motors necessarily differ in design, but the individual parts are of similar construction to those used in the direct current equipment. Time limit control is obtained by the use of a motor-operated dial to cut the resistance out of the secondary circuit. In case of failure of voltage or on shutting down the pump, the arm automatically returns to the "off" position ready for starting. A small single-pole knife switch is provided for hand control, this switch short-circuiting the pressure governor. Fig. 3 shows a special panel installed by the Delaware & Hudson Company at their coal-pocket near Schenectady. The panel controls a 100 h.p., 220-volt 60-cycle slip ring induction motor, driving a centrifugal pump. In this instance, the panel is controlled by a separate pressure governor at a remote point.

The use of these panels is not confined to fire pump service alone, as they may be used to advantage in hotels, office buildings, stores, etc., for supplementing the city service and insuring a sufficient water pressure for everyday use. They may also be used in isolated places, such as summer hotels, manufacturing plants, etc., where power is available; or, in fact, anywhere that automatic control of pump motors is required.

CONTROL APPARATUS FOR ELECTRICALLY OPERATED VALVES

By W. M. Watkins

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The article first specifies several classes of service where the use of electric motors for valve operation is almost a necessity; and describes apparatus appropriate for the control of motors for this service.—Editor.

Before describing the apparatus generally employed in controlling valves operated by electric motors, it may be well to indicate briefly the field of the electrically operated valve. It is impossible to mention all cases in which the electric drive could be profitably employed, but there are some applications where its use has now become almost a necessity.

Steam Stations. Here large units are stopped and started several times a day, and are sometimes called into operation upon short notice. An electric motor for working the valves for the large exhaust piping makes possible a considerable saving of time in opening and closing, relieves the attendants from the labor of opening the large valves, and thus increases the efficiency of the operators. In cases of emergency it is sometimes impossible to approach a valve to shut it off; and here the motor-operated valve is good insurance against loss from shut-downs or damage to apparatus by steam and water.

Hydraulic Stations. Where the water pressure available is small and the volume of water to be controlled is large the size of the valve or sluice-gate sometimes becomes enormous. To open or close this by hand would be a wearisome task, and the electric drive is usually resorted to. Where the water is brought into the station in a pipeline from a reservoir above, the installation of an electrically-operated valve at the intake or at an intermediate point with controlling switch at the power station, is a safeguard against damage from a broken pipe. Fig. 1 illustrates a valve built by the Chapman Valve Company for the Ontario Power Company. The height of this valve is 30 ft. 3 in., the weight 130,000 lb., while the diameter of

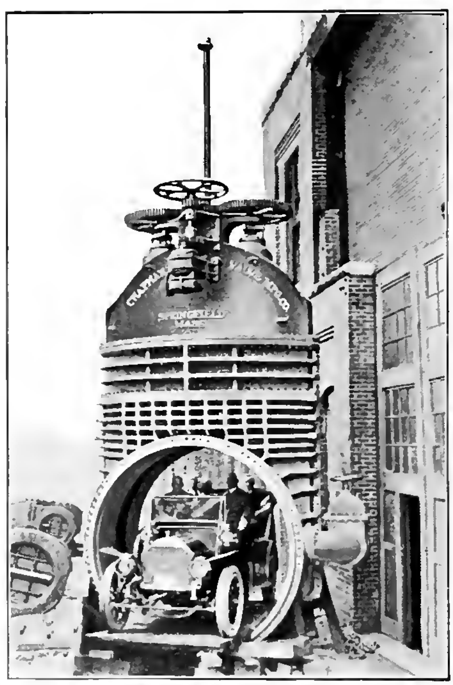


Fig. 1. Motor Operated Valve of the Ontario Power Company

the water-way is 9 ft. The valve controls a hydraulic turbine generating 12,000 h.p., and is operated by a 15 h.p. motor controlled from a distant station.

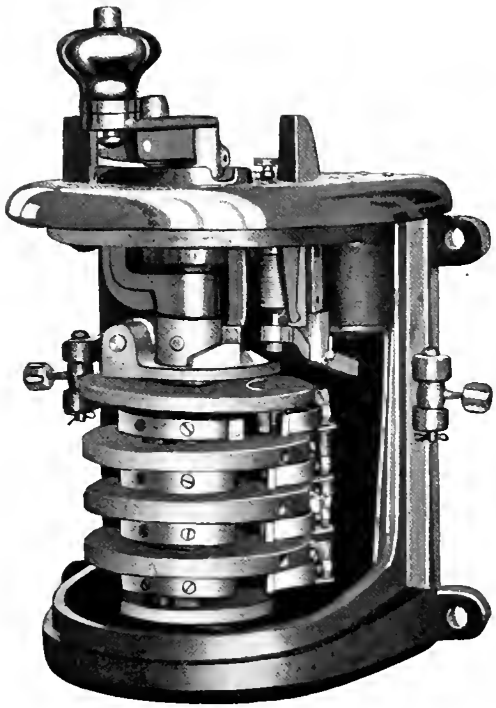


Fig. 2. Drum Controller for Motor Operating Valve

Municipal Water Supply Systems. There have been several instances within the past few years where large water mains have burst, causing great damage to property before the water could be shut off. In many of these cases there was considerable delay before employees of the water department, familiar with the location of the various valves, could reach the spot. A system of electrically operated valves can readily be installed to take care of such emergencies and disconnect the supply from any desired section, the control of all the valves being attended to by one operator at a central point.

Fire Protection Systems. Many cities and towns have outgrown their water supply to such an extent that their fire protection is inadequate in case of a severe fire. In such cases the only remedy seems to be an additional supply from a stand-pipe, or some such source, that can readily be turned on in case of need. An electrically operated valve may be used in such cases and controlled directly from the firemen's headquarters.

Manufacturing Plants. Sometimes it is necessary to locate valves in towers or other inaccessible places. Here the electric valve is a necessity for efficient operation. For fire protection around mills and factories electrically operated valves can, by the use of thermostats, be arranged to open on a rise of temperature.

The controller generally employed in electric valve service is of the drum type. Fig. 2 shows a drum-type controller provided with one running point, forward and reverse, as used with both direct and alternating current motors up to $7\frac{1}{2}$ h.p. No resistance is furnished with this controller, as most valve motors are of special design and may be thrown direct upon the line. The operation is as follows: To close the valve the controller handle is thrown in the position marked "close." The handle is held in this position by means of a latch until released by the operator. When the valve closes it throws a slight overload on the motor and causes an overload coil, situated on the interior of the controller case, to operate and release the controller drum, which is returned to the open-circuit position by means of a centering spring, thus stopping the motor. Stopping the motor by allowing the valve to jam and operate the overload trip is objected to by some manufacturers; and in such cases a limit switch, which makes contact and operates the overload trip, is made use of, which stops the motor as the valve reaches either end of its travel. Fig. 3 shows a type of limit switch often used, which is usually geared to the valve stem.

It is sometimes found desirable or expedient to operate valves from remote stations by means of push-buttons. In this case, a contactor panel is used, and as many push-button stations as desired may be furnished. The cost of running wire to these stations is small, as the only current carried is that necessary for the operation of the contactor solenoids. The push-buttons are usually mounted on a small panel, and consist

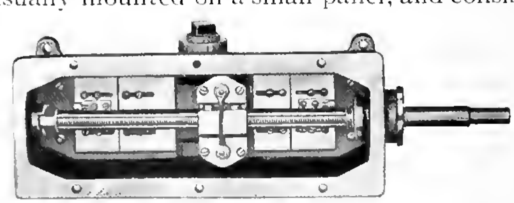


Fig. 3. Limit Switch

of a "stop," "open" and "close" button on the panel. Some form of indicating device may also be used to show when the valve is open, closed or operating.

GENERATOR FIELD RHEOSTAT CONTROL

By C. A. Jaggfr

Industrial Control Engineering Department, General Electric Company

The question of the field control of electric generators does not come strictly within the province of industrial control; but, so far as the manufacturer is concerned, the rheostatic apparatus for such purposes is similar in character to that used in motor applications, and many of the problems are of a similar nature. Field rheostats for generators are thus dealt with in the following single article. After touching briefly on early types, the paper describes some modern plate-type rheostats, tube-types, sprocket-operated, gear-operated, solenoid-operated and motor-operated apparatus, connection diagrams being shown where desirable. Considerable attention is given throughout the article to matters of design, while the concluding paragraphs deal with selecting a rheostat rating for given service.—Editor.

A field rheostat is a device to regulate the amount of current in a field circuit, either the amount of current induced from a separate source of excitation or that within the generating power of the field itself. In order to regulate the field current the rheostat must be a resistance element or combination of resistance elements, which will retard the amount of current in somewhat the same manner as a valve regulates the flow of a liquid. Such a rheostat being connected within an energy circuit must dissipate the energy which it absorbs. This is done in the form of heat; so that one of the first considerations is to deal with the best method of dissipating this heat without injury to the device itself or adjacent surroundings.

The earliest forms of field rheostats were extremely crude and unreliable. The first styles of moderate size to be installed included iron spirals in the form of springs strung between two wooden bases, these in turn being definitely spaced by supporting rods at the corners. On one of these wooden bases were mounted metal contacts arranged in a circle. The switch arm was pivoted in the center, so that by turning it in either direction a contact finger would pass over the contacts. The resistance coils in regular order were connected to the metal contacts at the back of the base, and the main field leads were brought to two terminal studs also attached to the wooden element. It can readily be seen that while ordinary ventilation could be obtained for the resistance to carry off the heat, the possibility of overheating meant that the wooden bases would be destroyed, possibly accompanied by a general conflagration.

Modern field rheostats, while performing similar functions, are constructed according to very different lines and are used with a great variety of generators. There are three points to consider in the general construction; viz., resistance material, insulation and switching mechanism. Considering the first, it is evident that the best results will be obtained from a material which has a low temperature coefficient, thereby having a constant resistance at various temperatures. This material must also be as nearly as possible non-corrosive in order that it shall not be affected by heating and cooling, or by ordinary atmospheric conditions. It is unusual practice for continuous duty apparatus to exceed a temperature rise of 200 deg. C., so that under these conditions properly selected resistance elements should last indefinitely.

In order to minimize the amount of auxiliary apparatus, field rheostats usually depend upon natural draught for ventilation. For large installations the size of the rheostat can be reduced by forced ventilation; but little is saved on the initial investment, and the general work of maintenance is increased. There are also disadvantages to be met with in water-cooled resistances, in that the electrolytic action shortens the life of the resistance elements to a marked degree. It is probably well that in the matter of field rheostats these methods of cooling need not be considered, as the largest field rheostats, while fundamentally controlling tremendous outputs of energy, are not in themselves of abnormal dimensions.

The insulating material in field rheostats must be given careful consideration, as weakness in this respect may easily cause a burn-out of the resistance, resulting in the failure of voltage on the part of the generator at a most critical period. There are a number of moulded insulating compounds of unusual mechanical strength, which are in many instances replacing the use of slate, marble and other natural products. Mica still holds its own in offering the best insulation for the highest temperatures; and in most types of rheostats mica is used for direct insulation between resistance elements and the supporting frame-work. The compounds are used largely for barriers and small bases on which current-carrying parts are mounted. Slate and marble are still retained for larger sections, this being most generally typified in the construction of switchboards.

The construction of dial switches on field rheostats presents a variety of combinations, to meet demands varying from very small currents up to those employed in the excitation of the largest separately-excited alternators. For currents up to 350 amperes, it has been found practical to use in the switch-arms solid sliding plungers, with the surfaces evenly faced and held by springs against the contact segments. Above this current, experience has proved that a laminated brush is more satisfactory, owing to the fact that more uniform contact can be obtained. Conductivity between the contact brushes of the switch-arm and the stationary dial contacts depends directly upon the area of the parts in contact and the pressure. It is evident that abnormal pressure will mean excessive wear, thereby eventually causing reduced contact and frequent renewals. With the proper balance between pressure and contact, we can keep the parts within reasonable dimensions and greatly extend the life of the moving elements, and at the same time keep the heating at a minimum. In the case of small currents, up to say 25 amperes, an ordinary straight finger contact brush, depending on the spring quality of the metal only, may be relied upon to carry the current. This method of contact, of course, is most easily deranged and would hardly be considered for large currents.

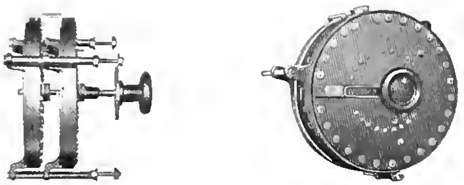


Fig. 1. Plate Rheostat for Switchboard Mounting

Fig. 1 illustrates a simple form of field rheostat adapted for mounting on the front or back of switchboard. It is made in the form of plates, one or more being assembled on common tie-rods and connected in multiple. The resistance units for each plate are small wire-wound open coils, connected in series and imbedded in a fire-proof insulating compound. This form of construction is often used for maximum field currents of 60 amperes. This is possible with the simple finger contact switch-arm, as these switches are duplicated for the several plates, thereby carrying the current in multiple. The plate type rheostat has its limitations, however, in that for a given maximum current the total resistance which can be accommodated is limited by the mechanical dimensions of the plate.

Fig. 2. Sprocket-operated Tube-type Rheostat

This situation is met by constructing rheostats as shown in Fig. 2 In this case the resistance elements are in the form of tubes, having insulating bodies on which resistance wire is wound, and the whole covered with a fire-proof compound. The units are run singly or in multiple and the sets in series, so that almost any condition can be met within practical limits by simply increasing the depth of the rheostat. Owing to the fact that a single dial switch is employed with

Fig. 3. Gear-operated Tube-type Rheostat

tube-type rheostats, the plunger brush contact is used. One or more plungers, depending upon the current, are connected by flexible copper leads and held firmly against the dial contacts by springs. These are adjusted to give the exact required pressure. The plate and tube-type rheostats will take care of all small and medium self-excited and separately excited generators.

Where the maximum field current is much above 50 amperes, most field rheostats employ cast iron grid resistance units, since cast grids can be made of almost any cross section and length desired, and this reduces the number of resistance units to a minimum. As wire-wound units must be restricted to relatively small wires to facilitate manufacture, a large number of units would have to be used in multiple to carry large currents. These would require a multiplicity of connections, with greater opportunity for possible open-circuit. With cast iron grids separate wire connections between units can be eliminated, as the supporting lug of the grid is ground to a true even surface, and the current carried from one grid to the other through this means, pressure being accomplished by the clamping nuts at the ends of the tie-rods.

The steady advance in the size of separately-excited alternators has resulted in field currents as high as 700 amperes. In such instances several cast grid units are run in multiple, but the number of units thus connected is lessened as the field current is

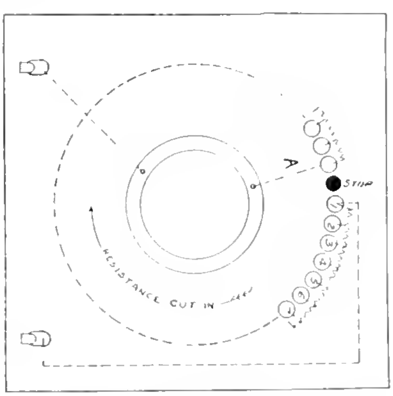


Fig. 4. Connection Diagram for Rheostats Shown in Figs. 2 and 3

cut down. Cast iron, while having a somewhat higher temperature coefficient than some alloys, is eminently suited because of its *relatively* low temperature coefficient, high specific resistance, mechanical strength and cheapness. The current density at which cast iron may be run depends largely on the amount of radiating surface for a given

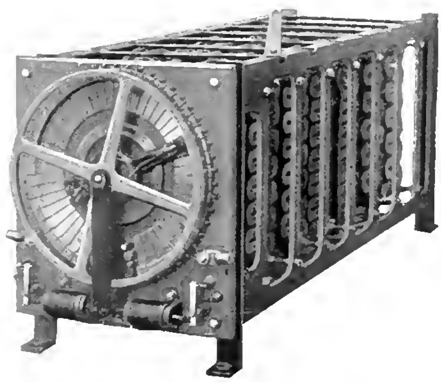


Fig. 5. Solenoid-operated Rheostat

cross-section. This is determined by the form in which the grid is cast. The forms of cast iron grids now in use are run at current densities of approximately 700 amperes per square inch for the heavier units, to approximately double this amount for the lightest grids. It must be remembered that several units grouped together will have somewhat less watt capacity per unit, for a given temperature rise, than a single grid running in the open air.

The largest number of field rheostats installed are manually operated. Of the latter class of rheostats, those which cannot be mounted directly on the panel are usually sprocket-driven as shown in Fig. 2. Some installations for the sake of convenience are made gear-controlled as shown in Fig. 3. Both of these illustrations refer to rheostats with tube-type resistance units. The simplest form of connections for these rheostats is shown in Fig. 4. The wire *A* is included to prevent an open-circuit in the rheostat in case the switch-arm contact should become accidentally impaired. It will be seen that if the circuit is not made through the switch-arm the entire resistance will be placed in circuit. This will mean that a minimum voltage will result in the generator field.

Electrically Controlled Rheostats

Rheostats which are electrically controlled are divided into two classes, those operated by solenoids and those by motors.

A simple form of solenoid-operated rheostat is shown in Fig. 5. Fig. 6 shows the method of operation. The switch arm is carried around by pawls, which engage the knurled rim of a wheel to which the switch arm is rigidly fastened. These pawls are controlled by a core actuated in common by the solenoids *A A*. When the solenoids are de-energized the pawls are disengaged, and in their normal position rest equidistant from the solenoids. To cut resistance into the field it is necessary to close to the left the single-pole switch *B*, Fig. 6. This energizes the left-hand solenoid, engages the left-hand pawl and moves the dial switch in a clockwise direction. When the solenoid core has reached its extreme point of travel, the winding of the solenoid is automatically open-circuited by the small switch *C*, and the pawl is immediately pulled to its neutral position by a spring, automatically closing the circuit of the solenoid switch by the small switch *C*. The same cycle of operation is then repeated until the switch *B* is opened. If it be desired to cut resistance out of the field circuit, the single-pole switch *B* is closed to the right, when the same cycle of operation is performed and the dial switch moves in a counter-clockwise, instead of a clockwise, direction. Each end of the switch dial is provided with a limit switch *D*, which is automatically operated by the switch arm to open the circuit of the solenoid when the resistance is entirely cut in or out. The purpose of this limit switch, *D*, is simply to protect the apparatus, in case the controlling circuit is left closed when the dial switch has reached its extreme point of travel in either direction.

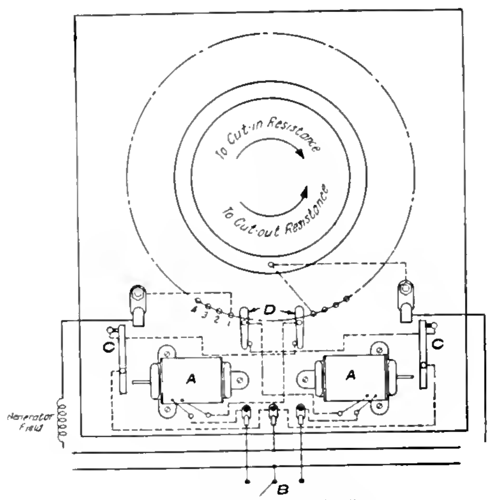


Fig. 6. Connection Diagram for Solenoid-operated Rheostat

Motor-operated rheostats have so far proved the most practical for field currents above 350 amperes, as the heavy contact on the dial switch is not easily overcome with the solenoid or hand-wheel control. The connections of this type of rheostat are shown in Fig. 7. Fig. 8 shows a rheostat for a 14,000 kw., 4600 volt turbo-alternator. The standard switch includes a series wound 115-volt motor, with a field winding which enables the dial switch to be operated in either direction by a single-pole double-throw controlling switch. As in the case of the solenoid-operated switch, each end of the dial switch is provided with a limit switch, which is operated by the switch-arm to open the motor circuit when the extreme range of travel has been reached.

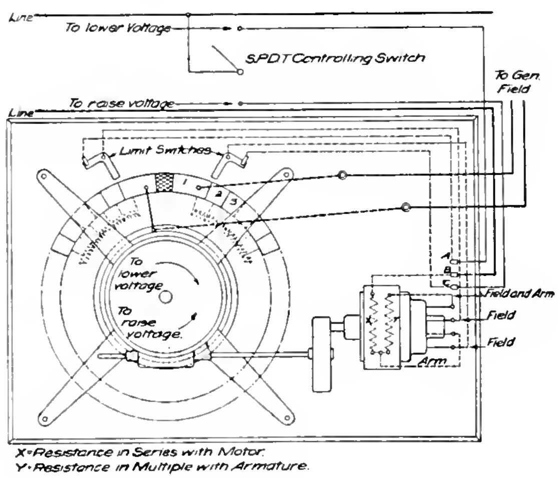


Fig. 7. Connection Diagram for Motor-operated Rheostat

The Selection of a Rheostat

In determining the proper field rheostat for a given service there are several points to be considered. In the first place, it has a maximum current rating limited by the resistance of the field with which it is connected in series. If, for illustration, a generator is separately excited from 125 volts and the resistance of the field is 12½ ohms, the maximum field current would be approximately 10 amperes. If a rheostat of 12½ ohms were connected in series with the field, the current would then be 5 amperes and the armature voltage lowered accordingly. Therefore a rheostat for this service would be tapered from first to last step from 10 to 5 amperes, and would maintain practically the same watts per step throughout. If this same rheostat were used with a generator separately excited from 250 volts and having a field resistance of 25 ohms, the first step of the rheostat would have sufficient capacity; but, after turning in the 12½ ohms, 6.7 amperes would flow instead of 5, which might burn out the rheostat. This shows the care which must be exercised if a rheostat, designed for one voltage, is used on a circuit of higher voltage. If the maximum capacity were satisfactory, and a 250-volt rheostat used on a 125-volt source, the only result would be that the rheostat would have more capacity than necessary after the first step was passed.

In the case of most self-excited direct current generators, a field rheostat having a little more resistance than the field will give sufficient regulation, but generally a reduction to 50 per cent. of the normal voltage is desired.

Fig. 8. Motor-operated Field Rheostat for 14,000 Kw. Turbo-alternator

This is advantageous, if for no other reason than to reduce the inductive kick to a minimum when the field circuit is opened by the field switch. It is always best if possible to have access to the actual no-load saturation curve of the generator. Fig. 9 shows a curve plotted against armature volts for a 23-kw. 125-volt self-excited generator. If it

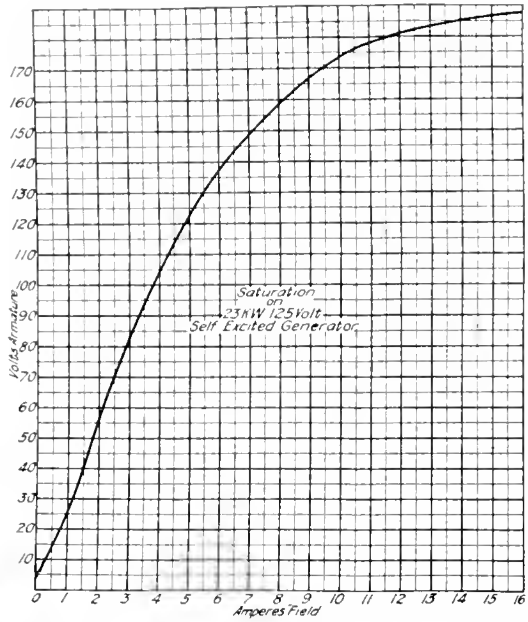


Fig. 9

is desired to reduce to 62½ volts, it will be simply necessary to follow down the curve and note the point of intersection, and then drop straight down to the amperes field at

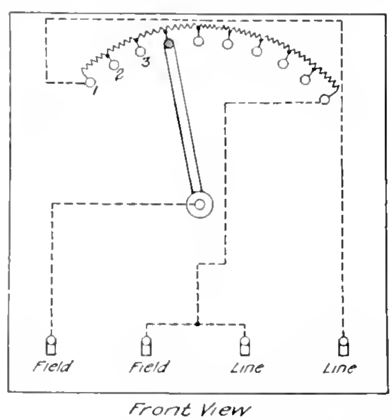


Fig. 10. Connections of Series Shunt Rheostat for Direct Current Generator

this point. By dividing this figure into 62½ volts and subtracting the field resistance, it will usually be found that the result will give sufficient resistance to reduce to half voltage. No two machines will show absolutely the same curves, and different lines of generators may show still different results. In other words, generators of the same kilowatt and voltage output will have different field characteristics. Generator speed, compounding, etc., must be considered as affecting the successful use of the rheostat selected.

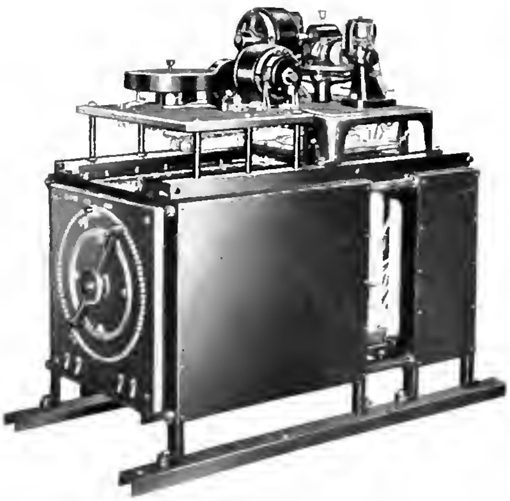


Fig. 11. Automatic Field Rheostat for Split Pole Synchronous Converter

In the case of some separately-excited direct current generators, such as boosters, it is often found desirable to have a range in armature voltage from zero to maximum. This is accomplished by a field rheostat having series-shunt connections as shown in Fig. 10. Rheostats are also used in multiple with the series field of boosters in order to act as adjustable shunts when delivering energy to feeder circuits. They are also used in synchronous converter fields to compensate for varying power-factor loads.

Field rheostats for separately-excited alternators will often give sufficient regulation in line voltage if the rheostat has a resistance equal to that of the generator field. It is, however, standard practice to include somewhat more resistance, owing to the fact that the machine may be operated through a considerable range of power-factor load.

A very interesting field rheostat application has been made in connection with a split pole synchronous converter. This machine is designed to give automatically constant current with widely varying load. There are three field windings on the machine known as the main, compensating and regulating circuits. The main and compensating fields each require a regular field rheostat. The compensating and regulating fields are connected in multiple, and in series with a special automatic field rheostat. This rheostat is shown in Fig. 11, the connections being seen in Fig. 12. This particular apparatus was furnished for a 500 kw. 245/260 volt converter. The mechanism of the rheostat consists briefly of a 3-phase motor, running continuously and operating through a worm and gearing. Two clutch coils, one connected through either contact of a contact-making ammeter, are employed. The dial switch of the rheostat, by means of a bevel gear mechanism, is operated in a clockwise or counter-clockwise direction, depending on which clutch coil is energized. The connections are such that when the switch dial is half cut in, the two auxiliary fields are short-circuited. Turning the switch-arm in one direction increases the current and boosts the main field, while turning the switch in the opposite direction changes the polarity and bucks the main field. In addition to the automatic features, there is a mechanism driven by a direct current motor, which enables the operator at the switchboard to also change the position of the dial switch, by means of a double-pole double-throw controlling switch. The device is fool-proof, being

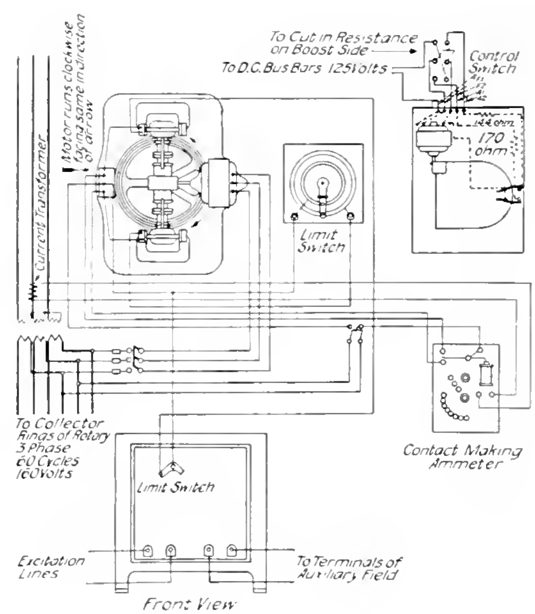


Fig. 12. Connection Diagram for Rheostat Shown in Fig. 11

mechanically and electrically interlocked; so that if the direct current motor should be run in either direction while the automatic features are in operation, no harm would result.

The continual development in functions of direct and alternating current generators is constantly widening the scope of field control, and there is no telling what problems will be forthcoming for future consideration.

LIQUID RHEOSTAT FOR MINE HOISTS

By G. H. Dorgeloh

Industrial Control Engineering Department, General Electric Company

This article describes a recently developed liquid rheostat for slip ring induction motors to be used primarily for mine hoists. The object in view was to produce a controlling device of very substantial and simple design, to eliminate all sliding contacts and magnetically-operated switches, to dispense with cast grid resistances in the secondary of the induction motor, and to assure a perfectly smooth acceleration, which is of the utmost importance in taking up the rope slack.—Editor.

The liquid rheostat described in the following paragraphs is of the rectangular tank construction, of heavy boiler plate. The two halves of the tank are bolted together to allow for transportation through restricted mine shafts, wherever it is desired to install the rheostat in one of the lower levels. The appearance of the rheostat is illustrated in Figs. 1 and 2, while Fig. 3 shows the internal construction. The tank with its auxiliary apparatus is mounted on a channel iron base, making a self-contained unit. The lower part is the electrolyte reservoir, and contains the cooling tubes; while the upper part constitutes the electrode chamber and contains the stationary plates, which are connected to busbars and thence to the slip-rings of the motor. The method of varying the resistance is by adjusting the depth of immersion of the plates. The electrolyte, consisting of a weak solution of water and sodium carbonate, has a high thermal capacity; and the capacity per unit volume is therefore a maximum. The plates are made of iron, as this material in connection with the solution previously mentioned, is not subject to abnormal corrosion and practically eliminates any objectionable polarizing effect. This is of great importance at low frequencies near the minimum slips. The liquid is lifted from the storage tank to the electrode chamber by means of a centrifugal pump designed for low head and large volume, direct-connected to a squirrel cage induction motor; while the liquid returns from the upper chamber to the storage tank by gravity. The pump set is kept running continuously during working shifts.

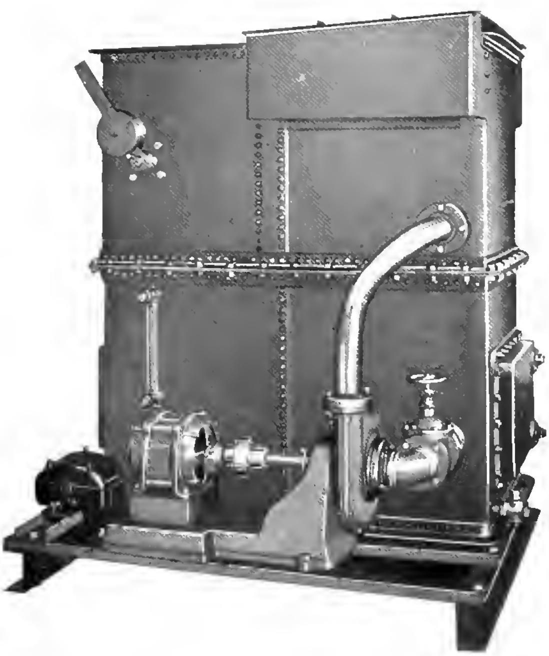
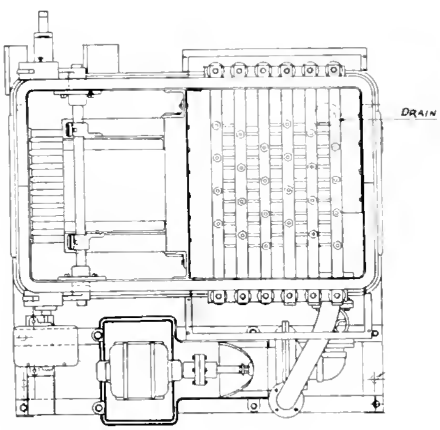


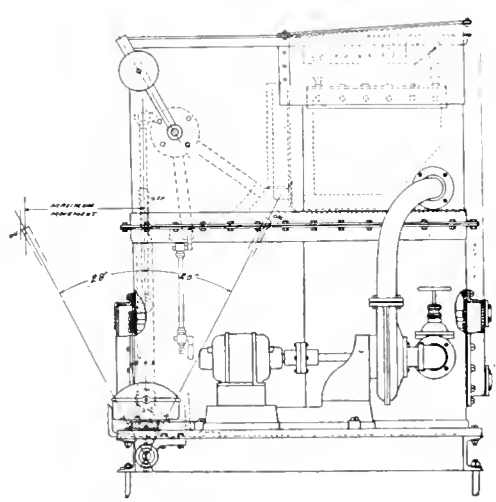
Fig. 1. Liquid Rheostat for Mine Hoist Induction Motor

In order to secure a smooth resistance change, it is necessary to prevent splashing. This is obtained by means of a pipe with proper length-wise opening and baffle-plate. The range of resistance between maximum and minimum for a given design is obtained by shaping the blades, the maximum practical range being shown in Fig. 4. It must be borne in mind that the plates should never leave the liquid, but that the immersion should always be such as to insure sufficient contact area to prevent local heating, the safe limit being about 7.5 amperes per square inch. The plates are easily removed by loosening two nuts and lifting them through the opening of the diaphragm against which the weir fits. The arrangement of this diaphragm is shown in Fig. 3. The extent of the opening at the diaphragm allows of very quick emptying of the electrolyte chamber, which is essential for quick reversal. Before the hoists are put into service it is customary to give them very severe tests, one of which is to let the hoist work unbalanced and lower a fully-loaded skip at full speed down the shaft. The control lever is then thrown over to the extreme position for raising the load, resulting in the slowing down of the motor and reversal without change of the control lever.

A noteworthy feature is the entire absence of stuffing-boxes for all bearings, the latter having been placed out of reach of the liquid. This reduces friction to a minimum and insures ease of operation. The weir is perfectly counterbalanced, the adjustable balancing weights being clearly shown in the illustrations.

Fig. 2. Liquid Rheostat for Mine Hoist Induction Motor





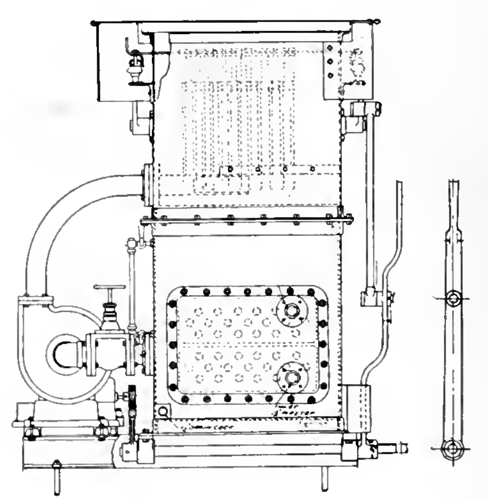


Fig. 3. Internal Construction of Liquid Rheostat

The system of operating levers is shown in Fig. 2. It will be noted that in the "off" position the main lever is vertical, with the weir in the extreme low position, a centering device in the form of a roller being provided to secure a positive "off" position. Movement of the arm in either direction from the neutral will raise the weir and close the upper chamber, allowing the liquid to be raised and thus gradually cutting out the resistance in the rotor circuit. Stops are provided to limit the travel of the operating lever. For remote operations a connecting link can be attached to the main operating arm or to the extended shaft, which is provided with a keyway for this purpose. During normal hoist cycles the lever is thrown over quickly and the liquid raised gradually, depending on the delivery of the pump. The time of acceleration can be regulated by means of the gate-valve at the suction end of the pump. In this way the acceleration is entirely automatic and independent of the operator. The acceleration curve shown in Fig. 5 is based on the adjustable sill being in the lowest position; with the sill in the highest position the acceleration can be reduced to eight seconds.

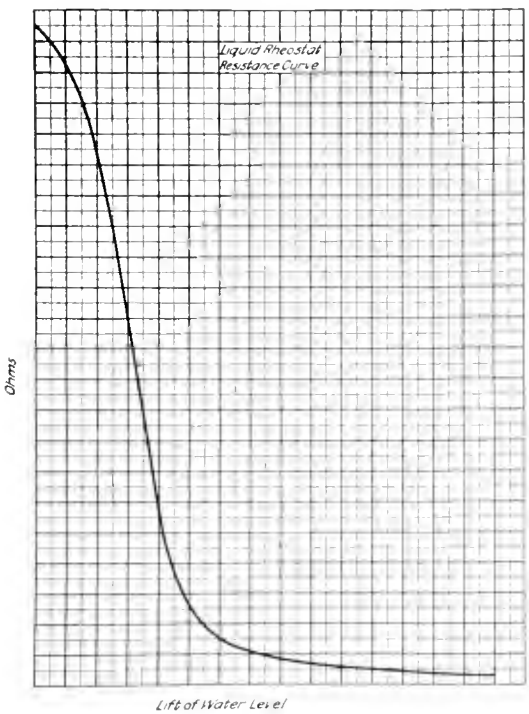


Fig. 4. Liquid Rheostat Resistance Curve

The object of the sill is to secure the necessary high resistance at creeping speeds and light loads for inspection trips, with the sill in its lowest position. In order to preserve the gradual cutting out of this high resistance during normal hoist cycles, the sill is moved to the top position, thus decreasing the maximum resistance and allowing the motor to get away immediately.

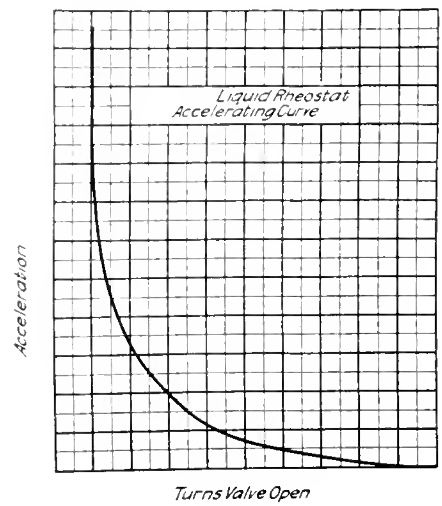


Fig. 5. Liquid Rheostat Accelerating Curve

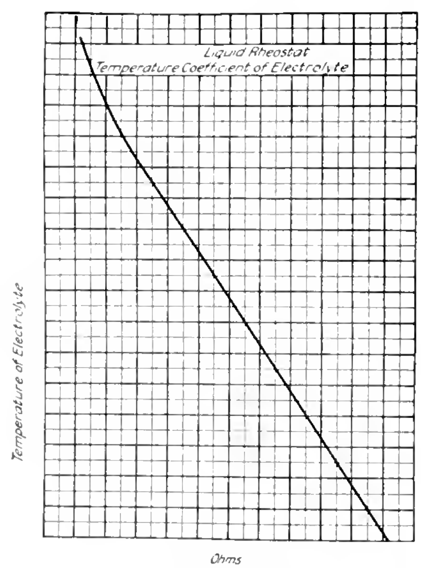


Fig. 6. Temperature Coefficient of Electrolyte in Liquid Rheostat

The main fulcrum shaft of the operating lever is extended across the rheostat, and a toothed sector fastened to the other end. This sector engages with a pinion on the shaft of the master drum-controller, insuring a positive drive for the latter. The "off" position of the master controller corresponds to the "off" position of the main lever. Movement of this lever in either direction will close the corresponding primary contactors, causing the motor to run in the proper direction. The contact rings of the master controller are so arranged that the primary contactors are energized at approximately 6 degrees movement of the main lever from the neutral. The hoist motor is thus completely controlled by one lever. The cooling tubes are arranged horizontally and go straight through the tank lengthwise; they are screwed in at one end, and at the other are provided with glands for ease of renewal if corroded. The tubes are usually made of iron, but, in cases where the only cooling substance obtainable is very acid mine water, they may be made of brass. Inlet and outlet connections for the cooling water supply are made at the pipe flanges, clearly shown at one of the water heads. A water-gauge is provided for indicating the height of the electrolyte in the storage tank.

The liquid has a rather high negative temperature coefficient. It is recommended that the temperature of the electrolyte should not exceed 60 deg. C.; and as a fair average it may be said that about ten gallons of cooling water per minute are required for every 100 h.p. dissipated continuously in the rheostat.

A DESCRIPTION OF A MODERN INSTALLATION OF THEATER LIGHTING AND METHODS OF CONTROL

By E. P. Bassett

Cincinnati Office, General Electric Company

In many of the modern spectacular plays the necessary scenic effects can only be produced by having the quantity, color, etc. of the stage lighting under close control. The manufacture of special apparatus for this purpose is of comparatively recent growth, but now represents a considerable industry. This article describes some of the special rheostat-dimmers used in modern theaters; and emphasizes the possibilities in this field by giving a complete description of the control equipment installed at the new Hartman theater at Columbus, Ohio.—Editor.

When one looks back at the old system of gas lighting in theaters, the many advantages obtained by the use of electricity are instantly seen. By no other system of lighting can the effects required for the modern elaborate theatrical productions be obtained. About the only point in favor of gas was that the amount of light could be easily regulated simply by opening or closing a valve. The fire risk of course was the worst feature, and the inflexibility would have rendered impossible the many effects now obtained. Instead of having all the lights on but one or two circuits, nowadays theaters are wired and equipped so that the auditorium and stage lights are divided between numerous circuits. With this arrangement the lights on any one circuit can, independently of all the others, be easily and quickly turned on or off, or the amount of light controlled from full illumination to the minimum amount desired.

The success of many productions depends to a large extent upon suitable stage lighting. In order to increase the scenic effects or to save current, it is very desirable oftentimes to reduce or dim the lights below their normal candle-power. For this purpose resistance is used; and the rheostats designed particularly for theater use are called "dimmers." By inserting the resistance of the dimmer in series with the lights on any circuit, those lights can be turned up or down simply by movement of the handle of the dimmer on that circuit. By providing a suitable number of resistance steps on the dimmer, the lights can be brought from full light to full dim without flickering, and as quickly or as slowly as desired; or, by leaving the dimmer lever on any intermediate point, the lights can be kept at any degree of brilliancy for an indefinite period.

Formerly the number of circuits was few and the number of lights on each dimmer was correspondingly large. For that reason the earlier types of theater dimmers were of large size and capacity, the maximum capacity of a dimmer being usually 150 16-candle-power lamps. Owing to the wider variety of effects and the greater flexibility desired, dimmers of smaller capacity were required; so that by now the size of the individual dimmer has been reduced, and 50 lamps, of 16 candle-power each, represent the maximum rating of a single dimmer plate. Where the number of lights on any one circuit exceeds that number, the required number of dimmer plates are connected in multiple, but with only one operating handle. By means of an interlocking mechanism and master levers, the various dimmers can be controlled so that any number may be operated in unison. It is customary to group the dimmers for the different colors together, and to have a separate master lever to control all white lights on the stage, another for all red lights, another for all blue lights, etc., and sometimes another for all of the auditorium lights. A grand master-lever or wheel can also be provided, so that every dimmer, or as many as are desired, may be controlled at the same time.

The latest type of interlocking theater dimmer is shown in Fig. 1. The cut shows a bank of seven interlocking dimmers each of 50 light (16 candle-power) capacity or less. By means of the master lever shown at the left any of the individual dimmers may be operated in unison. This style of mounting is suitable for installation just above the switchboard or just below it, so that the handles are within easy reach of the electrician. Each individual plate is about 16 inches in

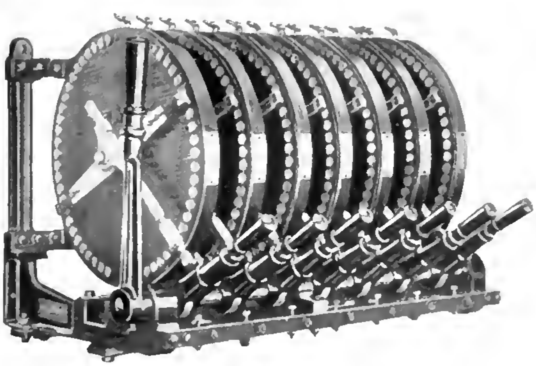


Fig. 1. Interlocking Theater Stage Lighting Dimmer

diameter, with a large number of contact buttons to which the resistance element is connected. The element is imbedded in the insulating base and is so proportioned as to give a very even gradation in lighting effect as the resistance is cut in or out of circuit. Each dimmer can be removed without disturbing adjacent plates, as shown in Fig. 2. When the width of a single row of plates becomes too great for the available space, the

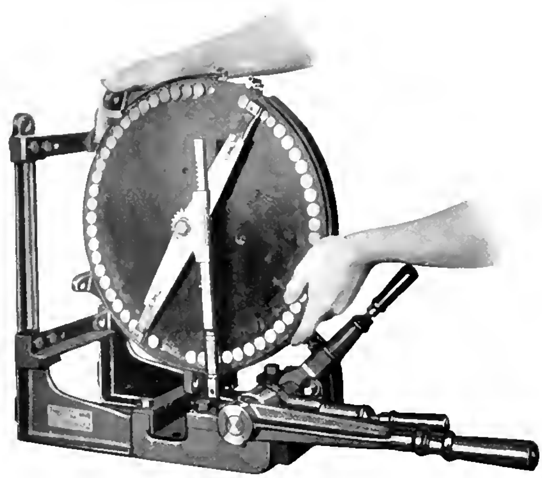


Fig. 2. Showing Method of Removing Dimmer from Bank of Plates

plates may be mounted in either vertical or horizontal additional rows. By extension of the rack rods, the plates can be operated from a distance, mounting the dimmers above the switchboard, against the back wall or below the floor. The operating handles and master levers are then mounted directly on the switchboard as shown in Fig. 3.

The recently-completed Hartman Theater, in Columbus, Ohio, is considered one of the best-equipped theaters in the country. In fact, as high an authority on theatrical matters as Mr. A. L. Erlanger stated that there was not a better-equipped theater in the world. The theater building is adjacent to, and—as far as the main entrance is concerned—is incorporated as a part of the ten-story Hartman office building, which overlooks the State House and the new Federal Building. It was originally intended to build both the theater and office building for $250,000; but as the work on the theater progressed, the equipment and decorations were elaborated upon, and the final cost of the theater alone was $200,000.

To the greatest extent possible, the interior is built of steel and concrete. The arrangement of the auditorium is very similar to the New Amsterdam Theater, New York City;

and the rich coronation-red tapestry of the seats is practically a duplicate of that used in the New Theater (later the Century Theater), New York City. A partial view of the auditorium is given in Fig. 4. The total seating capacity of about 1750 is nearly evenly divided between the orchestra, balcony and gallery, and every seat gives a clear and uninterrupted view of the entire stage. The most careful pains were taken to provide the stage with every device which could be required for the most elaborate productions. The Hartman Theater has the only actual sectional stage in the country, and the sections, of varying sizes, can be easily raised or lowered when necessary. Each section is supported by joisting hung in steel stirrups, which are themselves supported by steel girders. The joistings are further supported by wooden pillars which rest on jack-screws placed upon steel plates. The steel fire-proof curtain is one of the few steel curtains in the country. Its cost is about twenty times that of the ordinary asbestos curtain, and weighs 7600 pounds. It is raised and lowered by a 7½ h.p. electric motor with push button control equipment.

Fig. 3. Operating Handles and Master Levers for Switchboard, with Extended Rack Rods for Remote Control of Theater Dimmers

The stage switchboard is shown in Fig. 5. Mounted over the top of the board is the bank of dimmers controlling the various stage circuits; while at the right (not shown in Fig. 5) is mounted a separate dimmer for controlling all the auditorium lights. The stage lighting dimmer circuits are thirty-four in number, requiring forty-two plates. These are mounted in two vertical rows; but all of the individual dimmer handles are mounted on a single line of interlocking shafts at the lower part of the framework, bringing the handles within easy reach of the electrician. The interlocking shafts are four in number, and each section has its own master lever. Beginning at the left of the bank, the master lever at the extreme end controls all the white lights, except the pockets, which are divided among eight dimmers for the following circuits:

Fig. 4 Auditorium of Hartman Theater, Columbus, Ohio

White strips	96	lights
Five white borders (each)	96	"
White vertical borders	48	"
White footlights	144	"

Next comes the large grand master lever referred to later; and then the master lever for all the red lights, divided among seven dimmers, for the following circuits:

Five red borders (each)	48	lights
Red vertical borders	24	"
Red footlights	48	"

Then follows the master lever for all the blue lights, divided among seven dimmers for the following circuits:

Five blue borders (each)	48	lights
Blue vertical borders	24	"
Blue footlights	48	"

The master lever for the section at the right controls the twelve dimmers for the pockets, each dimmer being of 50-light capacity. The large grand master lever at the center of the bank has a separate shaft, shown above the shafts controlled by the four master levers above mentioned. The master levers, except the one for the pockets, may be interlocked with the grand master lever so that any or all of the twenty-two dimmers may be operated together. The twelve pocket dimmers are separate, and are controlled only by the master lever for that section. To the right of the stage dimmers is mounted the auditorium dimmer controlling the various orchestra, balcony and gallery lights. This dimmer is of 200-light capacity and is arranged for three-wire connections, while all of the stage dimmers are for two-wire balanced circuits. Plate type construction is not used in this instance, but construction similar to large capacity field rheostats is employed. The required number of resistance tubes are connected to contact buttons mounted on a slate base, and the contact lever is controlled by a bevel-geared vertical shaft and handwheel. Besides the foregoing apparatus the stage is furnished with a large number of single and double stage floor-pockets and wall-pockets, spot lights, flood lights, etc.

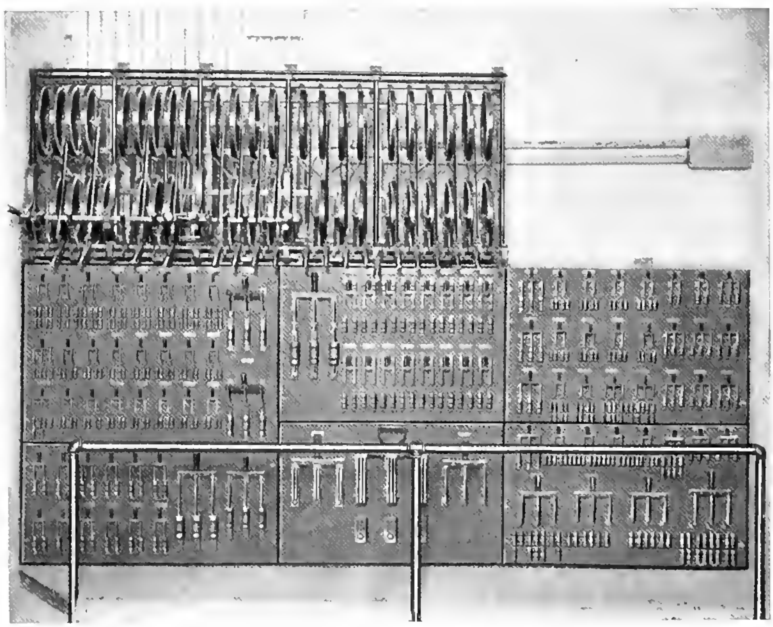


Fig. 5. Switchboard and Banks of Stage-lighting Dimmers at the Hartman Theater, Columbus, Ohio

CONTROL APPARATUS FOR INDUCTION MOTORS

I. HAND AND AUTOMATIC COMPENSATORS FOR SQUIRREL CAGE MOTORS

By Parker Dunning

Industrial Control Engineering Department, General Electric Company

A squirrel cage motor, if thrown direct on the line, may draw from 5 to $7\frac{1}{2}$ times full load current in starting, and an auto-transformer (or compensator) is used almost exclusively for starting this type of motor in order to limit the current. The auto-transformer is provided with several taps any one of which may be used for permanent connection, and a double-throw switch by the operation of which a reduced potential is impressed on the motor to bring it up to speed. With the switch in the starting position, the arrangement is equivalent to a step-down transformer, and the product of potential times current on the line is approximately equal to potential times current on the motor circuit. Compensators for motors up to and including 18 h.p., are usually provided with three taps for starting the motor, viz., at 50, 65 and 80 per cent. of line voltage, with line currents equal to 25, 42 and 65 per cent. of the current that would be taken if thrown on the line direct. Compensators for larger motors are provided with four taps, giving 40, 58, 70 and 85 per cent. of line voltage and taking 16, 34, 50 and 72 per cent. of the current that would be taken if thrown on the line direct.

Fig. 1. Starting Compensator with Overload Relays, Cover and Oil Tank Removed

A decade ago, all that was required in a compensator was an auto-transformer with double-throw switch assembled in a suitable case. In addition to this the industrial engineer of today requires all the protection and fool-proof features that can be included without too much complication. Auto-transformers of the hand-operated type are now usually provided with one coil for each phase to give a balanced condition at starting wherever practical. The unbalanced condition, however, is not a very serious matter, and two coils for three-phase motors are frequently used when the question of cost is to be considered. This is the case with the automatic type, where the additional contacts add considerably to the first cost of the device.

Other requirements have to be met. The arrangement and accessibility of taps is important, and the completed transformer should be practically water-proof. The switch should be equal to the best type of oil-switch, with sliding self-wiping contacts and with spring return attachments to prevent the auto-transformer from being left in the

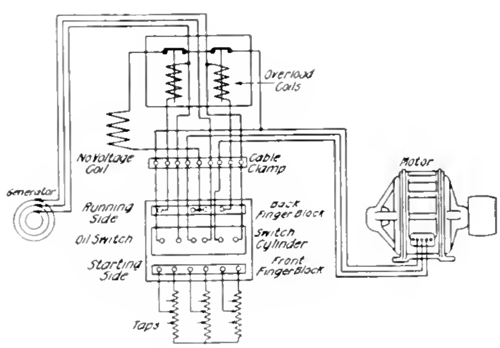


Fig. 2. Wiring Connection for Compensator Shown in Fig. 1

starting position, since it is designed for starting duty only and would burn out if left connected to the line. A means of compelling the operator to go first to the starting position must be furnished so as to prevent the motor being thrown direct on to the line and causing undue disturbance, which would thereby defeat the end for which the compensator was designed. When in the off position, all line leads should be disconnected from the motor. A low-voltage release is necessary for the proper protection of the motor, and is seen at its best where a large number of motors are used. In case of voltage failure, every switch on being tripped returns to the off position, thus preventing the enormous rush of current which would ensue when the station operator closed the feeder circuit. Overload devices should be furnished, either in the form of cartridge fuses or an automatic cut-out. Fig. 1 shows the latest type of compensator provided with overload relays, with cover and oil tank removed. The wiring connections of this compensator are shown in Fig. 2.

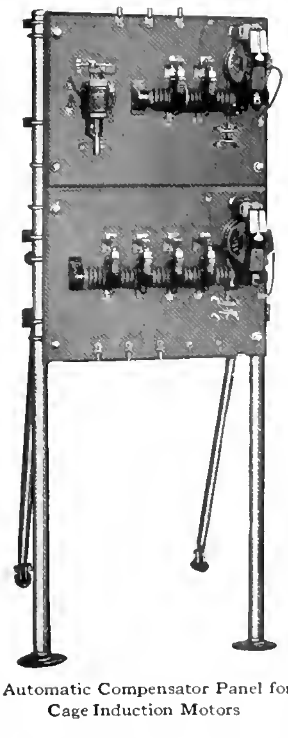


Fig. 3. Automatic Compensator Panel for Squirrel Cage Induction Motors

Automatic Compensators

For the remote or automatic control of squirrel cage motors an automatic compen-

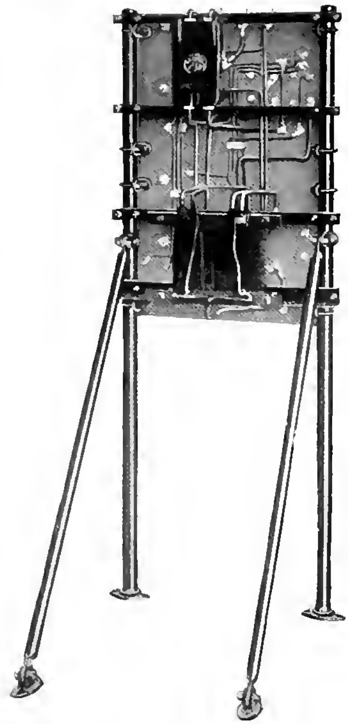


Fig. 4. Rear View of Automatic Compensator

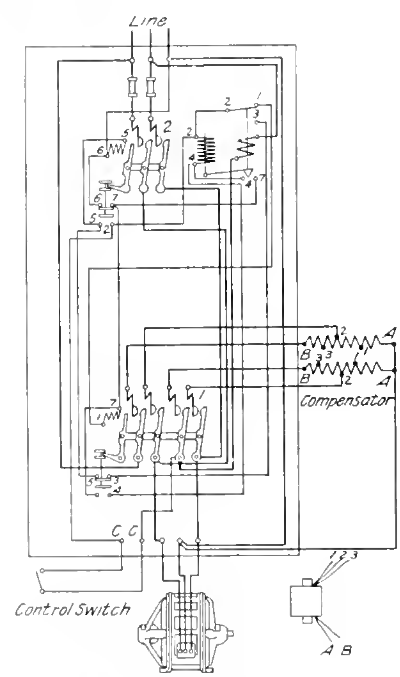


Fig. 5. Wiring Connections for Automatic Compensator for a Three-phase System

sator is used. This is particularly well adapted for use with motors in connection with pumping equipments, where the operation of the motor depends on the rise and fall of water in a tank, or upon the variation of air or water pressure. In the former case the rise and fall of a float in the tank opens and closes a float switch, which in turn opens and closes the control circuit of the compensator. In the latter case, the control circuit is opened and closed by a pressure governor. This type of compensator consists of a slate panel on the front of which are mounted a two-pole and a four-pole contactor, together with a current limit relay. On the back is mounted a two-coil auto-transformer with cartridge fuses for overload, enclosed in a cast iron box. Closing the control circuit energizes the starting contactor; and as the motor comes up to speed and the current falls to a value at which the current limit relay is set, the relay opens the starting contactor and closes the running contactor, and remains closed until the control circuit is opened. The arrangement is shown in Figs. 3 and 4, while the wiring connections for a three-phase system are shown in Fig. 5.

II. AUTOMATIC STARTING PANELS FOR SLIP RING MOTORS

By B. W. Jones

Industrial Control Engineering Department, General Electric Company

An automatic control equipment has been designed for use with slip ring induction motors requiring external secondary control. These starters operate by means of current limit acceleration and are particularly applicable for motors driving pumps or air-compressors where it is desirable to maintain uniform water level or air pressure, or in cases where the control must be situated at some point remote from the motor. These devices are designed for either two- or three-phase circuits and for voltages ranging from 110 to 2200.

The starter consists essentially of a main line double-pole contactor for opening and closing the primary circuit of the motor, and a suitable number of double-pole contactors, the latter being used to short-circuit the rotor or secondary starting resistance. The primary or main line contactors are controlled by a hand-switch, pressure-governor or float-switch. The secondary contactors are actuated by current limit relays operated by means of interlocks on each contactor. The whole equipment, together with no-voltage release coils, is mounted on a slate or marble panel.

In general the number of secondary contactors needed depends upon the motor capacity and the percentage of full load torque required at starting. There is a corresponding number of points of starting resistance. Fig. 1 illustrates the general form of panels for use with the smaller sizes of two- and three-phase motors up to 550 volts. The panels for the larger sizes of motors up to and including this voltage, requiring four steps of resistance or more, are represented by Fig. 2.

The higher voltages require panels with the main line contactor immersed in a tank of oil

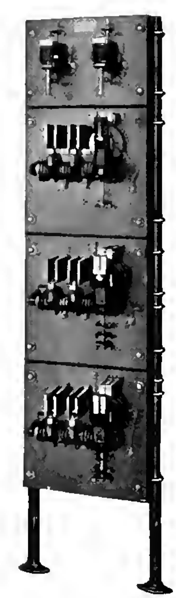


Fig. 1. Automatic Control Panel for Two- and Three-phase Slip Ring Motors, Smaller Sizes up to 550 Volts

and mounted on the rear of the board. This panel is shown in Fig. 4.

The conditions governing the starting and accelerating of a three-phase slip ring induction motor are briefly as follows: Some device—either hand- or automatically-operated—is used to close the three-phase main line stator circuit, all the secondary starting resistance being in series with the rotor circuit. As the motor accelerates the voltage across the resistance gradually decreases, with a consequent falling off in current. By decreasing the resistance in proportion to the voltage, the speed increases; until finally, when the secondary resistance has been completely short-circuited, the motor has attained full speed. In order that the motor should come up to speed in the shortest time practicable, and yet take a minimum of current from the line, the resistance must be short-circuited at a rate depending solely upon the decrease of voltage across that resistance.

The automatic starter with its equipment of contactors, relays and resistances, fulfills these conditions.

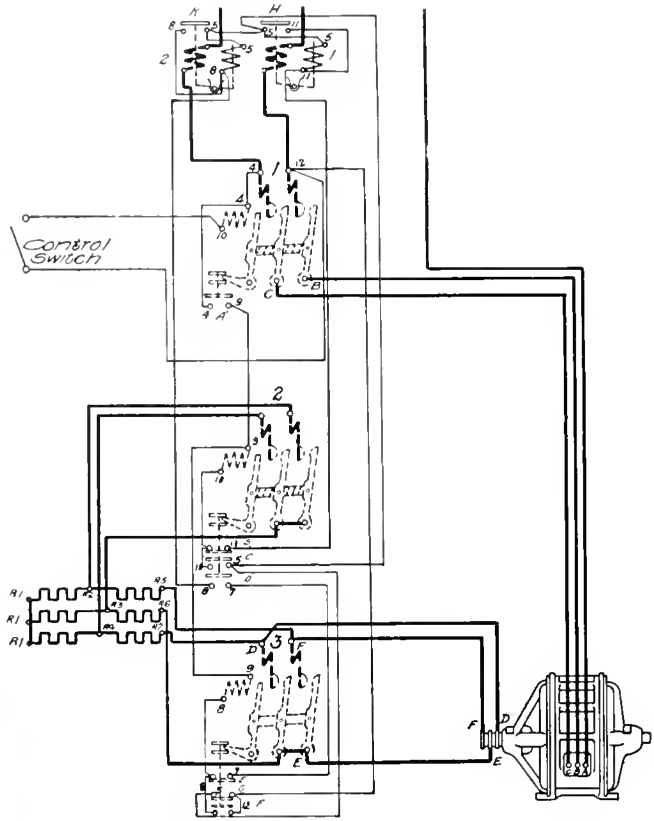


Fig. 3. Wiring Diagram of Three-point Automatic Control Panels for Slip Ring Induction Motor

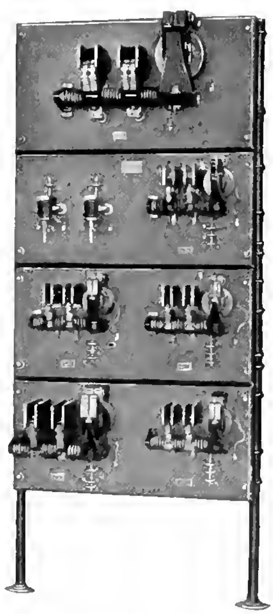


Fig. 2. Automatic Control Panel for Two- and Three-phase Slip Ring Motors, Larger Sizes up to 550 Volts

A diagram of connections for a three-point automatic starter is shown in Fig. 3. When the hand- or automatically-operated control switch is closed the coil of the double pole main line contactor No. 1, controlling two main lines, is energized and the contactor is closed. The third line is connected directly to the motor. The closing of contactor No. 1 throws full line voltage on the stator with all the resistance in the rotor circuit. The current limit relays *H* and *K* are held open by the sudden inrush of current, and none of the secondary contactors can be energized until, at partial speed of the motor, the current has fallen off to some predetermined value. At this value of current the iron core of the relay *H* falls, and the shunt coil of the first secondary contactor No. 2 is energized. The closing of this contactor short circuits one section of the resistance *R*. The primary current immediately rises, causing the motor to accelerate further. As the speed increases, the current again decreases and relay *K* drops, actuating the second resistance contactor No. 3, and so on until the motor has come up to speed. When the resistance has been entirely cut out by the closing of the last contactor all other secondary contactors are automatically opened.

The only continuous exciting current necessary is for the shunt coils of the first and last contactors. The exciting current for the contactor and relay coils up to and including 550 volts is obtained directly from the line. For

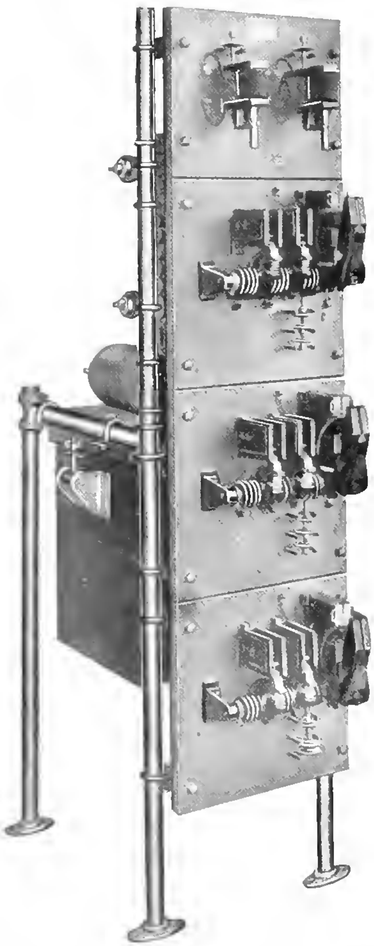


Fig. 4. Automatic Control Panel for Slip Ring Motors for Higher Voltages

higher voltages, such as 2200, a small potential transformer is used to reduce the voltage on the coils. In addition to this potential transformer there is also a current transformer necessary for the operation of the current limit relays.

OBITUARY

The death of Edward H. Anderson, of the railway engineering department of the General Electric Company, occurred at Schenectady, N. Y., March 30th. Nearly three years ago Mr. Anderson suffered from paralysis, but great vitality and a strong physique prevailed and he recovered after a few months rest. He was stricken again on January 4th of this year and a third attack proved fatal within a few days.

Although the late Mr. Anderson was but forty-four years of age he had already made a prominent name for himself in the great electrical industry. He was a well-known and talented railway engineer, having had to do with the design and perfection of some of the largest railway systems in this country. He is credited with a number of important patents relating to improvements in generators, railway motors, controllers, electric brakes, and electric power transmission apparatus; while he was also known for his electric automobile controller.

Mr. Anderson was born March 17, 1868, on his father's cotton plantation in South Carolina. He graduated from the University of South Carolina with honors, qualifying in civil, mechanical and electrical engineering. He came to Schenectady in 1895 and entered the testing department. In a few years he was made designing engineer in the railroad department, and this position he held until his death. In 1896 he married Miss Mary E. Anderson. Both he and his wife were well known in the social life of Schenectady, where Mr. Anderson was a member of the Mohawk Club, the Sigma Nu fraternity and an associate member of the A.I.E.E.

With such aptitude and industry did Mr. Anderson apply himself to electric railway work that he soon won his way to the front rank of his profession. For a time he applied himself closely to improving the design of railway apparatus, and the railway motors in general use today bear evidence of the importance of his work. Especially noteworthy is his scientific study of the railway motor with respect to its performance, energy consumption and heating under service conditions.

CENTRIFUGAL COMPRESSORS

Part III

By Louis C. Lowenstein

Engineer, Turbine Department, General Electric Company

The two preceding installments have dealt with the theory of the centrifugal air compressor and the application of this apparatus to the blowing of blast furnaces, cupolas, and Bessemer converters. In the present installment a number of applications of a more special nature are discussed; viz., the use of the air compressor in the manufacture of water and coke oven gases, for oil burning and forge work, and for pneumatic conveying in general; the more usual service of the compressor for compressing gases in tanks or other receptacles also receiving attention in the concluding paragraphs. It has been found necessary to divide the article into four parts, instead of three as stated in the editor's note to the first installment.—Editor.

Manufacture of Water Gas

In the manufacture of water gas, the generator is filled with a deep fire of coal or coke, and a blast of air is admitted in the bottom of the generator under the grate, and passes up through the fuel. The oxygen of the air unites with the heated carbon to form carbonic oxide. The nitrogen is not affected. These two gases, carbonic oxide and nitrogen, are termed the products of partial combustion, the meaning of which is that if more oxygen be added the carbonic oxide will ignite and burn to carbonic acid. These products of partial combustion are thus burned in the carburetor and superheater by admitting air from the blower. The result of this combustion is intense heat, which is taken up by the loose fire-brick, or checker-brick, with which the carburetor and superheater are filled. The resulting carbonic acid and nitrogen—products of complete combustion—then pass off to the atmosphere through the stack valve. The degree and distribution of heat in the carburetor and superheater are entirely under control, and can be adapted to the character of the oil used for carbureting. When the temperatures in these various shells are at the proper point, the air blasts are shut off and all combustion ceases. The stack valve is then closed and steam is admitted under grate in the generator. The passage of this steam through the highly heated fuel produces non-luminous water gas. As this gas enters the top of the carburetor it meets a spray of partially vaporized oil. The gas and the oil vapors pass together over the highly heated surfaces of the checker-brick, and the oil vapors are gasified and fixed in the presence of the non-luminous water gas. The result is a thoroughly fixed and permanent illuminating gas, which passes on to be scrubbed, condensed and purified in the usual manner. This period of gas making is continued until the heat in the apparatus is reduced to a point where it is not advantageous to continue. The oil and steam are then shut off, the stack valve opened, and the process of blasting and heating up is repeated. Alternations of this heating up, or "blow," and of gas making, or "run," are continued, each of which hardly ever exceeds six or eight minutes in duration, until it is necessary to stop and add fuel, and at longer intervals, clean the fire by removing the slag.

As can be seen from the process described above, air is simply introduced to assist combustion; that is, a certain weight of oxygen is required for combining with the heated carbon in the generator in order to form carbonic oxide, and a certain weight of oxygen is required in the carburetor for burning the carbonic oxide and producing intense heat. The amount of oxygen required in the generator for producing carbonic oxide and the amount of oxygen required in the carburetor for complete combustion can be determined from the amount of carbon contained in the fuel fed to the generator. If the amount of carbon is definitely known, the amount of oxygen can also be known, and therefore we can definitely determine the amount or weight of air which must be supplied to the generator in order to obtain efficient combustion of the carbon, and complete combustion of the carbonic oxide. It can therefore be seen that the successful and efficient operation of a gas producing plant depends largely upon the constancy of volume, or rather weight of air supplied, and not upon the pressure under which this air is delivered. If the fire is clean and free from clinkers, half a pound of air pressure possibly would be sufficient to give the desired quantity of air per minute. If, however, the fire is in an unhealthy condition, owing to the formation of a blanket of clinkers over the grate, a higher pressure is required to blast the same quantity of air per minute through the fire.

Therefore, centrifugal compressors furnishing air for the manufacture of water gas should be provided with a constant volume governor and also with a quick shutting and opening throttle valve, so that the blast can be shut off or started at each "blow" and "run," or during cleaning of the fire.

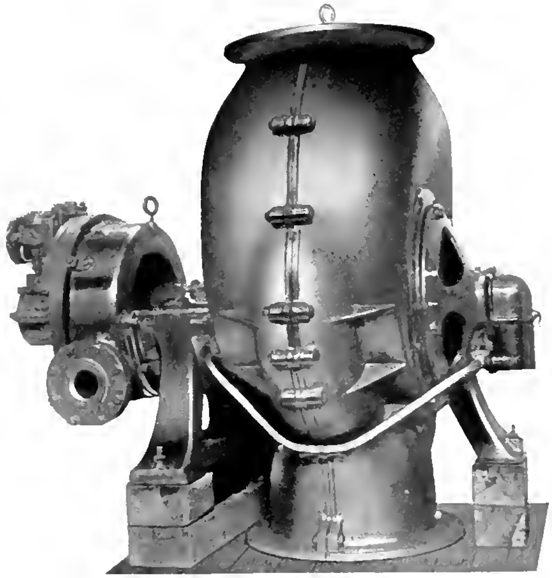


Fig. 22. Centrifugal Compressor Driven by 75 H.P. Curtis Turbine

Fig. 22 shows a photographic view of a turbine-driven centrifugal compressor used for furnishing air for water gas manufacture. This set delivers 10,200 cu. ft. of air against a nominal pressure of 1 pound. The turbine runs at 3450 r.p.m. and is rated at 75 h.p. Prior to the centrifugal compressor the ordinary fan or blower was almost wholly used. Even if good efficiency is not of importance, ease of operation and low cost of maintenance, combined with the greatest reliability, stand in favor of the centrifugal compressor.

Oil Burning and Forge Work

A large number of centrifugal compressors have been installed for oil burning and for forge work. In burning oil it is necessary to so atomize the oil that efficient burning is obtained. The makers of oil burners differ somewhat in their practice as to the necessary air pressures required to efficiently atomize the oil, some designs calling for air pressures of from 12 to 15 lb. per sq. in. This high pressure air is used to produce a high velocity jet, which divides the oil into an efficient spray, but which does not furnish sufficient air for combustion purposes. The remaining air necessary for complete combustion is either drawn in through the burner on the injector principle, or is supplied by drawing the air from the room under ordinary draft suction. Other designs call for air pressures of only 1 to $2\frac{1}{2}$ lb. per sq. in., and most oil burners designed for the lower of these pressures supply not only the air required for efficient atomizing of oil, but also enough air to produce complete combustion. When air pressures of $1\frac{1}{2}$ lb. per sq. in. or less are employed low pressure single-stage compressors of sufficient capacity to supply the entire amount of air needed, are used. For higher air pressures either single-stage or multi-stage compressors are used, which furnish high pressures and supply only the small amount of air necessary for vaporizing or atomizing the fuel oil. We may say in general that both systems have proven efficient, and where a large enough area is to be heated there is not very much difference between the low pressure and the high pressure system. It has been found, however, that where an intense and concentrated heat is to be applied the high pressure system is more adaptable. In automatic forging machinery a long piece must sometimes be bent or forged at only a certain part of the material, such as the bending of a long rod at one place. A very rapid and concentrated heat at this point will produce better work and save considerable fuel, and in these cases oil burners with high pressure air are used in order to produce an intense heat rapidly so that only a very small area is heated.

For successful oil burning or for forge work no special requirements are necessary, as far as the air compressor is concerned, except that of steadiness of air supply and high efficiency. The centrifugal air compressor delivers an absolutely steady supply with a higher efficiency than any other type of compressor, and therefore has found a large application in supplying air for oil burning and forge work. On some forge work it has been found convenient to tap the air supply so that it can be used for blowing the scale, cooling the dies, etc.

The most popular sizes of compressors for the low pressure systems have been those delivering from 1600 to 5000 cu. ft. of air per minute at a pressure of about 2 lb., while for the high pressure systems the capacities vary considerably.

The turbine-driven compressor shown in Fig. 22 is used for furnishing air for oil burning and forge work. One of these units is installed at the plant of Deere and Co., Moline, Ill. This concern has another turbine-driven compressor in use the capacity of which is 3000 cu. ft. per minute against 15 lb. pressure. The operation of these units is so satisfactory that reciprocating compressors for this work would not be again considered.

Ash Conveying

Pneumatic ash handling has been found to be most efficient. The usual method of installing such a plant is to provide a hopper into which the ashes are dumped, and to connect this hopper direct to the pipe line. At the receiving end of the pipe line a separator is used, the ashes dropping to the bottom of the separator and the air being drawn by the compressor from the top of the separator. In other words, the compressor is working as a suction machine drawing air from the hopper through the transmission line and out of the separator. No ashes, of course, pass through the compressor itself. The hopper is usually so arranged that if it contains no ashes the lid is closed and thus the load on the compressor is reduced, although most ash handling installations do not require the compressor to be run except for the short period during which the ashes are removed. The actual suction usually required varies from $1\frac{1}{4}$ lb. to $1\frac{3}{4}$ lb. Fig. 14 (April REVIEW) shows a photographic view of a 50 h.p. centrifugal compressor, many of which have been installed for this service. The compressor can handle 4200 cu. ft. of air per minute against a pressure of 2 lb., and is therefore amply large enough to produce suctions of $1\frac{1}{4}$ to $1\frac{3}{4}$ lb. The unit runs at 3450 r.p.m., the one shown being driven by an alternating current motor.

Pneumatic Cash and Mail Conveying

Quite a number of centrifugal compressors have been installed for handling pneumatic cash transmitting systems in department stores, and also for conveying mail and other matter. The General Electric works at Schenectady employ the pneumatic system for the delivery of mail, blueprints, and tracings throughout the larger part of the plant, and centrifugal compressors have been found to serve admirably for supplying the required suction. Fig. 23 shows one of the units employed on this system; it is direct connected to a 50 h.p. alternating current motor and is rated at 2400 cu. ft. of air at a pressure of $3\frac{1}{4}$ lb., the speed of the set being 3450 r.p.m. The compressors work by producing suction on the transmission lines.

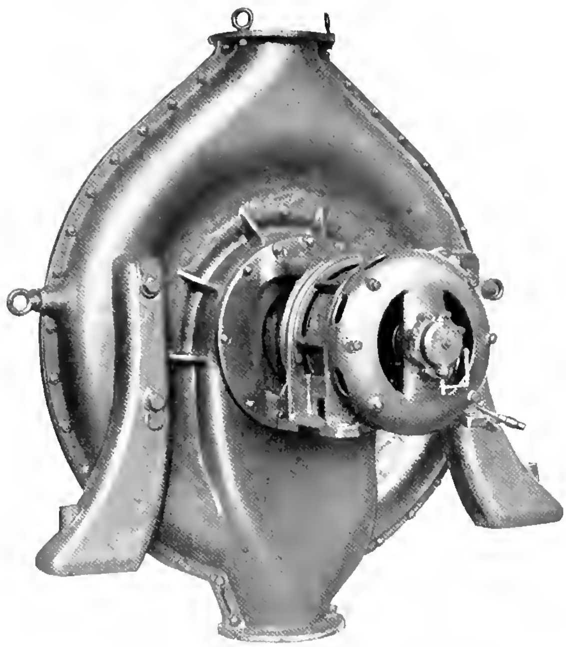


Fig. 23. Centrifugal Compressor Driven by 50 h.p. Alternating Current Motor

In a large department store in Chicago, a centrifugal compressor capable of delivering 7200 cu. ft. of air per minute at 1 lb. suction and driven by a 50 h.p. motor replaced a positive pressure blower requiring over 75 h.p. to drive it. The centrifugal compressor carried the same load with somewhat less than 50 h.p. load on the motor. There was a decided difference in the floor space required, and the cost of operation and maintenance was greatly reduced.

The great advantage in using a centrifugal compressor for this work lies in the fact that when the suction lines are suddenly opened by the insertion of a carrier in the transmission line, the compressor will respond instantly by drawing an enormous quantity of air (many times the amount its small driver would stand for any length of time) and thus establish a high air velocity, which will send the carrier promptly and rapidly on its way. The response of the positive pressure blower is by far too sluggish, unless a much larger unit is installed.

Sawdust Conveying

The problem of removing sawdust from woodworking machinery is a very interesting one, because the fan blowers heretofore used are extremely inefficient. The general scheme is to install a fan blower somewhere in the transmission line and to suck the sawdust into the transmission line, by placing proper collecting hoods at the end of the line and over the place where the sawdust is that is to be removed. The sawdust is drawn through the transmission line, passes through the fan, and is blown either into the continuation of the transmission line or into a storage bin. If the sawdust is compelled to pass through the fan, the side clearance between the fan and the casing must be made sufficient to prevent small shavings from becoming wedged in this space, thereby either jamming the impeller or wrecking it. With large clearance spaces the efficiency of the ordinary fan is extremely poor, sometimes only 20 or 30 per cent. It is much better to install a system in which the shavings and sawdust do not pass through the compressor—one similar to the ash handling or the pneumatic cash transmitting systems. In some cases the problem is increased by not only having to transmit shavings and sawdust, but also strips of wood. In practice, if any block of wood accidentally enters the transmission line and passes through the rapidly revolving fan, the bending or breaking of the blades of the fan usually results. On account of the peculiar property of sawdust in packing tightly around bends, and in some cases of being somewhat moist owing to the use of green wood, it is of advantage to install a suction system in which the amount of air sucked or pumped remains constant. Formerly the design had to be such that the velocity of air through the transmission pipes was relatively high to prevent clogging in the pipes; and even with this precaution trouble was frequently experienced. Keeping the air moving at such high velocities requires, of course, considerable power. If, however, a compressor is installed with a constant volume governor, the quantity of air sucked remains constant. Then the usual air velocities will ordinarily be sufficient. Should the sawdust become packed so as to clog up the transmission line at any point, the centrifugal compressor furnished with a constant volume governor would speed up and produce a greater suction in order to maintain a constant quantity of air delivered. At the restricted portions of the pipe line the velocity of air would be greater and therefore would remove once again the blocked material. This is of such importance that no installations for removing sawdust or similar material should be made without providing in some way for maintaining automatically the passage of a constant volume of air through the suction pipes, and thus producing high air velocities at the restricted parts of the transmission line. If the engineer laying out such a system knows positively that pipes cannot be clogged he can use pipes of much smaller diameter than those now generally installed for this work. The saving in first cost is very considerable. As the centrifugal compressor is admirably adapted for operation with constant volume governor control, and as the efficiency of this type of air compressor is higher than that of fan blowers, the former is rapidly supplanting the latter type for this service.

General Pneumatic Conveying

The centrifugal compressor can be used for conveying a great many dry substances, such as coal, cement, and other materials in industrial use. It has been proposed to transmit star h pneumatically, and similar material such as rice. The problem is not a very difficult one, and if a centrifugal compressor is used the efficiency of transmission is good. If the material to be transmitted is composed of large irregular shapes, like ashes, no constant volume governor is necessary. If, however, the material is of uniform shape or of very finely divided particles, and if there is any likelihood of the material being stalled around bends or of choking the transmission lines owing to small diameter of pipes, a constant volume governor installed with the centrifugal compressor will in most every case prevent clogging of the transmission line. The centrifugal compressor supplied should have a sufficient range of speed to produce a very high suction in emergency cases, so that if any clogging starts the quantity of air drawn through the transmission line remains constant, even if the compressor must greatly increase its speed to effect this result. The high velocity air produced at the point where it is most desired will greatly assist in removing any material which may have become clogged. When the centrifugal compressor is installed for intermittent service, where it is necessary to keep the compressor running so as to be available at any moment, one end of the transmission line can be nearly or entirely closed; the power required to drive the compressor being thus greatly reduced.

Coke Oven Gas

In the manufacture of coke a most important by-product is the coke oven gas. It is usual to install a compressor for producing a uniform suction on the coke ovens and for transmitting the gas through the scrubbers and purifiers to the gas holder. The process briefly is as follows:

The coal is rapidly carbonized by subjecting it to a high temperature in a closed oven or retort-like vessel. The products of distillation pass from the retorts or ovens through the neck and upwards into cast iron stand-pipes which are provided with goose-neck outlets dipping below the surface of the water in what is termed the hydraulic main. It is in this part of the process that the main bulk of the tar is obtained, together with ammonia liquor. The hydraulic main is provided with an overflow pipe through which all the tarry matters pass. This overflow pipe leads to the tar well, wherein the liquor products collect. The gas, having been freed from most of the tarry matters, passes from the hydraulic main at a considerably elevated temperature, carrying hydrocarbons in a vaporized state. It then passes through the compressor, and from the compressor it is passed through a condenser which removes the volatible and condensible products, some slight additional tarry matter and more ammoniacal liquor being again abstracted.

After circulating through the condensers, the gas passes through a scrubber filled with coke, over and through which trickles a light flow of water, or better, weak ammoniacal liquor; the gas passing upwards, meets this downward flow of liquor and gives up the hydrogen sulphide it contains, forming ammonia sulphide, etc. From the scrubber the gas passes on to the purifiers, where the hydrogen sulphide still remaining, the carbon disulphide vapor, and the carbonic acid are removed. The purifiers employ slack lime spread upon wood screens to absorb the hydrogen sulphide and carbon dioxide. From the purifiers the gas passes into the gas holders.

The air compressor must produce an absolute constant suction on the gas main and must also compress the gas so that it will flow through the condensers, purifiers, and into the gas holders. In order to produce a constant suction the centrifugal compressor is provided with a constant pressure governor —the Isbel Porter or similar type. This governor changes the speed of the compressor slightly whenever the suction pressure rises or falls a slight amount, in this manner keeping an absolute constant suction pressure on the gas main. The centrifugal compressors for this work are provided with tar drains and suitable openings for periodic cleaning of the compressor.

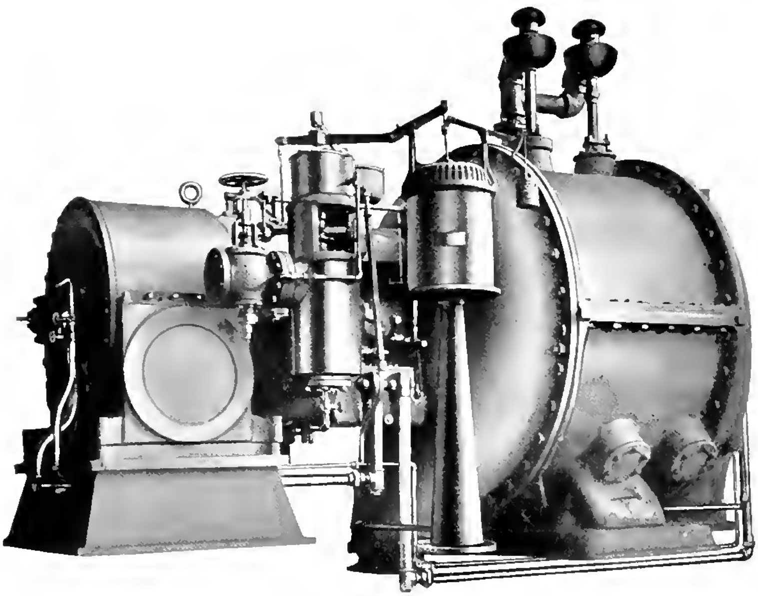


Fig. 24. Centrifugal Gas Booster Driven by 200 H.P. Curtis Steam Turbine

Fig. 24 shows a view of one of five units furnished to the Tennessee Coal & Iron Company for compressing gas extracted from coke ovens. This unit is capable of delivering 9000 cu. ft. of gas per minute against a pressure of 3.5 lb. per sq. in. The compressor is direct-connected to a steam turbine rated at 200 h.p. and runs normally at 3500 r.p.m. The constant pressure governor is mounted on a cast iron stand directly in front of the unit. The floating tank which responds to variations of suction pressure is connected by floating levers to the governing mechanism of the turbine.

General Applications

Besides the special applications mentioned, the centrifugal compressor is, of course, applicable to the more usual and general applications for compressing elastic fluids. The ordinary and most usual problems occurring in compressor work are those in which air or gas must be transmitted through pipes or compressed in air tanks or gas holders. All that is generally required is a compressor that will deliver a steady flow of fluid under a constant pressure, and one that is capable of responding to variations in volume delivered when the occasion arises. The centrifugal air compressor should not only be preferred on account of its higher efficiency, but also because it maintains this efficiency indefinitely, there being no wearing parts and no valves that leak, etc. The general characteristic curve of a single-stage compressor is similar to that shown in Fig. 25, from which can be seen the steadiness of pressure over a very wide range of capacity. Although the pressure is not absolutely uniform over the wide range of capacity, it is so nearly so that for most practical purposes the centrifugal compressor can be used without any governing mechanism whatever. If, however, as has been shown before, absolutely steady pressure is required, over the entire range of air capacity, a constant pressure governor can be installed.

If a centrifugal compressor is to work with a gas that would be injurious to health should any of it leak past the packings between the casing and the shaft, or if the machine is to be employed for suction purposes where it would be detrimental to have a slight leakage of air into the compressor, a water sealed packing is provided so that no escape of gas or sucking in of air is possible. In some very special cases where water cannot be used owing to the formation of destructive acids with the gas in question, other liquids are used for sealing, such as glycerine, etc.

Some of the general applications of centrifugal compressors are: compressing illuminating gas into gas holders or gas mains; compressing air for mine ventilation, for glass blowing, and for bottle making machinery; and exhausting air from grinding rooms, etc. Multi-stage centrifugal compressors have been installed for compressing air for sand blasting in foundries. When sand blasting cast iron a pressure of about 15 lb. per sq. in. is used, but for steel castings a pressure of 25 lb. per sq. in. is employed. Compressors have also been installed in sugar work for compressing SO_2 gas, and for transmitting carbonic acid gas, both of which are used in the process of sugar making. Fig. 26 shows a machine installed by the Holly Sugar Company in California for compressing SO_2 gas. This compressor is capable of delivering 2500 cu. ft. of air per minute against a pressure of 5 lb. per sq. in.

Fig. 27 shows a 6600 volt alternating current motor driving a single stage compressor which is rated at 20,000 cu. ft. of air per minute against a maximum pressure of 3.75 lb. per sq. in. This compressor is equipped with a constant volume governor which regulates the speed of the compressor by means of a water rheostat. This unit furnishes air for copper smelting at Great Falls, Mont., and illustrates clearly how

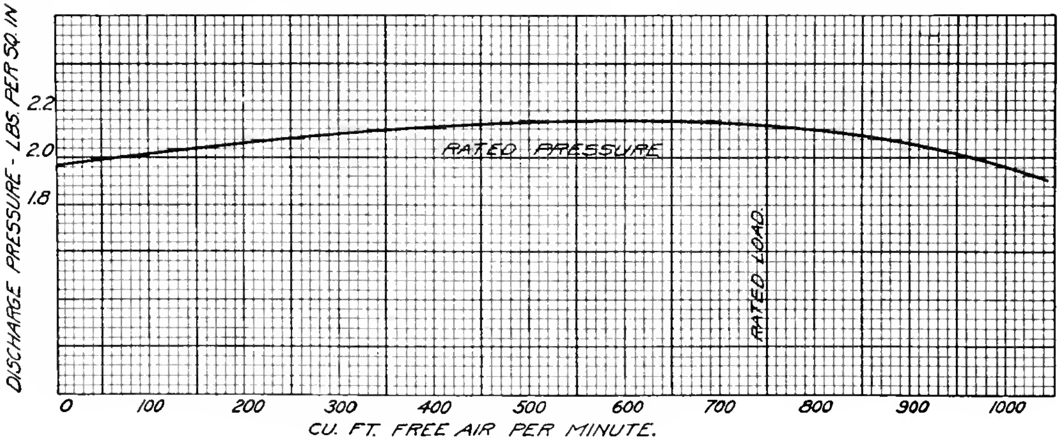


Fig. 25. Characteristic Curve of Single Stage Compressor

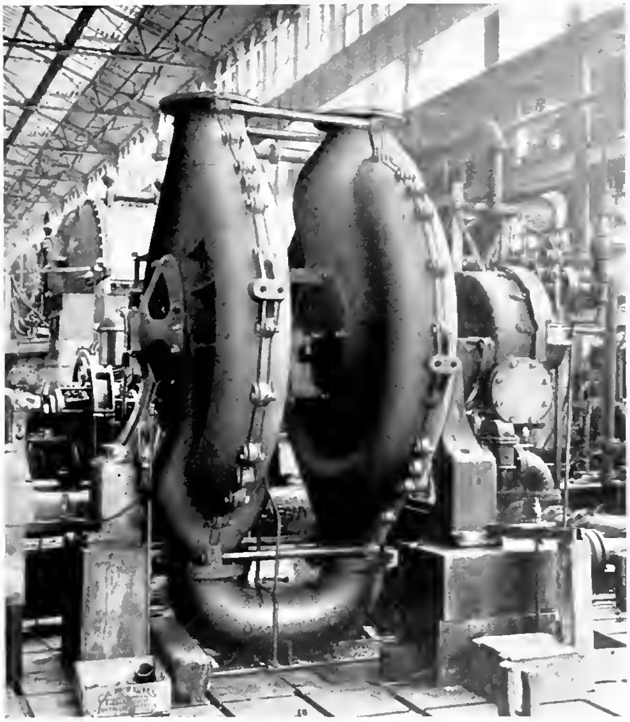


Fig. 26. Centrifugal Compressor Driven by 80 H P. Curtis Turbine

constant volume governing is accomplished when the driver is an alternating current motor.

In some cases it is desirable to use the centrifugal compressor as a booster to a reciprocating compressor, especially when it is desired to increase the capacity of the entire installation. This is very easily accomplished by installing a centrifugal compressor to initially compress the air from atmosphere to about 30 lb. pressure, and then by passing this denser air, which has already been compressed to approximately one-third the original volume, into the reciprocating compressor, the capacity of the reciprocating compressor is increased very nearly three times. It has even been proposed that no reciprocating compressor of large capacity should be installed for compressing air from atmosphere to very high pressures without havinga centrifugal compressor perform initial compressions up to about 30 lb. per sq. in. This will save having too large cylinders on the reciprocating compressor, because the centrifugal compressor will perform the initial compression and reduce the volume of the air greatly before the air enters the cylinders of the reciprocating unit.

It might be of interest to describe a centrifugal compressor used for cleaning producer gas, simply to show some of the very special

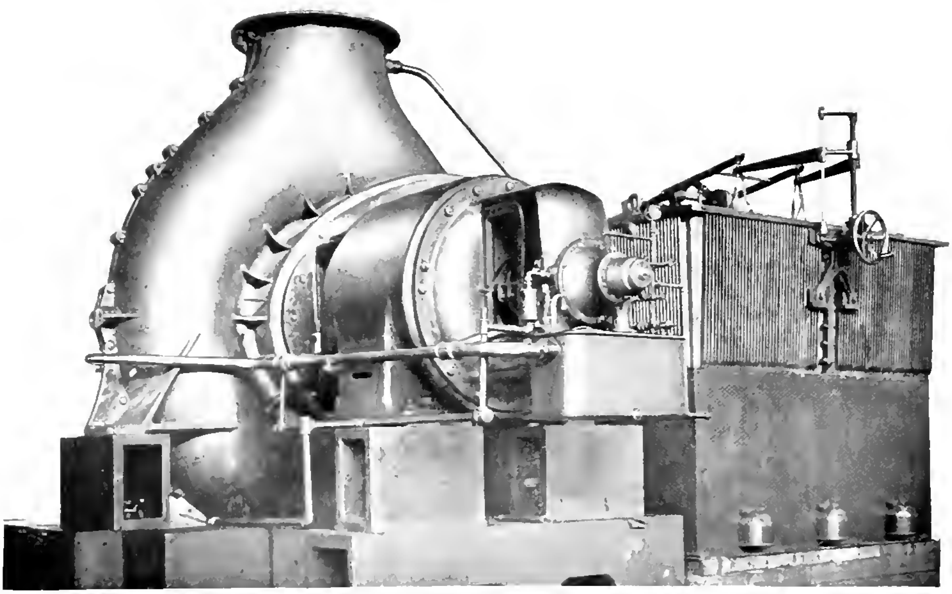


Fig. 27. Compressor Driven by 375 H.P. Curtis Turbine

uses to which this machine can be put. Fig. 28 gives a cross-sectional view of such a machine. The gas, after being generated in the gas generator, was previously passed through large scrubbers and cleaners before it was available for use in a gas engine. When the centrifugal cleaner is installed no scrubbers or other cleaners are necessary. The gas from the generator enters the cleaner at *A* (Fig. 28); it passes first through one side of the impeller *E*, having the blades *C*, into the discharge vanes *D*. The heavy particles are thrown by centrifugal force against the discharge vanes and casing and are washed down by water into the drain. The lighter particles, in the form of dust, are wetted down by the water sprays *S*, and also wash down into the drain. The gas having passed around the middle stationary partition *P*, flows inward through the other side of the impeller, *E*. Should any heavier particles (carbon dust, etc.) try to flow with the gas inward through the second side of the impeller the rapidly revolving blades *F* would throw them outward again. It should be noted that the blades on the first side of this impeller are somewhat larger in diameter than the blades on the second side of the impeller. Therefore the centrifugal pressure produced by the blades on one side is somewhat higher than that produced by the blades on the other side. This establishes the flow in the direction of the arrows. The cleaned gas then passes to both sides of the next impeller *L*, which operates exactly like any other centrifugal compressor. The compressed gas leaves at *B* and flows into a holder or receiver ready for use. These gas cleaners are very reliable and efficient.

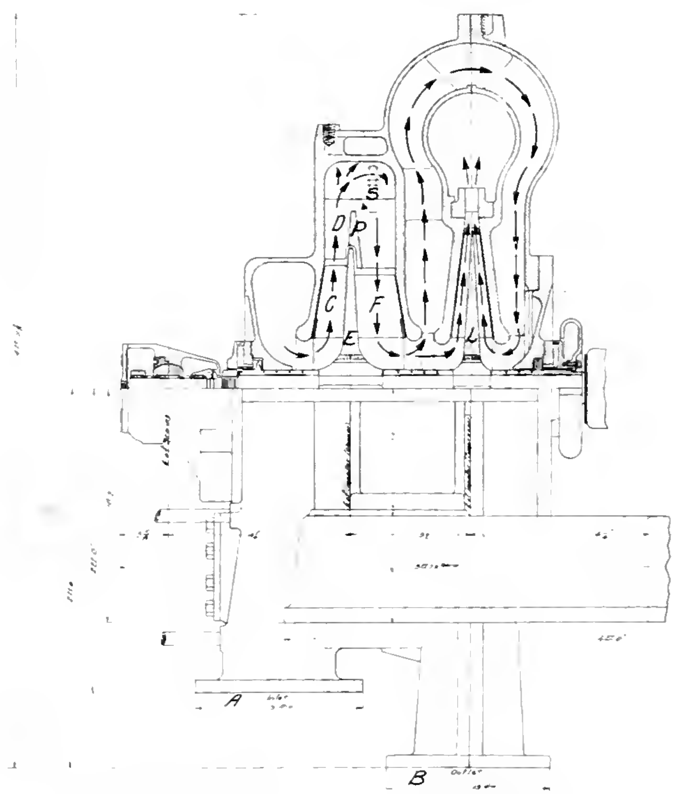


Fig. 28. Centrifugal Compressor Arranged for Cleaning Producer Gas

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On this and the following three pages are reproduced photographs of some of the engineers who contribute articles to the present Power Transmission number of the *General Electric Review.*

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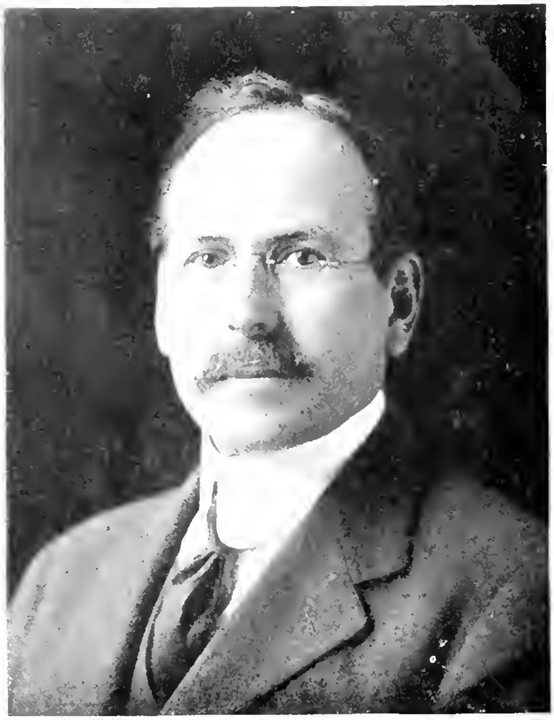
C. W. Stone



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RECENT HYDRO-ELECTRIC DEVELOPMENT, AND THE PROBABLE COURSE OF FUTURE PROGRESS

By David B. Rushmore

Engineer, Power and Mining Department, General Electric Company

This article gives some geographical statistics relating to the possibilities for hydro-electric development in the United States, showing figures of acreage of forests, annual water flow into principal drainages, etc., with details of the actual horse power which is at present being recovered. The remainder of the article is principally a review of recent progress. A presentation of some of the most noticeable general tendencies (tying together of large stations, increase in operating voltages, etc.) is followed by more detailed reference to progress in the design of electrical apparatus used in the station and on the line. A very interesting table is included at the end of the paper, showing at a glance the salient particulars of thirty of the most recent schemes.—Editor.

It is the purpose of this article to give a brief review of what has been accomplished hitherto in the field of hydro-electric development, and to indicate the probable course of future progress. Before doing this, it may be of interest to recount some of the fundamental facts which have a direct bearing on all hydro-electric development schemes, and to give some geographical statistics of the United States which have a reference to the development of the water resources of this country.

Energy is given out by the sun at the rate of 6.35×10^{27} h.p. Energy is received on the earth's surface at the rate of 2.6×10^{14} h.p. The area of the earth's surface is approximately 197,000,000 square miles; the area of the United States is about 3,027,000 square miles. Twenty-six per cent. of the earth's surface is land. The evaporation from water surface in the United States varies from less than 20 in. annually to more than 100 in. in a few places. The average rainfall over the United States is 29.4 in., which is disposed of in re-evaporation, in plant growth, in sub-surface flow, and in surface flow (known as "run-off"). It is the last which is available for water power developments, and may be said to comprise roughly one-third of the rainfall.

Forests—which regulate the stream flows, and which are rapidly being exhausted—constitute an important feature of hydro-electric development. The forests of the United States cover 550,000,000 acres, or about one-fourth of the country. The national forests comprise about 150,000,000 acres, distributed as follows:

Arizona	9 million acres
California	21 " "
Colorado	15 " "
Idaho	20 " "
Montana	20 " "
Nevada	1 " "
New Mexico	7 " "
Oregon	16 " "
So. Dakota	1 " "
Utah	7 " "
Washington	12 " "
Wyoming	9 " "
Alaska	5 " "

Principal Drainages	Drainage area in sq. miles	Flow per annum in billion cu. ft.	Horse Power: Minimum	Horse Power: Assumed maximum development
North Atlantic to Cape Henry, Va.	159,879	8,942	1,761,000	3,481,000
Southern Atlantic to Cape Sable, Fla.	123,920	5,560	1,050,000	1,630,000
Eastern Gulf of Mexico to Mississippi River	142,220	6,867	466,000	803,000
Western Gulf of Mexico west of Vermilion River	433,700	2,232	362,000	686,000
Mississippi River (tributaries from east)	333,600	12,360	2,180,000	4,450,000
Mississippi River (tributaries from west, including Vermilion River)	905,200	9,580	3,300,000	5,900,000
St. Lawrence River to Canadian line	299,720	8,583	5,570,000	6,740,000
Colorado River above Yuma, Ariz.	225,000	521	2,425,000	4,610,000
Southern Pacific to Point Bonita, Calif.	70,700	2,193	2,680,000	6,500,000
Northern Pacific	290,400	15,220	10,750,000	20,500,000
Great Basin	223,000	....	433,000	670,000
Hudson Bay	62,150	614	63,000	175,000
Total	3,269,490	72,672	31,040,000	56,146,000

The present rate of cutting the timber is three times the annual growth; while the yearly consumption is 20,000,000,000 cu. ft., valued at about $1,250,000,000. Wood is used every year in the following quantities:

90,000,000	cords of fire wood.
40,000,000,000	board feet of lumber,
123,000,000	hewed ties,
1,500,000	staves,
133,000,000	sets of heading,
500,000,000	barrel hoops,
3,200,000	cords of native pulp wood,
165,000,000	cu. ft. mine timber,
1,250,000	cords of wood for distillation.

The estimated available water power in the United States is shown in the table on opposite page.

In estimating these values an efficiency of 75 per cent. is assumed. The minimum flow has been based on the average of the two lowest 7-day periods in each year for a period of seven years, and the maximum flow upon the continuous power indicated by the stream flow for six months of the year showing the highest flow. The average flow for the lowest week of the lowest month of these six highest months was then averaged for a number of years. No storage was considered in either estimate. Basing an estimate on every available storage facility, it can be assumed that about 200,000,000 h.p. can be ultimately developed. This amount, however, is not economically available today, but represents the maximum possibilities upon the day when our fuel resources are becoming exhausted and their price for the production of power prohibitive.

Developed Water Powers in United States

The total developed water power of the United States as thus computed by the Bureau of Corporations in June, 1911, excluding developments of less than 1,000 h.p. each, was 4,016,127 h.p. Of this, 2,961,549 h.p. is classed as "commercial" power, and 1,054,578 h.p. as "manufacturing" power. Adding 2,000,000 h.p. to represent the power of developments of less than 1,000 h.p. each (this being the total, in round numbers, as reported to the Census in 1908), a grand total is obtained, in round numbers, of at least 6,000,000 h.p., as the total water power of the United States already developed or with development works under construction in June, 1911. Reference to the double-page map shown on pp. 368-9 will show that there is a marked geographical concentration of developed water power (as well as a similar concentration of potential power set forth above). Thus, nearly 50 per cent. of the developed "commercial" water power of the country is located in five States, as follows:

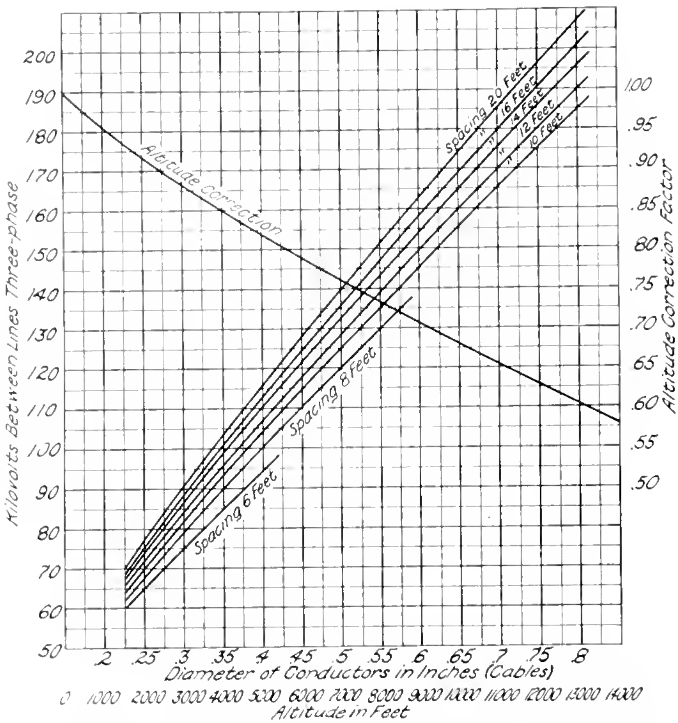


Fig. 1. Showing the beginning of corona voltage on transmission lines at sea level for various conductors and spacing. To find the voltage at any altitude, multiply the value found from the curve by the correction factor. For single-phase or two-phase take the three-phase voltage and multiply by 1.16.

	Per cent.
California	14
New York	13
Washington	10
Pennsylvania	6
South Carolina	5
Total	48

An even more marked concentration of developed water power employed in manufacturing is shown by the following summary:

	Per cent.
New York	30
New England States	36
Minnesota and Wisconsin	17
South Carolina	5
Total	88

Peculiarities of Modern Hydro-Electric Developments

Power transmission is becoming a development in the East as well as in the West, and has now ceased to be peculiar to the western parts of the country. The requirements for continuity of service are becoming greater, and in all parts of the work a much better class of construction is being used, from the hydraulic end to the distributing station. This means a greater capital charge, but a smaller expenditure for depreciation and repairs.

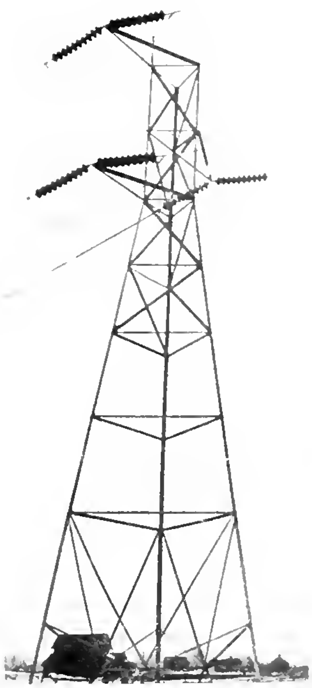


Fig. 2. 140,000 Volt Single-Circuit Strain Tower of the Eastern Michigan Power Company

Fig. 3. 140,000 Volt Suspension Insulator of the Eastern Michigan Power Co.

Practically all of the transmission systems which have been developed of late feed into existing transmission and distributing systems, and the problem of tying together two or more of these is becoming of increasing importance. In many of these cases a considerable proportion of the power is transformed to another frequency, and the best method for doing this depends upon the particular case under consideration. The choice of frequency for power plants and systems is always dependent upon local considerations and both 60 and 25 cycles are still being installed. The system which is finally to be used in the electrification of the big steam railroads is still one of the uncertain factors.

Government reports show that floods are becoming more frequent and more disastrous, due to the continued destruction of the forests, which continually changes the characteristics of the stream flows. Each year we hear of new records being made in the height of water and the severity of these disturbances. This tends to make a lower minimum flow, and is one of the factors working toward a greater development of steam auxiliaries in connection with water power generation of electricity. In most of the large transmission systems such auxiliaries are being increased in number and capacity.

At the present time many new hydro-electric plants are under construction and in contemplation. Questions regarding the rights in the public domain are so involved that prospective power developments so situated are, at the present time, almost impossible of being handled. Naturally investors do not want to hazard their money in a place where the titles are so uncertain.

The network of high tension distributing systems is becoming so complicated in many places that there is arising a greater necessity for the use of automatic relays, which will take the place of intelligent operators and which will cut out the part of the system on which a disturbance is located. While much has already been done in the development of these devices, a great deal more will be accomplished in the future, as the demand for such is becoming almost imperative. The necessity for the reduction of expense in connection with small sub-stations is also working in the same direction.

Modern generating and transmission systems are becoming so large that units of much greater single capacity are being developed; and there seems to be in sight no definite limit to the sizes which may be reached. The 14,000 kw. transformers at Shawinigan are the largest which have yet been built, and 20,000 kw. water-wheel generators are under consideration. Steam turbine units of this size have been in operation for some considerable time, and machines of larger output are now being developed.

So many plants are in successful operation at 100,000 volts that this may almost be called conservative. The plant of the Eastern Michigan Power Co. at 145,000 volts has been in operation for some time in an entirely satisfactory manner. The extensive system of the Hydro-Electric Commission of Ontario has also been brought into a satisfactory operating condition, and serious consideration has been given in New York State to other development along the same lines. The limitations to high voltage transmission are not clearly in sight. They may come from economic considerations, they may come from the loss due to corona, or they may be reached in connection with charging currents and transient phenomena. In this paper it is impossible to make a more than passing mention of corona limitations, which have been discussed at length elsewhere; but a considerable amount of data will be found to be condensed in graphic form in the curves shown in Fig. 1. The low frequencies have certain advantages for the very high voltages. In most plants ground wires are being installed without question and, of course, suspension insulators and steel towers. It is difficult to include representative illustrations which will show at all completely what has been recently accomplished in the field of high-voltage transmission; but the accompanying views, in Figs. 2 to 7, showing entries, oil-switches, suspension insulators, and other equipment of the Eastern Michigan Company will probably be of considerable interest.

Fig. 4. 140,000 Station - wall - entrance Eastern Michigan Power Co.

Among other recent interesting developments has been the selling of hydroelectric power to coal mines; while in other instances steam power is generated at the mines and transmitted over various distances for industrial use. The famous Harwood plant, which burns culm and produces power at a phenomenally low cost, has been in successful operation for some considerable time.* The Lehigh Navigation Electric Co. is a most interesting recent development. Here a 120,000 kw. steam plant will be installed at the mines of the oldest operating anthracite company, with New York and Philadelphia both within easy striking distance. The power will at first be supplied to a large cement mill load.

* A description of the Harwood Electric Co. will be found in the May, 1911, issue of the Review, page 242.

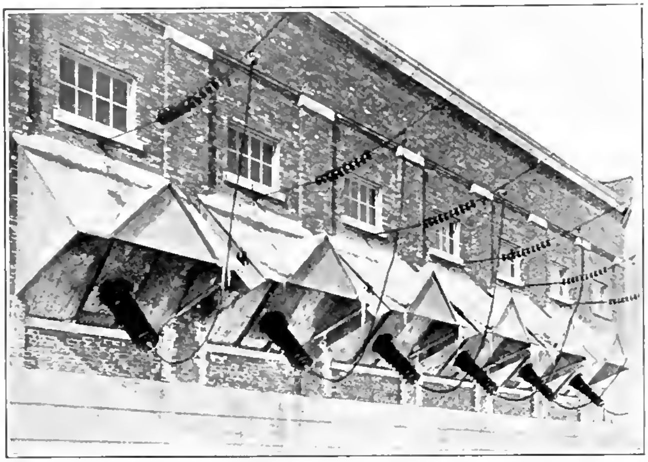


Fig. 5. 140,000 Wall Entrances at Zilwaukee Substation of Eastern Michigan Power Company

One of the serious economic and engineering problems is the taking of small amounts of power from high tension lines with low cost, and giving continuity of service to the local power user, as well as preventing this from becoming a disturbing element on the larger system.

Power Loads

A very large increase in the number and variety of power applications for electric motors is at present taking place, in connection with mining applications, irrigation, the use of electricity in agriculture, pumping, the electrification of dredges and shovels, etc. In the near future the electric furnace will become a considerable power consumer. While electricity has been used to only a small extent in the construction of the Panama Canal and of the New York State Barge Canal, both of these will be operated entirely by electric motors. The New York Aqueduct is an excellent example of the extensive use of electric motors in construction work. During the last two years the use of synchronous motors has become very greatly extended, and certain conditions of industrial work are necessitating the development of special alternating current commutator motors.

Transformer Connections

Changing conditions in the development of apparatus modify from time to time our ideas as to the best practice regarding transformer connections. Experience in transmission work* at present makes the delta high-voltage transformer connection appear to be most advantageous, although there is no objection to a high resistance grounded Y. As this, however, approaches a delta connection, the latter is better for certain reasons. A point of importance which seems not to have been appreciated before is that, with a delta high-tension transformer connection, disturbances coming in over the line are divided in their effect between the windings of two transformers, instead of the whole impulse being impressed upon a single transformer.

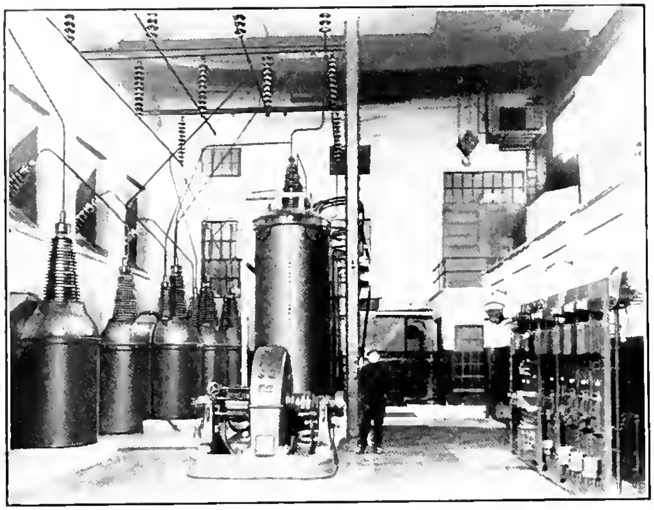


Fig. 6. Eastern Michigan Power Company. Interior of Substation showing 140,000 Volt Oil Switches, Insulators and Entrances

Apparatus*

Generators: The increase in size and number of units in recent power houses and systems has necessitated the use of external reactances, and an increase of the reactance in generators and transformers. Reactance as high as 20 per cent. is being contemplated for certain generators, which must, of course, be combined with approximately straight saturation curves. It is highly important that arrangements be made for the ventilation of generator pits, and these machines are now being designed with enclosed end rings in order to control the path of the moving air. The corona effects in armature windings have been studied and should be considered when machines are to be installed at high altitudes. As most machines are being sold on a maximum rating, and as the temperature is to be measured by resistance coils placed in the armature winding, it is important to have this matter clearly understood. 11,000 volt generation is now considered safe by designing engineers, and a considerable number of power houses are being installed with that generator voltage. Water-wheels are being designed with much larger outputs for single runners and with higher speeds for a given capacity, necessitating improved designs in vertical bearings; and the question is being solved in some cases by a combined pressure and roller bearing. Common practice has been to specify 100 per cent. excess speed in all

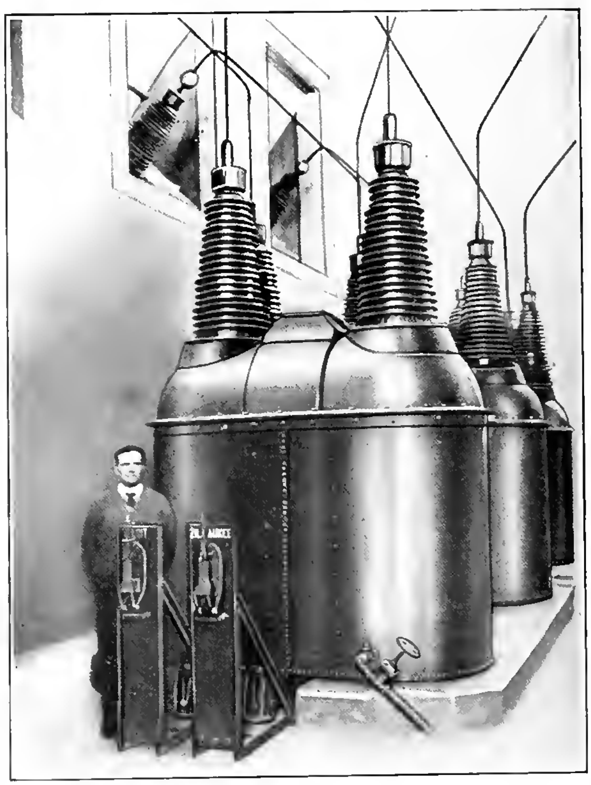


Fig. 7. 140,000 Volt Oil Switches in Zilwaukee Substation of Eastern Michigan Power Company

* Most of the apparatus which is touched upon in a general way in the present article is dealt with in greater detail by various engineers in the following pages.—EDITOR.

water-wheel generators, although in many cases this is excessive and necessitates unwarranted expense. In order to pave the ground for standardization by the A.I.E.E., plans are being carried through for a complete discussion of this subject. The efficiency of water-wheels has been much improved of late, and over 90 per cent. has been obtained in some recent tests.

Exciters: In certain cases the so-called Keilholtz system gives sufficient flexibility; and where this does not, the desired result may be obtained—as is done by the Ontario Power Co.—by the use of a system of alternating current water-wheel generators and a separate motor-generator set for each of the main generators. In this case an automatic voltage regulator is used on each direct current machine of the small motor-generator sets, and an auxiliary device is added which takes care of cross-currents between the machines.

Transformers: The cause for many transformer breakdowns is difficult of determination. After years of construction with the lowest possible reactance, this has been changed to reach a magnitude of sometimes 6 per cent. or 8 per cent. There is an increasing demand for large self-cooled transformers in places where the water supply is limited, and also for transformers suitable for use in outdoor sub-stations. Single and three-phase transformers are used as special conditions determine. The high-voltage bushings have of late given great satisfaction.

Switches: Switches have been increasing very considerably in capacity, and up to 45,000 volts have had specially-developed porcelain bushings. The large capacity units which are being installed have necessitated the use of suitable switches, and the 15,000 volt motor-operated oil switch has been developed for this condition. The development of relays is going to be one of the most important lines of future work.

Reactance: Reactance is one of the most important subjects under consideration at present, both as regards its introduction into apparatus, and its use externally both on the high and low-tension lines and in the main bus. Its use has necessarily not become standardized as yet. When made without capacity and used with a shunt resistance, it is in some cases being considered in connection with transmission lines and with the use of moderate reactance transformers.

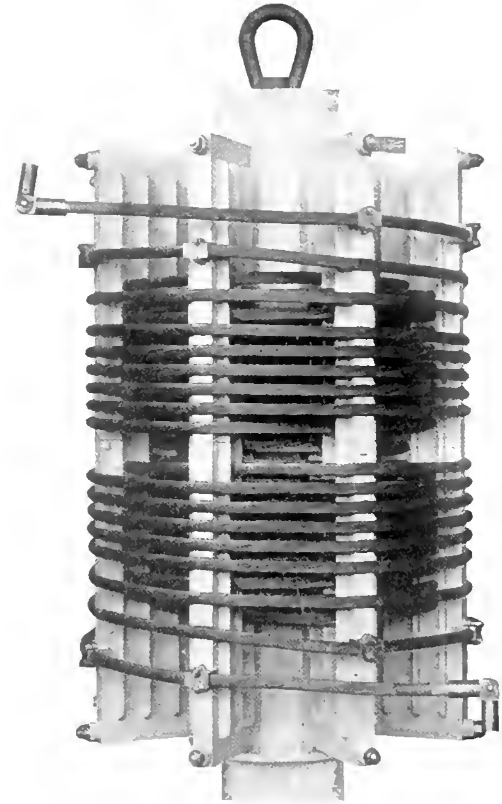


Fig 8. 300 Kv-a. 50 Cycle Power Limiting Reactance Coil

Transmission Lines: The majority of disturbances are due to causes which originate on the lines. The use of suspension insulators affects the decision regarding copper or aluminum as a conductor, while the grading of suspension insulators is being seriously considered. Hemp centers for conductors have caused serious trouble and are not being recommended. In some cases where suspension insulators are used in connection with ground wires, the insulation of the line seems to have been brought above the breakdown point of lightning.

In concluding this review of hydro-electric development, it may be of interest to append the following table, which shows at a glance the more important particulars of some of the recently-planned schemes:

RECENT HYDRO-ELECTRIC INSTALLATIONS

Name and Location	Transmission Voltage	Present Capacity of Plant	Ultimate Capacity of Plant	Kv-a. Capacity of each Generator	Kv-a. Capacity of each Transformer	Frequency	Total Length of Transmission in Miles	Date Installed
Eastern Michigan Pr. Co. Michigan	140,000 △	10,000		3333	3000 s-ph.	60	125	1912
Mexico Northern Pr. Co. Mexico	110,000 Y	31,200	46,800	7800	2500 s-ph.	60	125	1912
Mississippi River Pr. Co. Keokuk, Ia.	110,000 Y	135,000	270,000	9000	9000 3-ph.	25	150	1912
Georgia Power Co. Tallulah Falls	110,000 Y	30,000	60,000	10000	3333 s-ph.	60	160	1912
Ontario Power Co. (Hydro-El. Comm.)	110,000 Y	78,800	175,000	8776 7500	3000 s-ph.	25	280	1910
Sierra–San Francisco Power Co. Cal.	104,000 Y	34,000	34,000	8500	2233 s-ph.	60	100	1910
Yadkin River Pr. Co.	103,900 Y	27,000		6000 3000	2500 3-ph.	60	150	1912
Great Falls Water Pr. & Townsite Co. Montana	102,000 △	21,000	21,000	3500	1200 s-ph.	60	135	1910
Southern Power Co.	100,000 Y 50,000 △	66,000		3000	4000 s-ph. 2000 s-ph.	60 60	500 400	1910 1908
Great Western Pr. Co. California	100,000 △	40,000	100,000	10,000	10000 3-ph.	60	157	1909
Central Colorado Pr. Co. Colorado	100,000 △	20,000	20,000	5000	3333 s-ph.	60	183	1908
Appalachian Pr. Co., Va.	88,000 △	23,000	75,000	4000 2600	6000 3-ph.	60	180	1912
Mexican Lt. & Pr. Co.	85,000 Y	55,000		5000 12500	1800 s-ph. 6000 s-ph.	50	94	1910
Katsura-Gowa, Japan	77,000	30,000	56,000	7500	3500 s-ph.	50	65	1912
Pennsylvania Water & Pr. Co., Holtwood	70,000 Y	42,500	92,500	7500 10000	7500 3-ph. 10000 3-ph.	25	40	1911
San Joaquin Lt. & Pr. Co. Fresno, Cal.	69,500 Y	16,000	16,000	4000	1500 s-ph.	60	75	1910
Connecticut River Pr. Co. Vernon, Vt.	66,000 Y	20,000	20,000	2500	5000 3-ph.	60	60	1910
Central Georgia Pr. Co. Lloyd Shoals, Ga.	66,000 Y	12,000	18,000	3000	3000 3-ph.	60	65	1910
Power Construction Co. Shelbourne Falls, Mass.	66,000 Y	18,000	24,000	2000	3000 s-ph.	60	30	1912
East Creek El. Lt. & Pr. Co., Ingham Mills, N.Y.	60,000 △	8400	8400	2800	2800 3-ph.	25	25	1912
Washington Water Pr. Co. Washington	60,000 Y	48,600	100,000	2250 5000 13900	2250 3-ph. 5000 3-ph. 5000 s-ph.	60	260	1911
Michoacan Pr. Co. Mexico	60,000 Y	10,000		1500 3500	600 s-ph. 2300 s-ph.	60	75	1910
Jhelum River Hydro-El. Scheme, India	60,000 △	4000	12,000	1000	1000 s-ph.	25	50	1908
Great Northern Power Co., Minnesota	60,000 △	22,500	60,000	7500	7500 3-ph.	25	14	1906
Electrical Development Co., Niagara Falls	60,000 △	62,000	95,000	8000 10000	2670 s-ph.	25	80	1911
Puget Sound Pr. Co. Washington	58,000 Y	14,000	28,000	3500	2333 s-ph.	60	46	1907
Chattanooga-Tennessee River Pr. Co.	45,000 Y	22,500	22,500	2250	2250 s-ph.	60	33	1912
Cia Docas De Santos Brazil	44,000 △	15,000	75,000	3000	1000 s-ph.	60	33	1910
Schenectady Power Co.	30,000 △	15,600	15,600	4000 1800	4000 3-ph. 1800 3-ph.	40	27	1908
Mohawk Hydro-El. Co. Ephratah, N. Y.	22,000 △	3750	5000	1250	500 s-ph.	60	11	1911

GENERAL TREND OF DEVELOPMENT IN TRANSMISSION AND DISTRIBUTION OF ELECTRIC POWER AS SHOWN BY RECENT TRANSFORMER PRODUCTION

By W. S. Moody

Engineer, Transformer Dept., General Electric Company

The general trend of development in transmission and distribution of electric power is illustrated in a very striking manner by the curves shown in this article. These are all based upon figures of the transformer business of the General Electric Company; but doubtless the conclusions drawn therefrom may safely be applied to the development of the power transmission business in the United States. Some of the points brought out by the curves are: The rapid and regular increase in maximum voltage; increase in kv-a. capacity of high voltage transformers; extension of the limits of what is known as "low voltage" for urban distribution; increase in use and capacity of self-cooled transformers and outdoor transformers, and in the number of automatic feeder regulators in use.—Editor.

It is often of interest and value to the business man who is, day after day, concentrating his energy and thought on what is directly before him, to forget his immediate problems and take a general survey of accomplishments made in the more or less immediate past; and from this review to form a conception of the general tendency which is being taken by the business in which he is particularly interested. It is more than likely that the general directions in which transmission and distribution of electric power have been rapidly developing during the past few years are not fully appreciated, even by many of those taking a most active part in these accomplishments. I therefore trust that the following data which I have compiled may be of timely interest.

First, I would draw attention to the rapid and rather regular increase in voltages used for transmission (not only an increase in maximum voltage), and also to the remarkable increase in kilovolt-ampere capacity of the high voltage transformers produced, which is, of course, a direct measure of the amount of power transmitted.

Fig. 1 shows in graphic form the production of transformers in kilovolt-amperes for the years 1900 to 1911 inclusive. This tabulation includes only transformers larger than 100 kv-a., as smaller units rarely are used on transmission lines. Each year's production is subdivided into five classes, the bulk of the production being in the class covering transformers for 50,000 volts and below. The next class includes transformers from 50,000 to 60,000 volts; the third class from 60,000 to 80,000 volts; the fourth class from 80,000 to 100,000 volts; and the fifth class, or upper division, transformers over 100,000 volts. It will be seen that previous to 1901 no transformers for over 50,000 volts were in use, and that since that time there has not been any marked increase in the use of transformers between 50,000 and 60,000 volts.

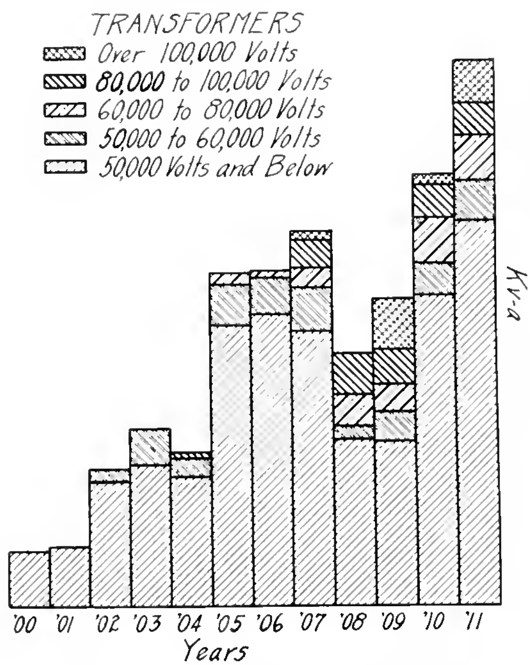


Fig. 1. Transformer Production, Classified by Voltages

Transformers for 60,000 to 80,000 volts were first built in quantity in 1905, and for several years the production in these transformers has been about equal to that of the second class. A few transformers for voltages between 80,000 and 100,000 were made in 1904; but they were first built in quantity in 1907, in which year also a few transformers were built for 110,000 volts. During 1909 about 17 per cent. of the total were over 100,000 volts, and in 1911 about 9 per cent.

A considerable quantity of those built in 1911 were for voltages in the neighborhood of 140,000. The chart also shows that, in 1911, there was about the same amount of business

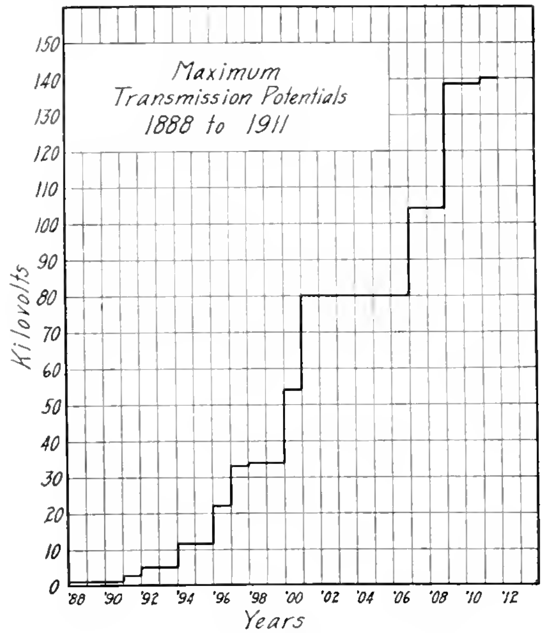


Fig. 2. Maximum Transmission Potentials

in transformers for over 100,000 volts as in the class between 60,000 and 80,000 volts, and more business than in the other two classes between 50,000 and 100,000. From this it would seem that transmissions at from 100,000 to 140,000 volts can now be regarded as thoroughly practical.

There is, perhaps, one more conclusion worth drawing from this record. The increase in voltage of transmission indicates, of course, the increase in distance over which the power is transmitted; and we must conclude that the possibilities of comparatively short-distance power transmissions, such as 50 or 60 miles, are becoming exhausted, and that the longer distance transmissions of 100 miles and upwards are fast becoming necessary. This has been particularly noticeable in California and in the northern part of the United States, where abundant water power is available, at a considerable distance, however, from points of large consumption; and the fact that difficulties in these high voltage transmissions, including transformers, line protection, etc., have been fairly well met, will no doubt lead to much further development of such distant powers in the near future. Whether it will be found profitable to still further increase transmission voltages is problemetical, because of corona limitations; but it will be noted from Fig. 2 that the increase in voltage has averaged about 10,000 volts per year ever since 1894. As an indication of the immediate further extension of the upper limit of voltage, it may be mentioned that numerous requests have been made during the current year for transformers of voltage of 150,000 and over.

Fig. 2 shows the maximum potential for which transformers have been built from 1888 to 1911. The first 20,000 volt transformers were built about 15 years ago; and the present maximum being approximately 150,000 volts, shows very close to 10,000 volts per year as the average increase. Another point which a study of the records

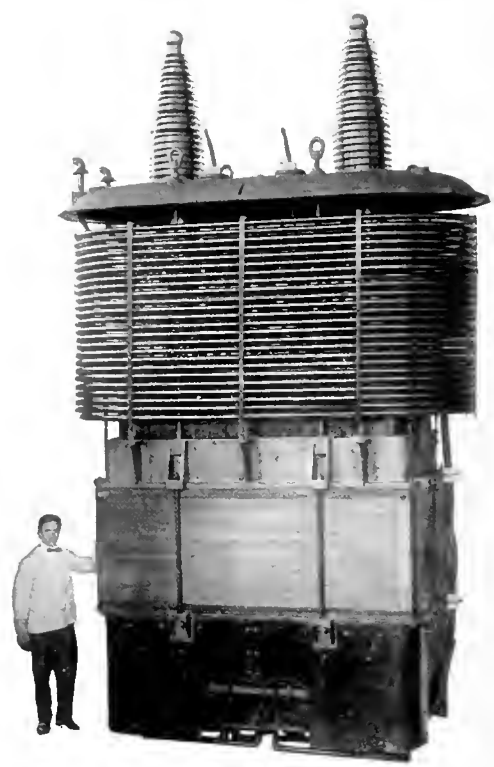


Fig. 3. 3000 Kv-a. 140,000 Volt Water-Cooled Transformer Without Case

has brought out impresses very forcibly upon one the fact that urban distribution is being carried on at voltages considerably higher than previously. For some 15 years, practically all such distribution was done with voltages between 1000 and 2400. During the last four years, however, the business in small transformers for 5000 to 15,000 volts has wonderfully increased, as shown in Figs. 4 and 5. In transformers for approximately 6600 volts, for instance, the production for 1911 was more than 30 times the production three years ago. Fig. 5 brings out the fact that transformers designed for approximately 10,000 volts are beginning to be used for such distribution. The growth in this business has not been as marked as the growth in 6600 volt transformers, but has increased approximately 12 times in the same period.

There are two points which these data make prominent. First, the general "low voltage distribution" class of transformers now includes transformers up to 10,000 volts, and possibly should be considered to reach 15,000 volts; whereas previously 4,000 volts was considered the safe maximum limit for these "direct-to-customer" transformations. The second point is that the art of transformer manufacture has so materially advanced that the cost of such transformers is relatively low compared with the savings due to the increase in voltage, and that with these low costs the transformers are still fully dependable.

A glance at transformer production for a number of years past brings us to another line of thought which is also very instructive.

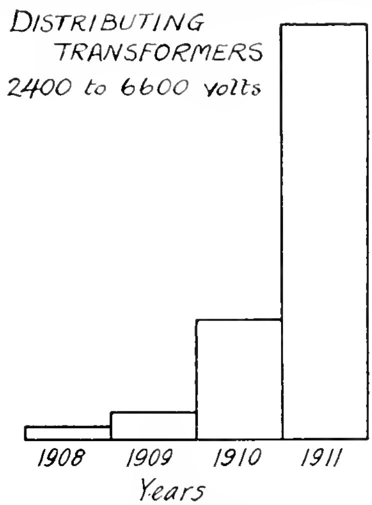


Fig. 4. Production of Distributing Transformers 2400 to 6600 Volts

Fig. 6 shows the maximum unit of transformer built from 1888 to 1911. About 1899 the 1000 kv-a. unit was first exceeded, but it was not until 1905 that transformers were built for over 3000 kv-a. in a single unit. In the last six or seven years the

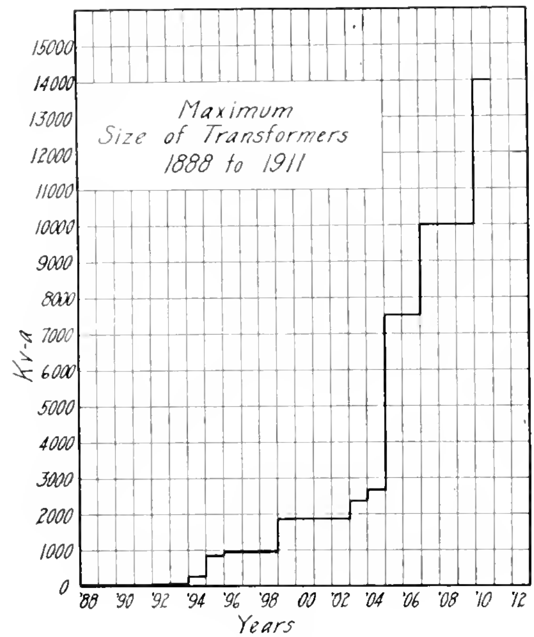


Fig. 6. Maximum Size of Transformers

increase has been very marked, and this, of course, goes hand-in-hand with the increase in voltage. In other words, it would not

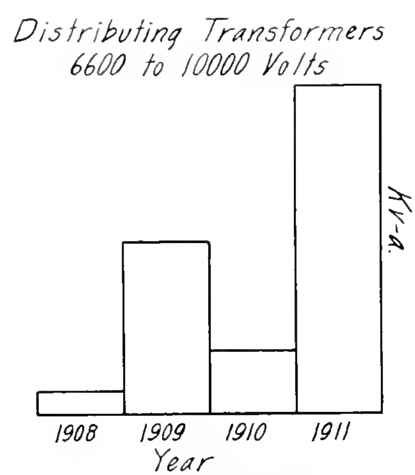


Fig. 5. Production of Distributing Transformers 6600 to 10000 Volts

pay to transmit small quantities of power at very high voltage; and it is, therefore, only where very large quantities of power can be developed, and where very large generating and transmission units are practical, that there is any possibility of profit in such transmissions.

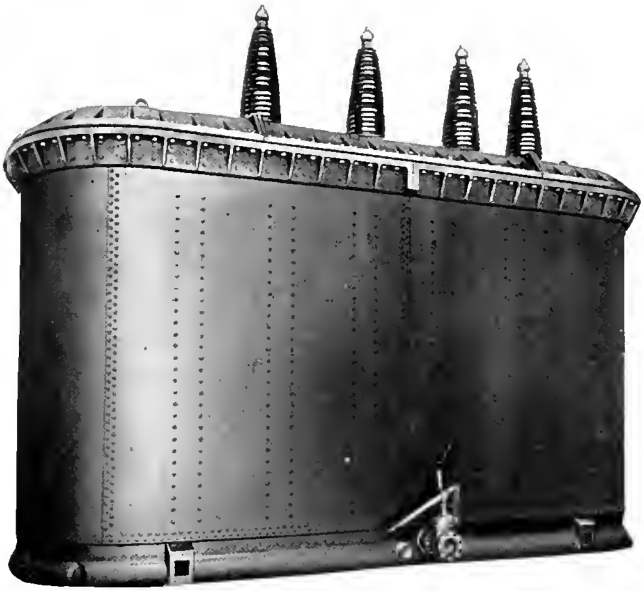


Fig. 7. Three-phase Water-cooled Transformer 1400 Kv-a. 97,000 Volts Between Lines

Fig. 8 shows the average kv-a. capacity of large transformers built during the last twelve years. This also shows an interesting change in practice; for not only has it been found necessary to build very high voltage transformers in large capacity, but it has also been found advisable to use the parts so developed for still larger moderate voltage sizes year by year. This figure refers only to units of 500 kv-a. and over. Fig. 9 gives the production of all sizes of transformers since 1888. The trend of this curve certainly does not show any sign of becoming flat. It has for years been said that the annual production of transformers must begin to reach a maximum and that production would cease to show such a marked increase; but, as this curve shows, no one can yet see that the transformer business, and, therefore, the development of transmissions, has yet begun to reach its limit.

Self-cooled Transformers

There has been a decided tendency in recent years toward the use of fairly large self-cooled transformers; that is, transformers filled with oil which depend entirely on radiating surface for the dissipation of heat, no forced circulation of air, water or oil being used, and, therefore, no auxiliary cooling apparatus being required. Considering transformers of 250 kv-a. and larger only, we find that the business has increased several times from 1908 to 1911, the increase in total kv-a. per year being over seven times. The average capacity has also increased in this same time from 430 kv-a. in 1908 to over 1000 kv-a. in 1911 with corresponding increase in the sizes of individual units.

Outdoor Transformers

There has also been a marked increase in demand for transformers which can be installed directly out of doors. This practice is one which commends itself very strongly in certain classes of work, in isolated mills for instance and in small cities along the lines of long transmission, as well as in tie-in substations where several different systems are connected together. An expression of the increase of this also in percentage would be meaningless, because it is practically all of recent date. Transformers are in successful outdoor operation, however, for voltages as high as 110,000, and in sizes as large as 3330 kv-a. With increased familiarity of the power companies with this practice, it will doubtless extend

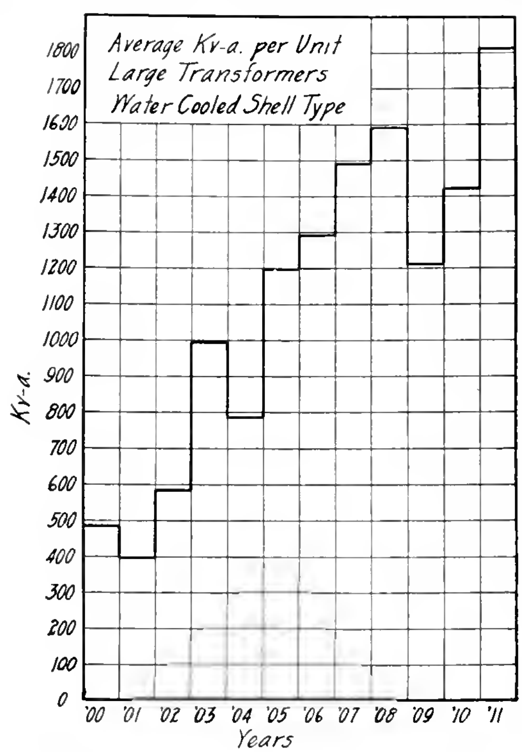


Fig. 8. Average Kv-a. Per Unit, Large Transformers

to a considerable degree. Fig. 10 shows a self-cooled outdoor transformer, in which the type of bushings used for this service can be seen.

Looking over in detail our more recent output, we have observed other points which cannot well be brought out in diagrams. One of these interesting points is reactance. Transformers of sizes over 250 kv-a. built in 1908, we find had reactance averaging in the neighborhood of 3 per cent. Similar designs built during 1911 show that this average has increased to between 5 and 6 per cent. This increase has been brought about on account of the general appreciation of the value of reactance for current limiting and regulating purposes. The increased size and speed of generating units, and the corresponding reduction in their reactance, has made such an increase in the inherent reactance of the transformer very desirable and often necessary.

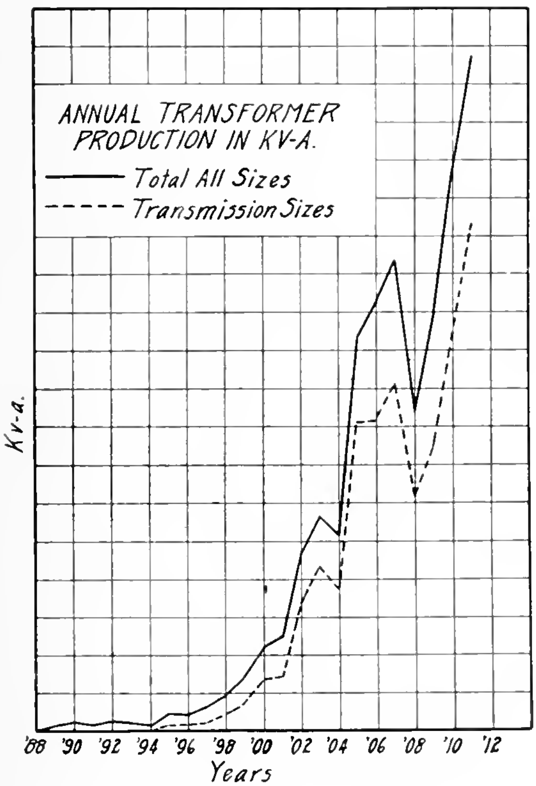


Fig. 9. Annual Transformer Production in Kv-a.

The remarkable increase in the use of automatic feeder regulators is shown in Fig. 11, and this is a direct indication of an important change in method of operation, viz., the substitution of close automatic control in the *local* circuits in place of a close regulation of transmission voltage.

Fig. 10. Self-cooled Transformer Outdoor Type

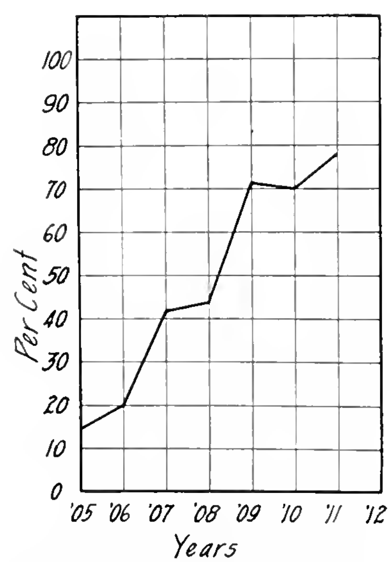


Fig. 11. Automatic Feeder Regulators

NOTES ON CONTROL AND OPERATION OF HIGH VOLTAGE TRANSMISSION SYSTEMS

By Charles P. Steinmetz

Chief Consulting Engineer, General Electric Company

The article in substance shows that relatively low voltage transformers and generators, because of their negligible electrostatic capacity and hence inability to respond to external surges and similar transient phenomena, may be switched on and off transmission lines without harm; provided the end turns of the winding connected to the line are heavily insulated or protected by choke coils. On the other hand, high voltage transformer coils possess considerable capacity and are therefore of an oscillating nature, similar to the transmission line; they are subject to dangerous internal surges and surges entering from the line, which fact makes switching between transformers and line a dangerous practice. This danger may be obviated by doing all switching on the low tension side.—Editor.

In a consideration of the problem of controlling and operating high voltage transmission systems, the first question which arises is, what is high potential? To the bell hanger of the early days, the 110 volt incandescent lamp circuit was high potential, while the modern transmission engineer considers the 11,000 volt generator circuit as low potential. For the present purpose, the dividing line between high potential and low and medium potential is best drawn at that voltage at which the electrostatic capacity of the transformer becomes appreciable, since it is at this point that phenomena appear which do not exist at lower voltages, and which require a material change in the methods of control of the system to insure maximum safety and thus reliability of operation.

Theoretically, every electric circuit has capacity as well as inductance, and every circuit therefore stores energy electrostatically (or dielectrically, as more preferably called) and electromagnetically, through capacity in the dielectric field of the voltage and through inductance in the magnetic field of the current, respectively. At medium voltages, the only circuits in which the electrostatic capacity is sufficiently large to make itself felt are the overhead lines and underground cables; while in generators, transformers, etc., the electrostatic capacity is so small as compared with the inductance that the electrostatic energy is negligible and the circuit acts as one containing inductance, but not capacity.

In such an inductive circuit without capacity, the only change which can occur in the stored energy is an increase or decrease, such as accompanies the inductive discharge which occurs when operating a motor field; oscillations, waves and impulses can not exist, and when such oscillations or waves approach an inductive circuit (as from a transmission line) they can not enter it, but are stopped and reflected at its terminals. They then produce high voltage differences at the end turns of the inductive circuit, which may be represented by a transformer. Since in an inductive circuit without capacity the high voltage which may be produced by an electric wave approaching it, as lightning, is limited to the terminals, effective protection can be secured by extremely heavy insulation of the end turns as is customary in transformer construction, or by inserting an inductance—a choke coil—between the transformer or generator and the line. The high voltage then appears between the turns of the inductance, but does not reach the transformer, or reaches it with greatly reduced intensity.

Oscillations, stationary waves, traveling waves and impulses can exist only in circuits containing electrostatic capacity as well as inductance. At medium voltage, the electrostatic capacity of the transformer is negligible, as we have seen; it increases at a very high rate, however, with increasing voltage. The stored magnetic energy of the transformer is given approximately by its reactance voltage (commonly called "impedance voltage") times the current. In modern power transformers, irrespective of the voltage, the reactance is usually chosen between 4 and 6 per cent*, and the stored magnetic energy thus equals approximately from 4 to 6 per cent. of the transformer rating.

If we assume a transformer rebuilt for n times the voltage, then the length, and with it the capacity of the high potential winding, is approximately n times as great as before, and at n times the voltage thus gives n^2 times the

* In the early days, transformers had impedances of 15 to 20 per cent., and thereby gave poor voltage regulation. To improve the voltage regulation, the designs were changed to those giving lower impedance, so that finally impedances as low as 1 to 2 per cent. were produced. Then, however, experience showed that in high power systems such transformers are unsafe, owing to the enormous strains produced on the transformer and the system by the excessive starting currents, and, in case of accidents, by the excessive short circuit currents permitted by such low impedance transformers. This made it necessary to increase the reactance and devise transformer designs of 4 to 8 per cent. reactance. In high power central station practice, this danger has been forcibly impressed upon the operators, and usually a sufficiently high reactance is specified for the transformers to give reasonable safety of operation. In transmission practice, the recognition of the necessity of a reasonably high transformer reactance, to insure safety of operation, is not yet so universally recognized.

capacity current, since the capacity current is proportional to voltage times capacity. At n times the voltage, n^2 times the capacity current gives n^3 times the capacity volt-amperes, which represent the stored electrostatic energy.

This rapid increase in the capacity energy of the transformer with increasing line voltage means that the voltage at which the capacity effect becomes appreciable is fairly definite—about 60,000 volts. Hence below 60,000 volts the transformer is an inductive apparatus, into which oscillations and waves cannot penetrate; above this voltage, the high potential coil of the transformer is a circuit capable of oscillations and electric waves, into which oscillations and other disturbances from the transmission line can enter, can traverse the transformer winding and form nodes and voltage crests inside the transformer. This accounts for the fact that line disturbances occasionally produce break-downs far inside of the high potential transformer winding. The choke coil which protects the transformer at lower voltages may then become a source of danger: while it still keeps line disturbances away from the transformer, it at the same time obstructs the exit into the line of oscillations and other disturbances which originate in or at the transformer, and by reflecting them into the transformer increases their voltage and thereby their destructiveness.

The most frequent, and therefore most serious source of high voltage high frequency disturbances is switching; and especially dangerous is switching at the transition point between two oscillating circuits of different character, such as a transmission line and a transformer high potential coil. Thus high potential switching between transformer and transmission line is dangerous, especially to the transformer, and should be avoided as much as possible.

As seen, this applies only to those high voltages where the transformer capacity is appreciable and the transformer thus capable of oscillating. At lower voltages, where the transformer is a simple inductive circuit, switching between transformer and line is harmless and is the usual custom, as the impulse wave produced at the switch can not enter the transformer and is taken care of by the extra insulation of the end turns or by the choke coil. On the other, or line side, the impulse passes into the line and is rapidly dissipated by the line resistance, without giving rise to abnormal dangers. Thus the danger of switching, where such exists, is found not in the line but in the apparatus connected to the line. This is not always realized.

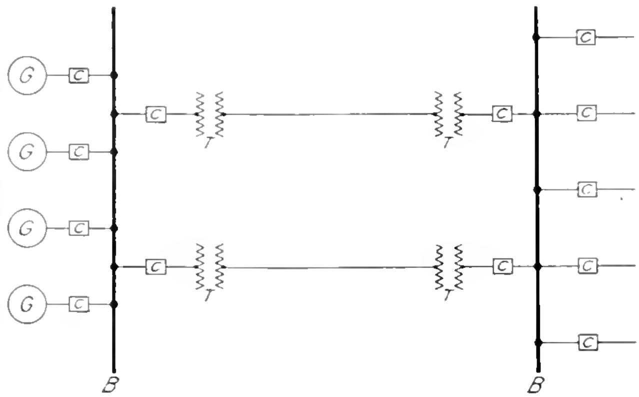


Fig. 1

In the control and operation of high voltage transmission systems it is therefore strongly to be urged that all the switching be done on the low tension side of the transformers, where it is practically safe; and preferably to have no circuit breakers between transformer and transmission line, but to connect the transformers permanently to the line and consider them as a part of the line. The safest arrangement would therefore be as indicated in Fig. 1, where G represents the generator, T the step-up and step-down transformers, B the low tension busbars, and C the circuit breakers. Disconnecting switches, that is, switches which can be opened only when there is no voltage on the circuit, would obviously be installed on either side of every transformer and circuit breaker, so as to isolate this apparatus for inspection or repair. As will be seen, in this case the high potential lines are separated and the paralleling done only on the low voltage side of the transformer. This offers the advantage that a ground on one line does not ground the other line also.

A frequent objection to such an arrangement is, that a disabled line also puts its transformers out of service, and arrangements are therefore desired for connecting every transformer or generator to every line. This can be done, but usually leads to such a complication in the switching and controlling arrangement that the gain is not comparable with the increased risk of accident resulting from the greater complexity of the arrangement. In very high voltage circuits especially, the simplest possible arrangement offers such an advantage in reliability that every effort should be made towards it.

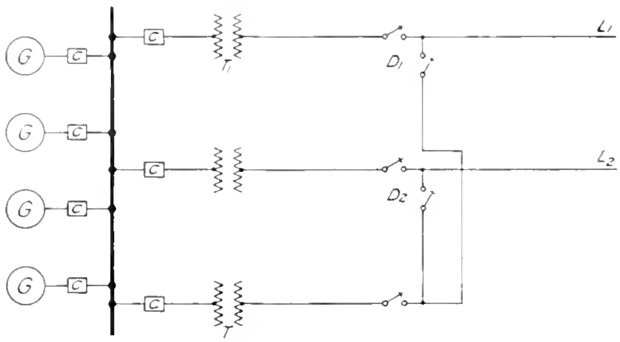


Fig. 2

In general, a spare transformer unit would probably be provided, so that in case of a breakdown in a transformer unit, its transmission line could be maintained in operation. Without material decrease in simplicity, the arrangement shown in Fig. 2 might then be used, in which T shows the spare transformer unit, which can be connected to either line by the disconnecting switches D. If then transformer T_1 burns out, its circuit breaker C_1 cuts line L_1 off the busbars. By means of the disconnecting switches D_1, the line L_1 is then disconnected from transformer T_1 and connected to transformer T, and the latter then energized by its circuit breaker C.

This operation involves a shut down of line L_1; but it is probable that with two lines in a high voltage transmission system, a transformer burnout in one line would usually shut down this line in any case. The same arrangement can then be used, in case of a breakdown of one line, to connect the spare transformer to the other line and carry double load over it, without a corresponding margin in transformer capacity.

While high potential switching is dangerous and should be avoided between oscillating circuits of different character, such as line and high potential transformer, it is harmless, as we have seen, between line and inductive circuit. It also is harmless between oscillating circuits of the same character, such as sections of the line, and therefore no serious objection exists against high potential switching between branch lines and main lines, or against high potential switching in the main lines at considerable distance from the stations for the purpose of sectionalizing the lines, in order to cut out a disabled section of a line and operate the rest of it in parallel with the second line. However, in case of line switching, any transformer located near the switching point would be endangered, and would thus require special protection.

The case where a simple arrangement of lines and transformers with low tension switches becomes difficult to arrange without material sacrifice in the flexibility of the system, occurs where several stations feed into the same transmission lines. Where the stations are near together, it is often feasible (and then very desirable) to use one station only as transformer station and feed from the other stations at a lower voltage (6600 or 11,000 volts) into the low tension busbars of the main station, as indicated for station B in Fig. 3. This offers a convenient way of utilizing induction generators in smaller stations and thereby eliminating practically all control from the smaller stations; that is, control them from the main station, as indicated at C in Fig. 3.

Naturally, in the manifold requirements under which transmission systems have to operate, instances will always occur where high tension switching is unavoidable, and thus no rigid rule can be established. Obviously, the larger the number of lines and of transformers which are connected together, the less are the disturbances, and with it the danger resulting from disconnecting one of the lines or transformers.

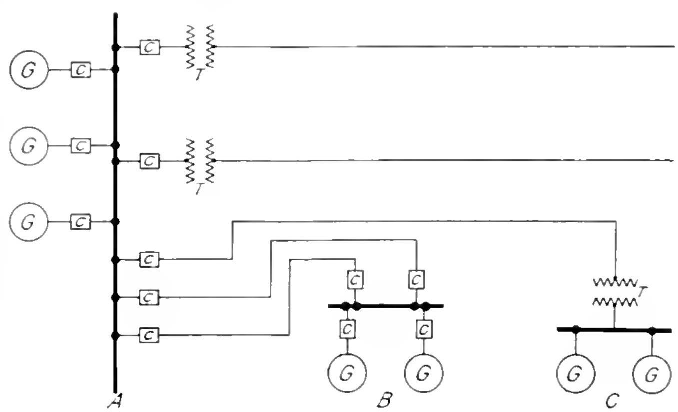


Fig. 3

SOME PROBLEMS IN CENTRAL STATION AND SUBSTATION OPERATION

By C. W. Stone

Manager, Lighting Department, General Electric Company

Under central station questions are considered, *first*, excitation: objections to individual direct-connected exciters; objections to motor-driven exciters and auxiliaries taking current from system; advantages of independent turbine-driven low-voltage generator for supplying exciters and auxiliaries; storage batteries for excitation with automatic regulator; use of circuit-breakers on exciters. *Second*, means of limiting trouble at times of short-circuit, by sectionalizing the busbars; by external reactances; by grounding the neutral, with or without resistance. Under substation apparatus are considered the relative advantages of synchronous converters and motor-generator sets. For large sizes a considerable field of usefulness may be found for the 3-unit set, with two d-c. machines and one a-c.—Editor.

In preparing this article it has been my intention to present some of the problems of central station and substation operation which are usually held to be of little account, but which, to my mind, are of very vital importance. In order to simplify the treatment, I have divided the paper into two parts; and shall consider those problems relating to central stations and those relating to substations under these two main headings.

Steam Central Stations

The vital part of the generating station is the exciter system. There is considerable diversity of opinion regarding the construction and operation of the exciter equipment, which is consequently very much less standardized than other parts, such as the operation of generating units, the lay-out of the boiler room, and so on. In the last few years there has been a growing sentiment in favor of direct-connected exciters. I think this has been largely due to the mistaken idea that, if each of the generating units is made self-contained, it tends towards simplification, and consequently reliability. While I believe very firmly that simplicity is what we should all aim for, I think it can be carried too far; and the very striving for simplicity may result finally in complication.

If we know — which we seldom do — what the ultimate capacity of the central station is going to be, we can then decide on the size of the units, and select the fewest number which will give efficient operation for the required load. Unfortunately, however, the capacity of the central station generally increases from year to year, and the load factor increases or decreases; so that, where we might build a station today containing three units, in a few years six or eight, or possibly ten, units might be required. With a station containing three units there is some justification for a direct-connected exciter; but where eight or ten units are in question there is no justification whatever, as it simply means complication.

There is another very serious objection to direct-connected exciters. Trouble with the direct-connected exciter may involve the shutting down of a large piece of apparatus at a time when its capacity is greatly needed, as, unfortunately, such accidents usually occur at times of peak load. A 25 kw. exciter, for instance, excites a 5000 kw. turbine. If anything happens to a brush, a brush-holder, a field winding, or one of the bearings, or to any other part of this small 25 kw. exciter, we lose the capacity of a 5000 kw. machine, at least temporarily, until such time as we can make other arrangements for excitation. How much simpler it would be if these machines were all excited from a common source, operated by means of a steam-driven exciter with a motor-driven exciter floating on the system. We should thus have two independent sources of excitation, the steam-driven and the motor-driven. Trouble which might develop in either of these sources would not necessarily involve the operation of the system, and certainly would not affect the operation of any of the individual units of the system.

It is the writer's opinion that the simplest and best method of obtaining excitation in the steam-driven power houses is to install a non-condensing turbine unit, consisting of a non-condensing steam end with a low voltage generator. All the auxiliaries, such as circulating pumps, exciters, etc., would then be motor-operated, current being taken from the low voltage generator. In the case of larger stations it might be advisable to have two of these low voltage generators. The steam from the turbines would, of course, be taken to the feed water heaters, and nothing but low voltage alternating current would be carried to the motor-driven auxiliaries. As an emergency connection with this exciter system, transformers could be installed so that the auxiliaries could be operated from the main system if necessary.

A great objection has always been raised against motor-driven exciters and motor-driven auxiliaries taking current from the system, on account of the fact that any short-circuit may cause them to drop out of step, and thus cause a shut-down. With the independent system described above, no such effect could of course be realized, since the excitation system is entirely separate and wholly in the control of the operator; so that, no matter what may happen outside of the station, he is assured of reliable operation of this, the most vital point of the system.

Another great objection to electrically-driven auxiliaries operated from the system has been brought out in the operation of some of the large systems. Where there are several large machines operating in parallel, with small auxiliaries operated from the system, the leads are necessarily small, the current transformers operating the relays are of small capacity, and consequently it is difficult to obtain adequate protection against trouble on these auxiliary circuits. If, in the case of the separate system, the tie connection or emergency connection described above were used, this trouble would not be apparent, since, with only one tie connection, the feeder would probably be of a capacity equal to that of the other feeders going out from the station; the protective devices therefore could be made as reliable as those on any of the feeder circuits, and of course much more reliable than those used for independent individual units, such as would be installed if independent auxiliaries were operated from motors from the system. The efficiency of such a system, of course, would be higher than that of any other now used; its first cost would usually be lower; and its reliability very much higher.

The use of storage batteries on exciter systems has been increasing considerably, and in many cases is very desirable. The use of these batteries has been more or less limited, owing in part to the fact that it was difficult to control such a system by means of an automatic voltage regulator. A system has been devised, however, which makes it possible to control the exciter system by means of such a regulator, with a storage battery floating on the system. It is operated somewhat as follows:—The exciters are operated in parallel, and are usually shunt wound. Floating on the exciter bus is the storage battery. Another set of exciter busbars is installed, called the exciting busbars, and the generator fields are connected to the bus. Between this bus and the exciter busbar a booster is installed, which can be operated to boost or lower the voltage, its field being controlled by an automatic voltage regulator. The exciter busbar is thus run at constant potential, and the voltage fluctuation is entirely on the exciting busses, being caused by varying the booster voltage by means of the regulator. With such a system the failure of any or all of the exciters should not seriously affect the system; since the storage batteries would furnish the excitation, and the voltage control be handled by means of the booster in exactly the same manner as if the exciters were themselves in operation. In case of trouble with the booster, it could be immediately short-circuited without doing any serious harm, and the system continue to operate without the automatic regulator.

With no exciter system is it advisable to install overload circuit-breakers, as it is preferable to run the risk of burning up and destroying an exciter than to run the chance of any shut-down on the system. Whatever protection is used, therefore, should be in the form of reverse current relays on the d-c. ends of the set, the a-c. ends being protected by overload devices set very high, and preferably of the time-limit type.

When the systems are of considerable size it is desirable to operate them in sections, i.e., to divide the busbars into two or more sections. This, however, is not the most economical method of operation, and consequently it has been customary to operate all the units in parallel on one system. With the older type of generating units, i.e., engine-driven units, there were two reasons why this could be done without causing any serious trouble in case of a short-circuit. In the first place, the stations themselves were not of very great capacity, and consequently the rush of current at times of short-circuit was limited. In addition to this the slow speed generators driven by the engines were of higher reactance than the more modern type of turbine-driven generator, and consequently the current was still further limited by this extra amount of reactance.

Within the last few years, the advent of the steam turbine generator, and the large increase in the capacity of the central station, has necessitated that some method of limiting the current at times of short-circuit be developed. The first step was to sectionalize the busbars and thus limit the amount of capacity connected together in parallel. The next step was to develop a reactance which could be used in circuit with each of these machines, so as to still further limit the flow of current in times of trouble. The next step was to develop a reactance which could be put in the busbar between the sections, thus allowing the operators to operate all machines in parallel, and yet at times of trouble limit the rush of current.

The design of these reactances, as has been pointed out elsewhere*, involved the solving of a number of new problems. In the first place it was desirable to avoid the use of iron in their construction, as the iron itself would soon have become saturated at times of short-circuit, thus limiting the amount of effective reactance. In addition to this, the construction had to be made as nearly fire-proof as possible, and very strong, since the greater part of the shock caused by short-circuit had to be absorbed in the reactance. A form of reactance was developed with a hexagonal concrete core. In this concrete were embedded radial arms, around which bare cable was wound. The cable was insulated by mica sleeves at the point of contact with the radial arms, and usually two or three layers were wound on the cores. One of the largest installations of the kind is in the Quarry Street and Fisk Street stations of the Commonwealth Edison Co. where each machine is protected by its own reactance, which limits the flow of current in case of short-circuit to about twelve times normal. The busbar is divided in the Fisk Street station, and between the two sections is installed a busbar reactance. The tie-feeders of the Quarry Street station are each protected with reactances, and the entire system thus operated in parallel. A recent short-circuit in a man-hole near the station demonstrated the usefulness of these reactances. The trouble was confined entirely to the particular man-hole, the switches on the feeders involved opened with no distress, and the system continued to operate without apparent disturbance. Similar short-circuits before the installation of the reactances usually resulted in damage to a number of switches, often damage to one or more of the generating units, and disturbance to the system such as caused the dropping out of step of most of the synchronous apparatus in the substations.

* See paper by Dr. C. P. Steinmetz, GENERAL ELECTRIC REVIEW, Sept. 1911.

Another method of limiting the trouble in case of short-circuit has been to ground the neutral of the system, in some cases with resistance, and in some cases without. Grounding the neutral of the generators on an underground system protects the system, as a rule, from a complete short-circuit across the phases, since most of the trouble on underground cables starts first as a puncture from one conductor to the lead sheaths. With a ground on the neutral of the system this would cause the circuit-breaker of the particular feeder to open. Without the ground connection, the circuit-breaker of the feeder would not open until the puncture had developed sufficiently to cause a short across the phase conductor. This usually takes a certain definite period of time, and considerable burning may, therefore, take place before the short develops; and after the short develops it is usually very much more severe than it would be with the grounded neutral system.

The insertion of resistance in this neutral ground circuit is for the purpose of limiting the flow of current in case of a break-down of any of the cables; although too much resistance would mean that the switches would not open, and consequently the fault would probably develop into a short across the phase. It is therefore advisable to limit the amount of resistance installed, and in all cases it should be so designed that, in case of short-circuits, a sufficient amount of current can flow to trip the switch with the lowest overload setting. Even with this amount of resistance in circuit, the feeder will not be disconnected from the system as promptly as it would be without the resistance; since, of course, in case of puncture from one conductor to the lead sheaths there is a certain amount of resistance in this circuit. In other words, it is not a dead short from one of the conductors to ground, but it must continue to develop until sufficient current passes to trip out the circuit-breaker. Without the resistance in the ground circuit, this point is reached very much earlier. In general, it may be said that with the installation of reactances in circuit, there is less need for resistance in the neutral circuit, as the current flow is limited by these reactances.

Substations

Various types of substation machines are in use, and no attempt will be made here to describe them all. It may be of interest, however, to bring out some of the points in connection with the operation of certain apparatus in this class.

In the operation of railroads, interurban and urban, practice has become pretty well standardized in this country, and in practically all cases the primary generation of power is at 25 cycles, and synchronous converters are used. These machines are nearly always compound wound. Reactance is used either in the form of a separate device connected in circuit with the converter, or in the form of the internal reactance of the transformer itself which may be designed of a high value.

In lighting systems where direct current is necessary, the practice has not become standardized to the same extent, and numerous types of apparatus have been developed. Where the primary generation of power is of 25 cycles, synchronous converters are used almost exclusively in this country. Where the primary generation of power is 60 cycles, however, we find motor-generator sets driven by induction motors, motor-generator sets driven by synchronous motors, and synchronous converters. In almost all cases the direct current end of the machine is shunt wound, whether it is a converter or a motor-generator set.

With motor-generator sets—whether induction motor or synchronous—the efficiencies are necessarily somewhat lower than is the case with converters, the difference being greater in the 25-cycle machines, but still quite marked with 60-cycle apparatus. A number of years ago induction motors were used to drive the d-c. generators in these motor-generator sets, as it was felt that they were more reliable and more stable. During the last few years, however, the tendency has greatly changed, and synchronous motors are used almost exclusively. These synchronous motors are reliable and stable in their operation, since they are equipped, as a rule, with heavy squirrel cage windings which act as anti-hunting devices. They may consequently be considered practically as reliable as any of the induction machines, while they possess the very great advantage that, instead of lowering the power-factor on the system, they may be used not only at unity power-factor themselves, but can be overexcited and thus raise the power-factor of the system, making up for deficiencies in other apparatus. This latter feature is particularly valuable on a 60-cycle system, since as a rule a large proportion of the load on such systems is carried by alternating current; whereas, with 25-cycle systems, as a rule most of the load is carried by direct current. In such 60-cycle systems the installation of induction motors, arc lamps, etc., results in a low power-factor which affects the load capacity of all the transformers, feeders and generating apparatus, as well as the regulation of the system. If, therefore, the substation apparatus is made up of synchronous driven machines, great economies will result by using these motors as synchronous condensers.

Numerous types of synchronous converter have been developed. Abroad, where the standard frequency is 50 cycles, a type of machine called the Cascade converter has been used to a considerable extent. This machine consists of an induction motor driving a d-c. generator, but differs from a straight induction motor set in that it is designed for a considerable slip, usually about 50 per cent. Half of the current which is delivered to the motor is transformed between its rotor and its stator, and is carried to the d-c. generator by means of taps connected to the d-c. armature, and to certain definite points on the rotor of the alternating current machine.

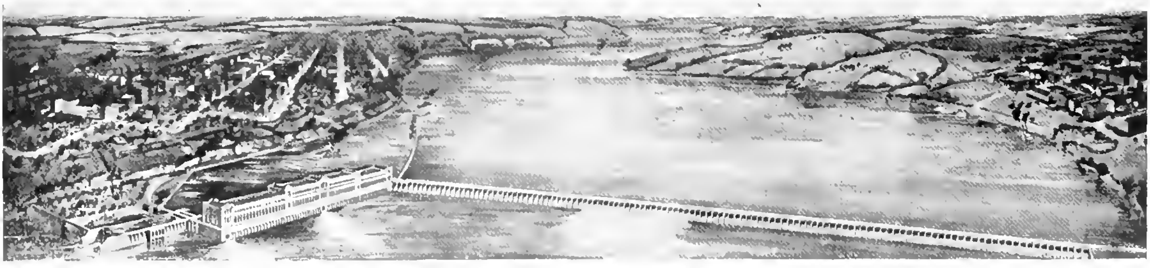
The other half of the energy is transmitted in the form of mechanical power, the a-c. machine acting as a motor and driving the d-c. machine as a d-c. generator. In this case the d-c. machine is half converter and half d-c. generator. The principal advantage obtained is that the d-c. machine would be operating at half the fundamental frequency of the system, thus somewhat simplifying its construction. The cost of such a machine is about midway between that of the synchronous converter and the standard motor-generator set. Its efficiency is somewhat lower than that of the straight converter, but not so low as that of the motor-generator set. It has therefore not been used to any extent in this country.

With regard to the gradual development of the modern synchronous converter and the types which are now regarded as standard in this country, the reader may with advantage be referred to an article by Mr. J. L. Burnham which appeared in the February, 1912, issue of the GENERAL ELECTRIC REVIEW. This paper shows the various schemes which have been proposed and adopted for obtaining close voltage regulation on the alternating current end, and considerable portions of Mr. Burnham's article are abstracted in a paper by Mr. H. F. T. Erben appearing on page 371 of this issue and dealing with substation machinery. The principle of the split pole converter and the series booster converter is dealt with at some length, while the paper includes a passage regarding the use of commutating poles with synchronous converters. With both the split pole converter and the series booster converter there are certain disadvantages; with the former the commutation at times of light load and low voltage is not so good as when the converter is running at full load or overload with boosted voltage. The synchronous booster type of machine at times of low voltage with light load operates at its best, and at times of overload with the voltage boosted it operates at its worst — the reverse of the behavior of the split pole converter. This is due to the fact that, when operating at times of heavy load with voltage boosted, the converter armature carries an excess current equal to the amount of energy required to drive the booster, as the converter exercises not only its converting function but also must act as a motor driving the booster. This causes a certain definite armature reaction which is in the direction to affect commutation.

The introduction of commutating poles will have a certain effect on the use of both the split pole converter and the series booster converter, as by the use of interpoles it is possible to build a machine running at a higher speed, occupying less floor space, and costing somewhat less than a machine without interpoles. If interpoles are used, regulating poles—such as are used with the split pole converter or series booster—cannot be used without incurring considerable complication, owing to the fact that the commutating poles are usually adjusted for a certain definite effect, dependent upon the load of the machine. If regulating poles are used with such a machine an unbalanced armature reaction results, which seriously affects the commutation. This is equally true with the series booster.

In cases where very large machines are used for substation work, it is possible that a later type of machine may find considerable usefulness. This machine is essentially a motor-generator set, but is made up of three units, two of which are direct current and one alternating current. The principal reason for the existence of such a machine is that the limitation in the design of a converter for low voltage results entirely from the amount of current which must be commutated. With the interpole converter more current per pole can be commutated with good results than with a non-commutating pole machine; but even with a commutating pole machine the speed is necessarily lower than for a machine of the same design of one-half the capacity. If the three-unit motor-generator set is used, each of the d-c. machines is one-half the capacity of the set. The set consequently runs at a higher speed than a two-unit set or a synchronous converter of the same output. A saving due to increase in speed would consequently result; while, in addition to this, the space occupied would be somewhat less. There are also numerous operating advantages. At times of light load in lighting substations for instance it is customary to operate one machine on one busbar, and another machine on the other busbar, both machines being usually only fractionally loaded. With the three-unit set it would be possible to operate one direct current machine on one bus and the other direct current machine on the other bus, thus operating only one set instead of two and working this set on a higher load. In addition, such a set could be operated at half load in case of trouble with the commutator of one of the machines; whereas, with a two-unit motor-generator set or a converter, trouble with the commutator would put the entire machine out of service.

The installation costs of such a machine would naturally be lower than those for a converter or a motor-generator set, since, at the potentials normally used in city work, the machine could be installed without the necessity of transformers, such as are used with the converter. No form of regulating device would be necessary, since the direct current potential could be varied by means of the field rheostats, as in the case of the older two-unit motor-generator set; while of course no large a-c. copper, such as is used to connect the transformer and the converter together, would be necessary.



Birds-eye View of Hydro-electric Development at Keokuk, Iowa, by the Mississippi River Power Company

METERING ON THREE-PHASE SYSTEMS

By L. T. Robinson

Standardizing Laboratory, General Electric Company

After a general statement of the main points to be considered in any method for metering electric power, the author goes into a detailed discussion of a number of well known arrangements of transformers and meters for measuring energy on three-phase systems, emphasis being laid to the questions of accuracy and suitability of each for the particular conditions of service for which it is employed.—Editor.

In giving consideration at this time to some general problems in connection with power transmission a somewhat general examination of metering arrangements which may be used on transmission systems may be of interest. The importance of this branch of the subject to the constructing and operating engineer is in most cases not fully realized. Usually power stations and transmission lines are erected for the purpose of procuring revenue from the sale of electrical energy, and when it is considered that all this revenue is procured on the basis of meter indications it is evident that careful consideration should be given to the metering arrangements provided.

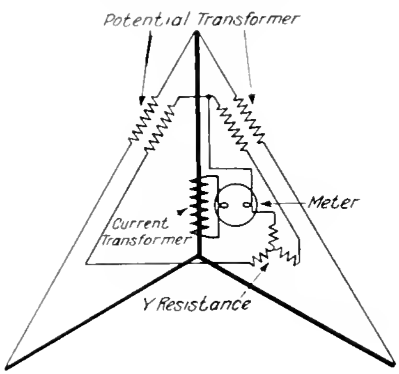


Fig. 1

The general result obtained should in each instance be in keeping with the relative return to be derived from the circuit to which the meters are connected. It is well known that various arrangements may be used, all of which might be classed as commercially accurate: some of these, however, are more nearly perfect than others and at the same time more expensive to install. They may also involve some slight inconvenience in reading, etc. From among such a variety of arrangements it seems evident that low first cost, if it can be combined with required accuracy, would determine the character of the outfit for individual small consumers, a number of whom are supplied from a given system; while on the other hand, in situations where very large amounts of power are sold over one circuit, the importance of great refinement in the meter records is to be emphasized. In the case of the numerous small consumers, if there is no inherent error in any definite direction in the meters and if they are all kept in good operative condition, the total revenue of the supply company will not be affected by individual uncertainties. On the other hand—the case where all the energy passes through one meter—there will be no opportunity to arrive at a generally correct result by a balancing of small individual errors. In the case of the smaller individual consumers it may be urged that the highest degree of refinement should enter into the measuring apparatus for the benefit of the consumer. This is admittedly the ideal point of view, but it certainly should not be carried to the point where the expense of the meter installation and its accessories would outweigh the advantage that would come from slightly increased accuracy.

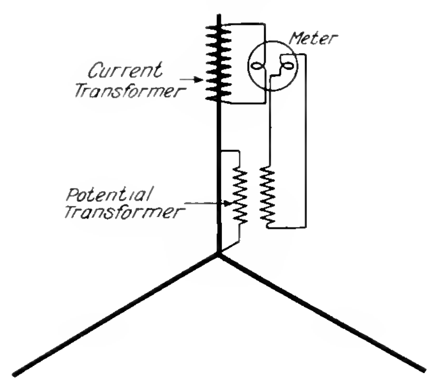


Fig. 2

With this general statement of conditions, some of the well known arrangements of transformers and meters will be considered in detail and a general estimate of their accuracy and suitability under various conditions of service given. It is fully appreciated that no general consideration of such a broad subject can be the basis of conclusions that would govern all individual cases. On the other hand, it is possible to differentiate between the various arrangements with some advantage. The general subject involves so much detail that the present discussion will be limited to three-phase systems, as it is believed that the greater part of the kind of service to be considered is furnished from three-phase systems.

The simplest arrangement which can be used on a three-conductor three-phase system is that shown in Fig. 1, in which a single meter has its current coil in one conductor and the potential coil is connected to the center of a "Y" impedance, each branch of which has equal reactance and resistance in amount correct to give proper voltage supply to the potential circuit of the meter. If the system has a neutral point on the generator or power transformers which is accessible from the meter, the potential coil of the meter is connected between one of the main conductors and this neutral, and the "Y" impedance is not required (Fig. 2). With either arrangement three times the registration of the meter is taken as the total power delivered and the register is sometimes arranged to record three times the energy delivered to the phase in which the meter is connected. Simple inspection of the diagram shows that the assumption is made that the same amount of energy is supplied by each of the conductors. Outside of a few very special situations, such is not the case, and therefore this arrangement should not be employed. The opinion is

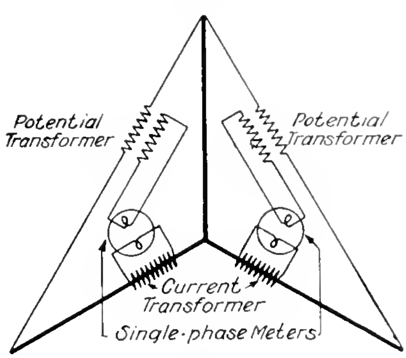


Fig. 3

many times expressed that synchronous and induction motors constitute a balanced load and therefore such an arrangement may be used where no other load is on the meter than a three-phase motor. Although it may be true that the power supplied through each wire to a three-phase motor is very nearly the same when the motor is supplied from a perfectly balanced voltage, it is also true that very small differences in voltage may cause quite large differences in current in the various branches; the differences becoming more marked as the size of the motor, and consequently the relative counter e.m.f. created by it is increased. In many cases this counter

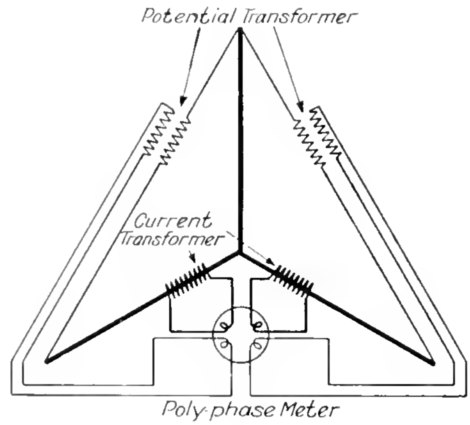


Fig. 4

e.m.f. is but little different from the impressed voltage, and consequently very small inequalities in the latter cause great differences in the current flowing. The most that can be said of this arrangement as applied to any ordinary situation is that it may serve as an indicator, giving a general idea of the energy transmitted over a circuit; but it is often too much in error even for this purpose, and as a method of accurate metering should be dismissed from further consideration.

Referring again to the three conductor circuit, the next simplest arrangement is that shown in Figs. 3 and 4. In both of these the well known two-wattmeter (Aaron) method of measuring power is made use of, which is correct for any condition of unbalanced voltage or current that can be devised, provided the meters and transformer themselves possess no imperfection. On high voltage circuits these arrangements require only two current and two potential transformers. The advantages and disadvantages of this general system, employing two single or one polyphase meter, will not be considered until various three-meter or three-element meter arrangements for this same three-conductor circuit are referred to. These are shown in Figs. 5 and 6.

Three potential transformers are employed in Fig. 5 and also in Fig. 6. In Fig. 5 they are connected "YY" and in Fig. 6 "Y-delta." Three current transformers are shown in each figure, as consideration of the effect of the influence of interconnected current transformer secondaries cannot be undertaken here. Such interconnection is satisfactory under certain well defined conditions, but any inaccuracies resulting from a too general use of

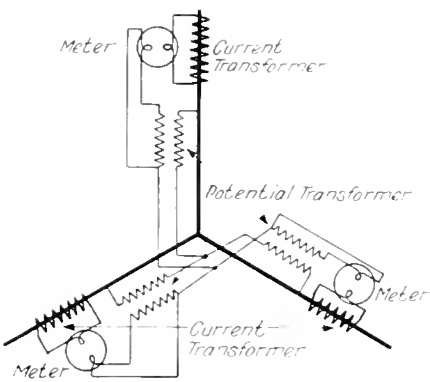


Fig. 5

these interconnections would affect the general result only as imperfections in the current transformers. With regard to the potential transformers the "YY" and "Y-delta" arrangements will be briefly referred to, but consideration of any effect that may come from the connection used will again be considered as giving results appearing, if at all, as slightly modified transformer errors.

Returning now to the two-meter or two-element meter arrangement, Fig. 3 and Fig. 4: between these two combinations the two-element meter should undoubtedly be chosen as most convenient and satisfactory for ordinary service. The accuracy obtained is as good as that which can be obtained with two single meters working under the most favorable conditions; and usually the accuracy is slightly better because the addition of the record of the two halves is made without the possibility of error that might come from reading each element separately and adding them together afterward. There is, of course, to be considered the question of interference between the two elements when combined into a single meter and mounted in the same case. Perhaps this should not be referred to, as it may be a minor detail which hardly belongs in an article like this; still, it may be said that while this error has been quite apparent in meters which have been made, it is not found in a good two-element meter constructed according to correct modern practice. As will be referred to later, the three-meter method of measuring three-phase power has some very small advantages over the two-element meter. None of these advantages exist in connection with the two single meters of Fig. 3, as contrasted with the two-element meter of Fig. 4; therefore in the final analysis it would be quite generally admitted that the two-element, or so called polyphase meter is to be preferred.

When we come to the consideration of three meters for a three-wire three-phase system we have a choice of the arrangements shown in Fig. 5 or Fig. 6. Usually Fig. 6 is to be preferred because there is less chance of unbalancing the voltage on the potential transformers due to unequal loading of the secondaries. Inequality of loading of the secondary with "Y" primary and "Y" secondary connection subjects the potential transformers to primary and secondary voltages different to some extent from those for which they were built. This has the effect of varying the ratio slightly from the marked value; and if the difference in loading of the secondaries is sufficient, the primary of one or two of the transformers may be damaged by the high voltage which is thrown on it. If the secondary of one of the transformers should be accidentally short-circuited for a time, its primary impedance would be so reduced that the other two transformers would be subjected

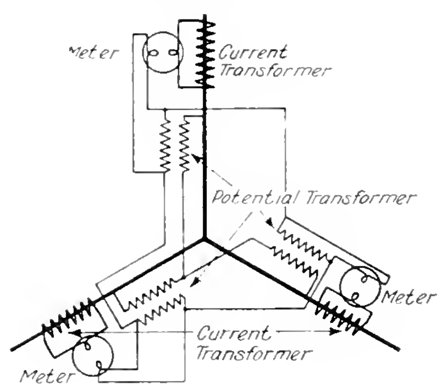


Fig. 6

to very nearly delta voltage; in which case the windings of the transformers themselves might become damaged. It is also apparent that the meters themselves would be subjected for a time to a voltage different from that for which they were made, thus causing inaccuracy. This would be true to some extent even with slight inequality of secondary loading which might easily occur in practice. On the whole it seems that inasmuch as only a very slight degree of refinement in metering over that which may be obtained by the two-element meter is possible in connection with these three meter arrangements, the difficulties with this "YY" arrangement of potential transformers are more than enough to outweigh any possible advantage that might be thought of when three meters are employed.

Considering the primary "Y", secondary delta arrangement, it is well known that equality of voltage on the primaries is quite definitely established by exchange of current through the secondary circuits of the transformer group in case the secondary loads are not equal. This prevents very abnormal operative conditions in the individual transformers and insures that the meters will be run at the proper voltage.

It is still unwise to allow any considerable inequality of loading on the secondary of the transformers because of the difficulty of estimating the effect on the ratio and phase angle of individual transformers. Such an effect would usually be very small and would depend on the transformers and general arrangements used. Quantitative values cannot be given except for definite individual cases. It is also true that with "Y-delta" connection there is some very slight difference between the ratio of the transformers used in this way from the ratio and phase angle which would be found under similar conditions of voltage, frequency and load on a single-phase circuit. All these rather complicated considerations cannot be discussed here in detail; they are simply mentioned to show that they have not been overlooked and will be disposed of for the present by saying that all of the differences that would modify the operation of a potential transformer by reason of "Y-delta" connection would not in any ordinary case amount to more than a small part of 1 per cent. and therefore the disadvantages already referred to of the "YY" connection should make the final choice fall on the "Y-delta" arrangement.

We now have a three-meter arrangement on a three-wire three-phase system and can consider briefly whether all this complication is worth while in view of the satisfactory performance of the two-element polyphase meter for the same service. As disadvantages we have the somewhat increased cost due to the three meters, the additional instrument transformers, and the trouble of reading and recording three separate meters: as advantages, failure of one meter or even two meters does not entirely obliterate the daily or monthly record.

Two separate meters connected as in Fig. 3 do not possess this advantage over the polyphase arrangement of Fig. 4, because each meter can give no indication of value in determining any definite part of the total energy. The estimation of errors due to transformer phase angles is much more easily and correctly made, and under some circumstances corrections may be applied. The load is divided between the meters in a definite way, independent of power-factor, and the actual range of power-factor through which the meters themselves are required to operate is not more than the range of power-factor to which that branch of the circuit to which the meter is connected is subject. To be sure, meters are made very perfect as regards error due to commercial variations of voltage, frequency, power-factor, etc.; but having produced an instrument that is very nearly perfect in these particulars, it is still evident that any arrangement that will lessen the severity of the requirements to be met by the individual meter element in order to handle a given case will in a small degree be preferable to another more simple and nearly as effective an arrangement when the very last degree of refinement is desired.

Considering for a moment the application to four-wire three-phase systems, the objections to the "YY" arrangement of the potential transformers is removed and the connection shown in Fig. 7 may be employed. This is practically arranging the metering as if there were three single-phase systems whose return sides are combined together in one common return wire. By reason of the fact that no inter-connection of potential transformers is required and because of the fact that the meters cannot be subjected to variations of voltage greater than those properly belonging to the circuit, this arrangement is even slightly superior to the three-meter arrangement on a three-wire system and in fact leaves nothing to be desired. Whatever degree of precision can be obtained in the individual meters and instrument transformers is applied directly to the measurement of power.

A two-element meter is sometimes applied to the measurement of power on four-wire three-phase systems by suitably dividing the current coils into three groups which are connected into the circuit as shown in Fig. 8. This arrangement has much to recommend it on the score of simplicity and convenience: on the other hand the theoretical accuracy of the measurement is not as good as that of the two-element meter on the three-wire circuit. The instrument measures correctly the energy on two branches of the system, but for the third branch the actual current in this branch is used in combination with the vector sum of the potentials on the other two branches.

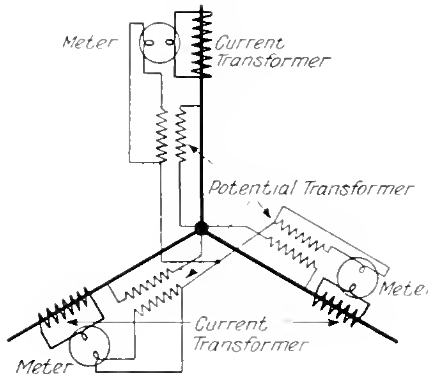


Fig. 7

This means that 1/3 of the energy may be incorrectly measured by the slight amount caused by the voltage unbalancing of the system and by the fact that the current in this branch may contain harmonics, such as transformer magnetizing currents, which would find some power component in its own voltage not to be found in the vector sum of the other two voltages. Also the equivalent range of power-factor to which the meter is subjected when measuring this approximate 1/3 of the total energy may be much greater than that of the branch of the system to which the current coil is connected. These things together have the effect of making the indications of such an instrument slightly inferior in accuracy to the three-meter arrangement, but usually not enough so to justify the added complication of the three meters. It should be distinctly noted that although this arrangement is a compromise, it is a very good one and that the results obtained with it are usually fairly comparable with those obtained with the two-element meter on three-wire circuits. Finally the various combinations arrange themselves in the following order of accuracy. There is a very big gap between (1) and (2).

(1): The single meter with "Y" resistance, or connected to neutral, commonly known as balanced three-phase meter, Fig. 1 and Fig. 2. This in its general application can be considered only an indicator at most and of value only as an aid to internal distribution of charges, if it should be used at all.

(2): The two-element polyphase meter adapted for connection to four-wire systems, Fig. 8, which, although it has some theoretical disadvantages and has passed through many structural defects, is entitled to almost the same degree of confidence that can be given to the theoretically perfect arrangement of two-element polyphase meter on a three-wire system.

(3): The two-element polyphase meter on the three-wire system, Fig. 4, which is a theoretically perfect arrangement, if the meter itself and the instrument transformers are perfect, and comes so near to reaching the highest degree of accuracy that may be obtained, that it should continue to serve for almost every requirement with complete satisfaction to the buyer and seller.

(4): The three single meters with "Y-delta" potential transformers for use on a three-wire system, Fig. 6. This has some very small points to recommend it for situations where first cost and convenience need not be considered and where the very highest attainable accuracy is sought.

(5): The three single meters with potential transformers connected to the common neutral on the four-wire system, which should be used only under conditions on four-wire systems similar to those referred to under (4) for three-wire systems.

To sum up the subject in one paragraph, arrangement (1) should not be used at all;

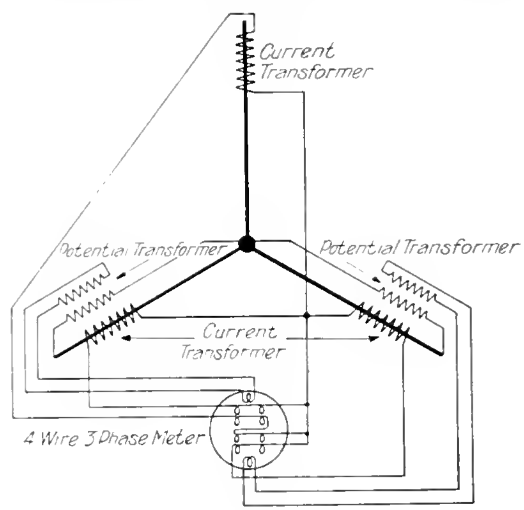


Fig. 8

(2) and (3) should be used to take care of practically all requirements; and (4) and (5) should be reserved for the most special conditions of unbalanced load and low power-factor, and where the large amount of energy to be charged for demands the greatest care in the installation and upkeep of the entire metering arrangements.

FACTORS IN LINE TRANSIENTS

By G. Faccioli

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In order to foresee and as far as possible to control the intensity and location of disturbances set up by transients on transmission lines it is necessary thoroughly to understand all the factors which affect the nature and behavior of these transients. This article cites a case of generator, low tension switch, transformer, high tension switch, and line, enumerates these constants, and shows how their value may be calculated. It then considers three methods of starting up and shutting down and predicts the degree of disturbance which is likely to be caused in each case. The conclusion reached is that switching should be confined to the low tension side in all cases where high tension switching is not absolutely necessary.—Editor.

In the study of high-tension lines the transient conditions of the line are as important as the normal conditions of operation. In fact, the electric transients are generally responsible for failures, and it is therefore necessary to form a correct idea of all the factors which affect the nature and the behavior of the transients. These factors are the constants of the circuit, the amount of energy involved, the frequency of the oscillation produced, etc. The discussion of a concrete case will prove instructive.

Let us examine the simple system represented in Fig. 1. This system includes a 10,000 kv-a. three-phase generator G; a 10,000 kv-a. three-phase step-up transformer T, delta-connected on both low and high tension sides; and an unloaded three-phase line. This line is 150 miles long and consists of three No. 000 B.&S. gauge stranded copper cables, the distance between centers of conductors being ten feet. The voltage on the low-tension side of the system is 10,000 volts, and on the high tension side 100,000 volts. H is a low-tension oil switch between

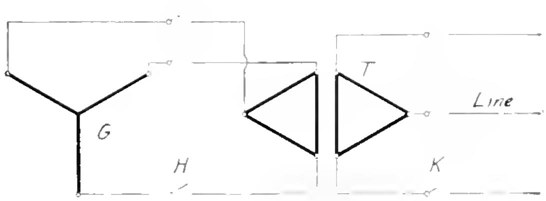


Fig. 1

the generator and the transformer. K is a high-tension oil switch between the transformer and the line.

Constants of the Line

Resistance R. The resistance per thousand feet is 0.0617 ohm, and the total resistance of each conductor of the line is 48.9 ohms. The resistance, however, will not be taken into account in our calculations.

Inductance L_1. For this size of conductor and for a distance of ten feet between conductors, the tables give an inductance of 0.4 millihenry per thousand feet, or a total inductance of 0.316 henry per conductor.

Capacity C. The capacity between two conductors is 0.00136 microfarad per thousand feet of circuit. The capacity between each conductor and neutral is twice the value given above, or 0.00272 microfarad per thousand feet of conductor. The total capacity of each line conductor to neutral is then 2.16 microfarads.

Charging Current j. To calculate the charging current of the line we will assume that the line capacity is concentrated in two

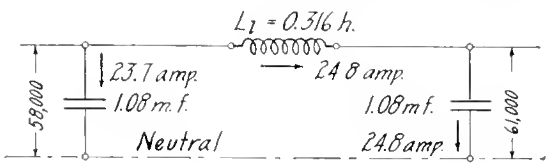


Fig. 2

condensers, one at the beginning of the line and the other at the end of the line, as shown in Fig. 2. The two condensers are identical and each has a capacity of 1.08 microfarads. The charging current of the condenser situated at the beginning of the line is, at normal operating voltage:

$$58000 \times 2\pi \times 60 \times 1.08 \times 10^{-6} = 23.7 \text{ amperes}$$

In this formula 58,000 is the voltage applied across the condenser (from each conductor to neutral, since 100,000 volts is the normal voltage between line conductors); 60 is the frequency; and 1.08×10^{-6} is the capacity of the condenser in farads.

We can find the charging current of the other condenser at the end of the line as follows:

Let us call i the charging current of this condenser, and e the voltage applied to it. e is equal to 58,000 volts *plus* the boosting voltage which the leading current i produces in flowing through the inductance L, and which adds directly to the 58,000 volts. This boosting voltage is:

$2\pi\ f\ L\ i = 2\ \pi\ 60 \times 0.316\ i = 119\ i.$

(f, the frequency of the system, is 60 cycles.)

The voltage across the condenser is then:

$e = 58000 + 119\ i.$

But the current i is given by:

$i = e \times 2\ \pi \times 60 \times 1.08 \times 10^{-6}.$

$= e \times 408 \times 10^{-6}.$

By combining this last equation with the above expression for e we have:

$e = 58,000 + 119 \times e \times 408 \times 10^{-6}.$

$= 58,000 + 0.0485\ e.$

$= 61,000$ volts.

At the end of the line 61,000 volts are applied across the condenser. The charging current of this condenser is then:

$i = 61,000 \times 408 \times 10^{-6} = 24.8$ amperes.

The total charging current of the line is the sum of the charging current of the condenser at the beginning of the line, *plus* the charging current of the condenser at the end of the line. That is to say

$j = 23.7 + 24.8 = 48.5$ amperes.

Natural Impedance. The natural impedance of a line is given by the expression $\sqrt{\frac{L}{C}}$, where L and C are respectively the inductance and the capacity of the line.

In our case the natural impedance is

$$\sqrt{\frac{0.316}{2.16 \times 10^{-6}}} = 383 \text{ ohms.}$$

Therefore, if the line carries full load current (which is 58 amperes per conductor), and this current is instantaneously interrupted at the maximum point of the wave, a voltage is produced between each conductor and neutral equal to:

$82 \times 383 = 31,400$ volts.

This assumes that all the electromagnetic energy stored in the line by the presence of 82 amperes (which is the maximum value of the full load current) is instantaneously changed into electrostatic energy.

Stored Electrostatic Energy. This energy is given by $\frac{CE^2}{2}$, where C is the capacity and E the voltage. In our case the maximum value of the voltage between each conductor and ground is $58,000 \times 1.41$. The maximum stored energy in the condenser between each conductor and neutral is:

$$\frac{2.16 \times 10^{-6} \times 58,000^2 \times 1.41^2}{2} = 7200 \text{ joules or}$$

watt-seconds.

This means that if this energy is supplied at a constant rate in one second, this rate is 7.2 kw.; if it is supplied at a constant rate in 1/100 of a second, this rate is 720 kw., etc. The total electrostatic energy stored in the line is $3\frac{Ce^2}{2}$, where C is the capacity from each conductor to neutral, and e is the *effective* value of the voltage from each conductor to neutral. In our case, the total electrostatic energy of the line is:

$$3 \times \frac{2.16 \times 10^{-6} \times 58,000^2}{2} = 10,800 \text{ joules.}$$

In the above we have taken the voltage from each conductor to neutral and the capacity from each conductor to neutral. As a check we will calculate again the electrostatic energy of the line by taking the voltage between conductors and the capacity between conductors.

The capacity between two conductors is, as given by the tables, 1.08 microfarads per 150 miles of 2-wire circuit; that is to say (see Fig. 3), the total capacity between the conductors A and B is 1.08 microfarads. Now let us add the conductor C and represent the capacity between conductors as shown in Fig. 3. Between A and B we have a condenser c, and in parallel with it two other condensers c—one from A to C and the other from C to B. The total capacity between A and B is then equal to:

$$c + \frac{c}{2} = \frac{3}{2}c$$

This total capacity is 1.08 microfarads. It follows that:

$$c = \frac{3}{2} \times 1.08 = 0.72 \text{ microfarad.}$$

This is the figure for capacity which we must use in calculating the electrostatic energy stored in each condenser c between two line conductors. The maximum value of this energy is:

$$\frac{0.72 \times 10^{-6} \times 100,000^2 \times 1.41^2}{2} = 7200 \text{ joules.}$$

($100,000 \times 1.41$ is the maximum voltage across two conductors).

The total electrostatic energy stored in the line is:

$$3\times\frac{0.72\times10^{-6}\times100{,}000^2}{2}=10{,}800 \text{ joules, as}$$

before.

It is interesting to note that the equivalent condenser between each conductor and neutral has three times the capacity of the condenser c, and twice the total capacity between line conductors.

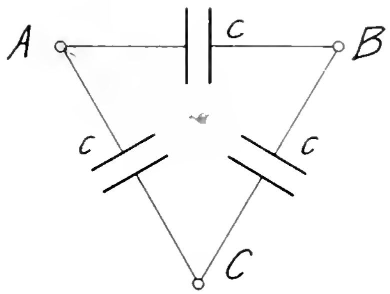


Fig. 3

Electromagnetic Energy. This is given by:

$$\frac{L\,I^2}{2}$$

where L is the inductance and I the current.

In our case when the line is carrying full load current the maximum value of this energy is given by:

$$\frac{0.316\times82^2}{2}=1060 \text{ joules per conductor.}$$

The total electromagnetic energy of the line is:

$$3\times\frac{0.316\times58^2}{2}=1590 \text{ joules.}$$

Natural Frequency of the Line. The lowest frequency of oscillation of the line is given by:

$$\frac{1}{4\sqrt{L\,C}}$$

when the length of the line is $\frac{1}{4}$ wave length. In our case this frequency is:

$$\frac{1}{4\sqrt{0.316\times2.16\times10^{-6}}}=302 \text{ cycles.}$$

This frequency occurs, for instance, when the line is open at one end and short-circuited at the other end, because then at the open end of the line the current must be zero and therefore the voltage is maximum; while at the short-circuited end of the line the current is maximum and the voltage is zero. It follows that the voltage is zero at one end and maximum at the other, and the simplest distribution of voltage to give these conditions occurs when the length of the line is one-fourth of the length of the voltage wave. If the line is open at both ends, then the lowest frequency of oscillation occurs when the line length is $\frac{1}{2}$ wave length, which gives a frequency of 604 cycles.

It is interesting to form an idea of the time employed by a wave to travel the length of the line, which is 150 miles. The velocity of propagation is 188,000 miles per second—the velocity of light. To cover 150 miles a wave traveling at this velocity will then require:

$$\frac{150}{188{,}000}=\frac{1}{1250} \text{ second.}$$

Constants of the Transformer

Inductance. The inductance L_0 of the transformer when open-circuited can be obtained as follows:

The magnetizing current of the transformer is 5 per cent. of the full load current, which is 33.3 amperes through each winding of the high-tension delta. The magnetizing current is then:

$$\frac{5}{100}\times33.3=1.665 \text{ amperes}$$

through each winding of the high-tension delta. The voltage across this winding is 100,000 volts. We have then at 60 cycles:

$$100{,}000=2\,\pi\times60\times L_0\times1.665$$
$$L_0=159 \text{ henrys.}$$

We may calculate the value of the equivalent transformer inductance L_t reduced to Y-connection instead of the delta-connection. That is to say, the transformer inductance L_t is connected between each line conductor and neutral, and is traversed by the line current. Across L_t is then applied 58,000 volts, and the magnetizing current flowing through it is:

$$1.665\times1.73=2.88 \text{ amperes.}$$

We have then:

$$58{,}000=2\,\pi\times60\times L_t\times2.88; \text{ whence}$$
$$L_t=53 \text{ henrys.}$$

These figures apply when the transformer is open-circuited, and represent the inductance offered by the main iron circuit of the transformer. The values of L_0 and L_t are not constant at all voltages, but increase at lower voltage because the flux density in the iron circuit decreases and the exciting current decreases more rapidly than the voltage.

When the transformer is loaded and carries current in both primary and secondary windings, then the inductance encountered by the load current is the leakage inductance of the apparatus L_r.

The reactance of this transformer is 4 per cent.; which means that the full load current flowing through the apparatus gives a reactive drop equal to 4 per cent. of the terminal voltage. The full load current flowing through each winding of the high-tension delta is 33.3 amperes. The terminal voltage across each winding of the high-tension delta is 100,000 volts. The reactive drop produced by the full load current is:

$$\frac{4}{100}\times 100{,}000 = 4{,}000 \text{ volts.}$$

We have then

$$4{,}000 = 2\,\pi\times 60\times L_r\times 33.3\text{; whence}$$
$$L_r = 0.318 \text{ henry.}$$

This is the leakage inductance of each of the three sides of transformer delta. If we reduce the inductance to an equivalent Y, as before, we obtain as leakage inductance of each leg of the Y, 0.106 henry. This leakage inductance is constant at any voltage because it is produced by a flux through air.

Electromagnetic Energy. The maximum electromagnetic energy stored in the transformer by the full load current is:

$$\frac{0.318\times 33.3^2\times 1.41^2}{2} = 352 \text{ joules, for each}$$

side of the delta; or

$$\frac{0.106\times 58^2\times 1.41^2}{2} = 352 \text{ joules, for each leg}$$

of the equivalent Y. The total electromagnetic energy stored in the three-phase transformer is:

$$3\times\frac{0.106\times 58^2}{2} = 528 \text{ joules.}$$

Capacity. The capacity of each side of the high tension delta to ground is measured as 0.004 microfarad. This capacity is distributed throughout the winding.

Electrostatic Energy. Referring to Fig. 4, let us consider the instant at which the winding AB has maximum e.m.f. across it. At this instant the values of the different voltages are given by the projections of the corresponding vectors on the axis XX. The voltage AB is 141,000 volts. The point A has a potential to ground equal to the projection of the vector AN, i.e., $PN = 70{,}500$ volts (the vector AN is 82,000 volts). Likewise B has a potential to ground of 70,500 volts. The central point D of the winding AB is at ground potential, since the projection of the vector DN on the axis XX is zero. The electrostatic energy of the half-winding AD is equal to one-half the product of the capacity, 0.002×10^{-6} farad, multiplied by the average value of $\int e^2\,de$, in which e, the voltage, varies from zero to 70,500 volts. This energy is $\frac{1}{2}\times 0.002\times 10^{-6}\times\frac{1}{3}70{,}500^2 =$ 1.63 joules. The half-winding DB has also a stored energy equal to 1.06 joules. The whole winding AB has then a stored energy of 3.32 joules.

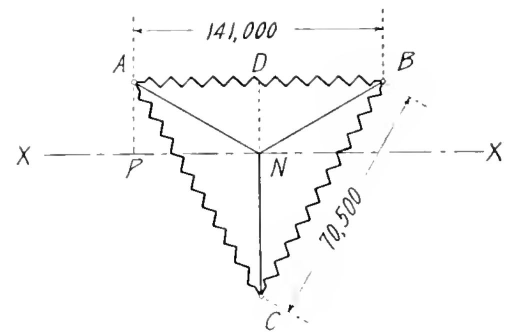


Fig. 4

At the instant assumed the voltage AC is 70,500 volts, the point A has, as we have seen before, a potential of 70,500 volts to ground and the point C is at ground potential. The electrostatic energy of AC is then

$$\frac{1}{2}\times 0.004\times 10^{-6}\times\frac{1}{3}70{,}500^2 = 3.32 \text{ joules.}$$

3.32 joules are also stored in the winding BC. The total stored energy is 9.96 joules.

In addition to the capacity to ground, which we have so far considered, the transformer windings possess capacity between turns. The value of this capacity is uncertain and therefore is omitted in the calculations.

Generator

Inductance. We have seen that the charging current of the line is 48.5 amperes through the high-tension side of the system.

If the generator is excited at no-load at 2800 volts across each leg of the Y, and the transformer and line are connected to the generator, the voltage rises from 2800 to 5800 volts, which is the normal full voltage of the system. Under these conditions the current flowing through the generator is 485 amperes (neglecting the exciting current of the transformer); which means that 485 amperes flowing through the inductance L_g of the generator have produced a boosting voltage equal to

$$5800 - 2800 = 3000 \text{ volts.}$$

We can then figure L_g as follows:

$$2\pi \times 60 \times L_g \times 485 = 3000;$$

whence

$$L_g = 0.0164 \text{ henry.}$$

If we refer L_g to the high tension side, we must multiply the above value by the square of the ratio of transformation. We obtain

1.64 henrys.

This is the value of the synchronous inductance of the generator; that is to say, this inductance includes the leakage inductance of the armature windings in air and the armature reaction. In some oscillations, however, the flux due to the armature reaction, which passes through the air-gap of the machine and through the pole pieces of the field, has no time to establish itself permanently, and therefore the inductance of the generator taking part in the oscillation is

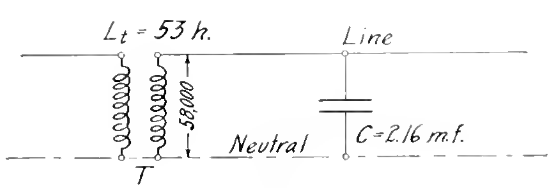


Fig. 5

only the leakage inductance of the armature windings.

In our case this leakage inductance figures at 0.00276 henry referred to the low-tension side, and 0.276 henry referred to the high-tension side.

Electromagnetic Energy. At full load the current flowing through the generator winding is 580 amperes. The maximum electromagnetic energy due to the total synchronous inductance of the machine is then

$$\frac{0.0164 \times 580^2 \times 1.41^2}{2} = 5520 \text{ joules for each}$$

leg of the Y.

If we take the leakage inductance only, we have

$$\frac{0.00276 \times 580^2 \times 1.41^2}{2} = 930 \text{ joules for each}$$

leg of the Y.

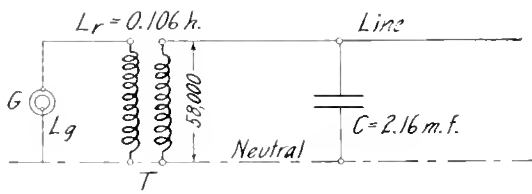


Fig. 6

Transformer and Line

Natural Frequency. If the low-tension side of the transformer is open circuited and the connections are as shown in Fig. 5, then the natural frequency of the system is determined by the concentrated inductance of the transformer and the concentrated capacity of the line (we neglect the inductance of the line conductors). This frequency is then

$$\frac{1}{2\pi} \frac{1}{\sqrt{53 \times 2.16 \times 10^{-6}}} = 14.8 \text{ cycles}$$

It is to be noted again that this frequency occurs when the voltage of the system is 100,000 volts between phase conductors. If the voltage is lower, then the inductance of the transformer is higher and the frequency of oscillation is lower.

Generator, Transformer and Line

Natural Frequency. Referring to the system shown in Fig. 6, its natural frequency is determined by the line capacity on one side, and by the sum of the leakage inductance of the transformer *plus* the inductance of the generator on the other side. In the case of a sudden impulse the inductance of the generator is limited to the leakage inductance of the armature windings, and therefore, (neglecting the inductance of the line) the total inductance of the system is

$0.106 + 0.276 = 0.382$ henry.
The capacity of the line is
2.16×10^{-6} farads.

All these values are referred to Y-connection and cover one leg of the Y. The frequency is then

$$\frac{1}{2\pi}\frac{1}{\sqrt{0.382\times 2.16\times 10^{-6}}}=175 \text{ cycles.}$$

If the iron of the generator takes part in the oscillation, then the inductance of the generator and the transformer is 1.64 henrys, and the frequency becomes 84.5 cycles.

Energizing the System

The constants of a system, such as we have calculated, are necessary, as we said before, in the study of electric transients. Let us take a simple example, as for instance the energizing of the system of Fig. 1. The system may be energized in three different ways, and we propose to find which one produces the minimum amount of danger to the installation. These three different methods are:

1. The switches K and H are closed when the whole system is dead. Then the field of the generator G is gradually excited to its normal value, thereby increasing the voltage on the whole system by uniform steps. In this case, no switches are operated under tension.

2. The switch K is closed when the system is dead, but the switch H is left open. The generator G is then excited and finally the switch H is closed, thereby connecting the transformer and the line to the generator. In this case only one switch, viz., H, is operated under tension.

3. The switches K and H are left open and the generator G is excited; then the switch H is closed and the transformer is thereby connected to the generator. The switch K is next closed and the line is energized. In this case, both switches H and K are closed under tension.

A possible fourth method, which consists in bringing the generator G and the transformer T together gradually to full voltage and then closing the high tension switch K, need not be discussed, as the study of the other three methods covers this fourth case.

While discussing the starting up of the system, we will also analyze the phenomena connected with the shutting down of the system. Evidently the shutting down of the system can be performed by three methods analogous to those just mentioned, viz.; a first method in which no switching is done under tension; a second method in which the low tension switch H only is opened under tension; and a third method in which both the high-tension switch K and the low tension switch H are opened under tension.

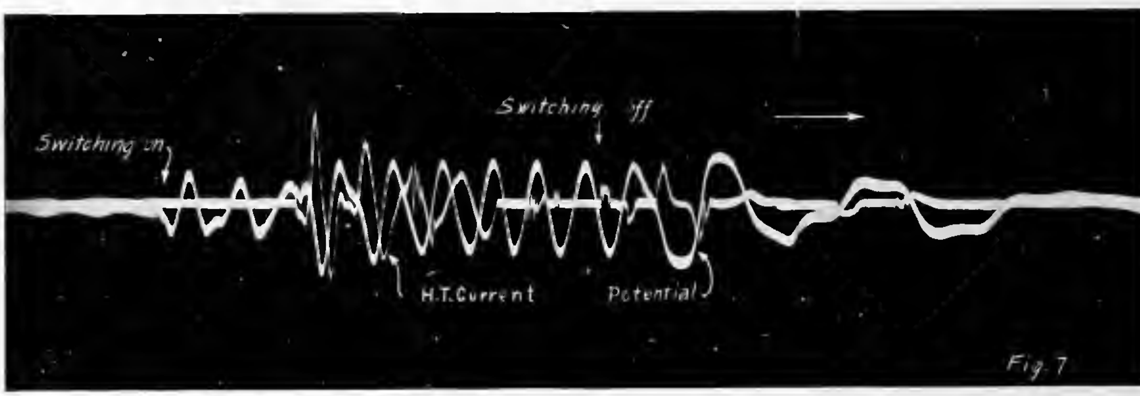


Fig. 7. Switching on and off by low-tension switches, 10,000 kv-a. transformer and 150 miles of transmission line. Waves of high-tension current and low-tension potential

First Method. The energy is applied to the system or withdrawn from the system slowly and by gradual steps. It is easily perceived how this method produces the minimum possible amount of disturbance and of danger. Unfortunately, in practice it is impossible to follow this method in the majority of cases, and therefore its practical importance is comparatively small.

Second Method. Before the switch H is closed, the line and the transformer are connected together but are not connected to the generator G, which is excited to 2800 volts per leg. After the switch H is closed and the resulting oscillation has died out, the voltage of the generator is 5800 volts per leg, and the voltage across the high-tension conductors is 100,000 volts.

When the switch *H* is being closed and the transformer and the line are being connected to the generator, practically all the energy supplied to the system must pass through the iron of the transformer, and therefore steep wave-fronts are eliminated. Electromagnetic energy is supplied to the main iron circuit of the transformer, the line capacity being charged through the inductance of the generator, the leakage inductance of the transformer, and the distributed inductance of the line.

It is this charging of the line condensers through an inductance which produces an oscillation in the circuit. This oscillation varies in intensity according to the point of the wave of e.m.f. at which the switch *H* closes the circuit. The two limit cases are the zero point and the maximum point of the wave of e.m.f. At the zero point of the wave of e.m.f. under normal conditions of operation, the magnetizing current of the transformer is maximum. However, at the moment the switch is closed the current is zero, and therefore the closing of the switch at the zero point of the wave of e.m.f. causes a rush of magnetizing current, which, of course, is limited to the low tension side of the system. On the other hand, if the circuit is closed at the zero point of the wave of e.m.f. at the instant of closing, no potential is applied to the line condensers and the voltage oscillation is reduced to a minimum.

Conditions are different when the switch *H* closes the circuit at the maximum point of the wave of e.m.f. In this case under normal operating conditions the magnetizing current of the transformer is zero. It follows that the closing of the switch at the maximum point of the wave of e.m.f. does not call for any rush of magnetizing current. As far as the line is concerned, however, maximum e.m.f. is instantaneously applied to the empty line condensers, and therefore the oscillation of the e.m.f. is maximum. The maximum over tension which can be obtained in this case is equal to the impressed voltage; that is to say, the maximum possible voltage across the line condensers during the oscillation is double the maximum operating voltage.

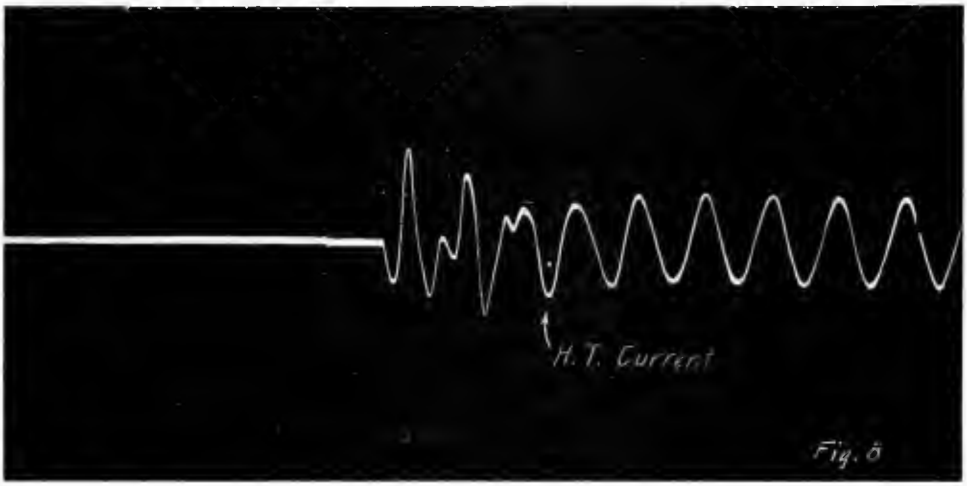


Fig. 8. Switching on 150 miles of 100,000 volt transmission line by high-tension switches. Wave of high-tension current

The oil switch generally closes the circuit by an arc before metallic contact is permanently established, and this arc strikes in the majority of cases near the maximum value of the wave of e.m.f. It is then to be expected that the closing of the circuit by the switch *H* will commonly occur near the maximum point of the wave of e.m.f. In general, the oscillation of the circuit produced by closing the switch *H* consists of a wave of fundamental frequency (60 cycles), on which is superimposed a wave of the frequency at which the line condenser and the inductance of the transformer and of the generator exchange energy. This latter frequency we have seen to vary from 175 to 85 cycles. This oscillation is, however, damped by the resistance of the circuit, which so far has been neglected.

In conclusion, on the high-tension side of the system we have an oscillation of e.m.f. and current of short duration (a few fundamental cycles) consisting of 175-cycle damped waves superimposed on the normal 60-cycle waves. On the low-tension side of the system a rush of magnetizing current may be added to the oscillation of the current.

When the system is shut down by opening the switch *H*, the following phenomena occur: The switch *H*, which is of the oil type, opens the circuit at the zero point of discussed above. The record gives the current on the high-tension side and e.m.f. on the low-tension side of the circuit, and shows that the three contacts of the switch may not close at the same time. In fact, the e.m.f. across two conductors appears about three cycles before the current begins to flow in the third conductor.

Third Method. The generator is first excited to 2800 volts per leg and the transformer alone is then energized by closing the switch *H*. A rush of magnetizing current will occur (as we have seen before) if the circuit is not closed at the maximum point of the wave of e.m.f. This possible rush of current, however, cannot be high on account

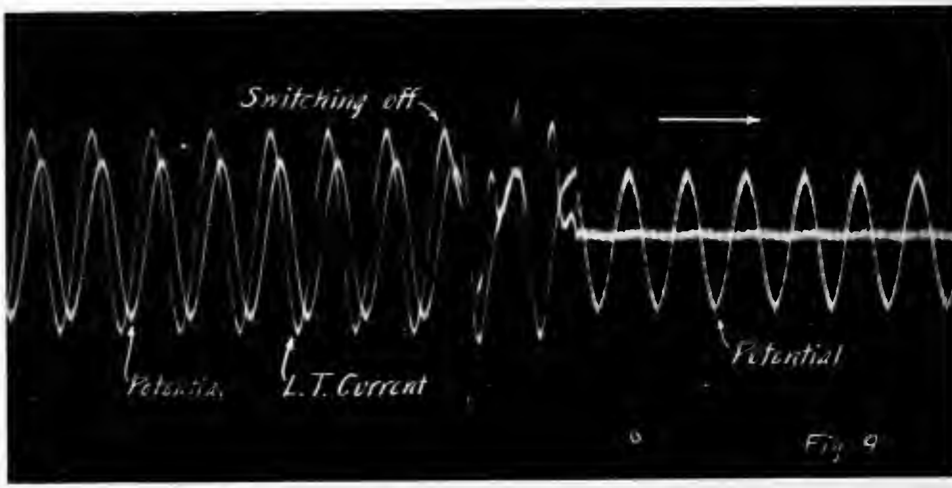


Fig. 9. Switching off 150 miles of 100,000 volt transmission line by high-tension switches. Waves of low-tension current and potential

the wave of current. This corresponds to the maximum point of the wave of e.m.f. Then at the instant the switch is opened, the transformer has no electromagnetic energy stored in it, but the line capacity has stored the maximum amount of electrostatic energy. Since the line and the transformer are connected together (but disconnected from the generator), the energy of the line will produce an oscillation of current and voltage between line capacity and transformer inductance at a frequency which we have found to be 15 cycles at full voltage and less at lower voltages.

Fig. 7 represents the two kinds of oscillations just mentioned, obtained in closing and opening the low tension switch of a system connected as shown by Fig. 1, and with practically the same constants as those of the low voltage applied to the transformer.

The switch *K* is now closed. At the first instant the energy stored in the high tension circuit of the transformer enters the line with a sudden impulse; then, as soon as the iron of the transformer becomes active, the leakage inductance of the transformer and generator and the line capacity reach their equilibrium through a 175-cycle damped oscillation. Fig. 8 shows the high tension current when the switch *K* is closed in the circuit under discussion.

To shut down this system we open first the switch *K*. While the generator and the transformer on one side and the line on the other side are still connected by the arc in the switch, an oscillation takes place between the two parts of the circuit at the usual frequency of 175 cycles. But as the arc in the switch becomes longer and the transfer of energy from the generating system to the line becomes more difficult, the two parts of the circuit become more and more independent; and finally, when the arc is broken, the line on one side and the generator and the transformer on the other side oscillate at their own natural frequency. This frequency is 302 cycles for the line, and the oscillation lasts until all the energy left in the line when the circuit was broken is dissipated.

The transformer, however, has not been disconnected from the source of power and its electrical connection to the generator has remained unchanged. On the other hand, during the process of opening the switch the in closing and in opening a circuit by high-tension switches are similar, as they both include the oscillations produced when the arcs strike and when the arcs are broken. These successive arcs increase the danger of cumulative oscillations. The opening of the switch *H* to disconnect the transformer from the generator is of no particular interest.

Fig. 9 gives the low-tension current and e.m.f. when the switch *K* is opened at 100,000 volts in the system shown in Fig. 1. This record shows no cumulative oscillation. Cumulative oscillations are shown in Fig. 10, which gives the current and e.m.f. on the low-tension side of a transformer at the moment of disconnecting its high-tension

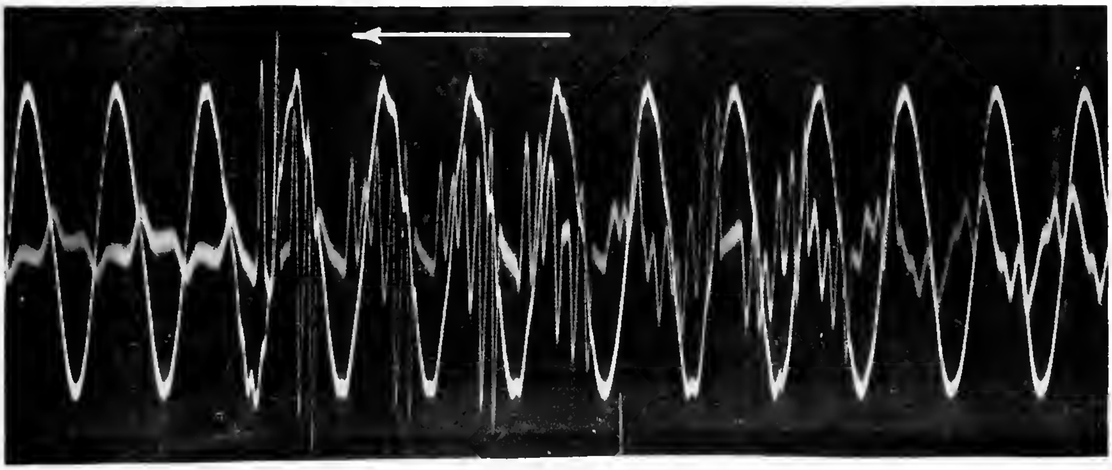


Fig. 10. 28 miles of single-phase 100,000 volt line with two 3333 kv-a. transformers at end) switched off by high-tension switches. Waves of low-tension current and potential

electrical connection between the transformer and the line has increased in flexibility and in resistance. The transformer is then receiving energy from one side, which it finds more and more difficult to pass to the line on the other side. In other words, the transformer is in danger of being subjected to cumulative oscillations, which grow gradually in intensity and often give destructive results.

It may be seen at once that the behavior of the arc in the high-tension switch plays a most important role in this phenomenon. As a matter of fact, the closing and the opening of a high-tension switch do not occur through one arc only. Generally, several arcs are established and extinguished before the circuit is permanently closed or opened. The oscillations obtained therefore winding from an unloaded line. The constants of the system covered by this last record differ considerably from the constants of the system discussed heretofore.

We can draw the conclusion that operating the high-tension switch *K* is not to be recommended and that the second method of starting up and shutting down the system of Fig. 1 is preferable. Many other examples might be cited to show that low-tension switching should be adopted in all cases where high-tension switching is not absolutely necessary.

The methods employed in analyzing switching phenomena may be applied to investigate all other transients; and thereby it is always possible to foresee and frequently possible to control the intensity and location of the disturbances that may endanger the system.

AUTOMATIC PROTECTION OF ELECTRICAL DISTRIBUTION SYSTEMS

By E. M. Hewlett

Engineer, Switchboard Department, General Electric Company

This article discusses briefly recent tendencies in the use of relays for the protection of electric supply systems. The general arrangement of connections should be made as free from complications as possible, for normal and abnormal conditions; while, in general, the type of relay itself should be of strong mechanical design rather than of extreme delicacy and refinement.—Editor.

A simple system of electrical distribution is best because it gives the greatest possible assurance of uninterrupted service. With a simple system having radial feeders it is comparatively easy to obtain automatic protection; while the liability of trouble on any one line interfering with the operation of the rest of the system is reduced to a minimum, as it is only necessary to disconnect individual circuits.

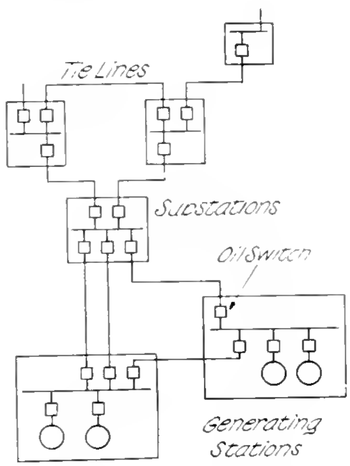


Fig. 1. Complicated System, with Substations in Series and Tie-Lines Between Substations

In laying out systems which must of necessity be more or less complicated, the question of continuity of service should be as carefully considered as the efficiency of copper distribution, since the latter is only one of the factors. A single shut-down might cause loss of revenue sufficient to offset a considerable saving in copper, not to mention loss of prestige, etc. Some companies have intricate systems with tie-lines between stations and several distributing points in series—an arrangement which presents difficulty in providing protection on account of the interconnections, for trouble in any one line may cause a shut-down of a large portion of the system. This is unfortunate, particularly since it seems that in a number of such cases the systems might have been laid out in a less complicated manner and even with a possible saving in copper. On systems where several generating stations are required it would often be wiser to operate them separately, but so arranged that in case of emergency they could be connected together with tie-lines. Where this is impracticable, on account of the unequal distribution of load on the different generating stations, it would be better to equalize the load by means of tie-lines between generating stations—giving in effect the operation of all generators in parallel on one bus—than to have cross feeders to the different centers of distribution. The tie-lines should be provided with switches which would open and separate the different generating stations in case of emergency.

The growing tendency of automatically protecting generating and distributing systems seems to have led many to lose sight of the advantages of rugged and simple apparatus in their endeavor to get a delicate selective system. This has often led to the choice of highly sensitive and delicate devices to put in the hands of station attendants, who, while experienced in operation, have neither the time nor the inclination to take care of such apparatus. The devices selected are

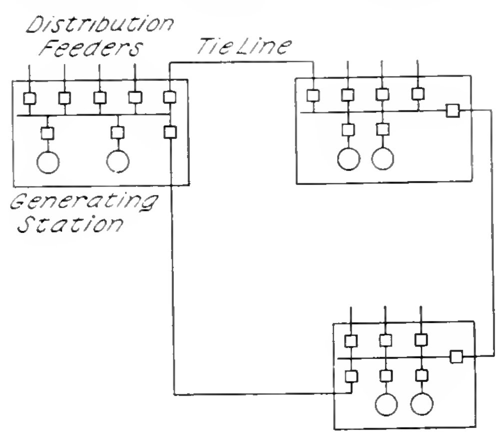


Fig. 2. Simple System, with Tie-Lines Between Generating Stations

often inherently too refined for practical service; or the scheme of protection planned requires such close margins of relay settings that a disturbance in one part of the system may throw out other parts, and consequently defeat the main object of the protective devices, viz., continuity of service. It would almost seem that some systems were laid out merely on the basis of theoretical considerations or from experience gained from laboratory work, rather than from the result of practical experience and knowledge of operating conditions. A device which can be made to work in the laboratory is not necessarily suitable for commercial service. An automatic system of protection, to be safe, must be in working condition at all times when receiving ordinary care, simplicity and reliability being most important qualifications. In some cases protective devices of extreme delicacy and accuracy may be required, but then it is invariably necessary to provide expert attention. Unless such attention is available, and the expense of maintaining it is justified, it is a mistake to install a delicate piece of apparatus when a rugged one would give more satisfactory results.

Sometimes systems are over-relayed because the designing engineer, in order to be on the safe side, introduces relays in the circuits which the operator cannot or will not use; the result being that he renders some of them inoperative, by plugging or otherwise, to prevent unnecessary interruptions of service. This may be at the expense of needed protection to the apparatus. Where, on account of improperly laid out systems, relays have failed to give the desired protection they have sometimes been summarily condemned as worthless, and others more sensitive substituted in the hope of bettering the service. Quite naturally however, this does not improve the results because the conditions under which the system works is actually the underlying cause of failure. Before deciding upon the system of connections a careful study should be made to determine the simplest possible arrangement, when taking into account not only the delivery of power under normal conditions, but also continuity of service under abnormal conditions. This will involve a study of automatic protection, and a careful consideration of the characteristics of the various types of relays.

AUTOMATIC VOLTAGE REGULATION OF POWER TRANSMISSION SYSTEMS

By H. A. Laycock

Power and Mining Engineering Department, General Electric Company

This article describes various types of automatic voltage regulating apparatus, commencing with a regulator for power stations where all the exciting units operate in parallel for the station. In some cases the plan is adopted of providing an independent exciter with its own regulator for each generator unit, the exciters not being paralleled. A regulator is described which, by automatically adjusting the excitation of synchronous motors in the load circuit, provides automatic power-factor regulation on the system, while a description is also included of a device for automatically reducing the excitation on generators, in cases where, through sudden release of a short-circuit, etc., the station voltage tends to rise excessively.—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.

In the past the standard method of operating the larger central stations was to have two or more exciters of sufficient capacity for all the generators, the exciters being operated in parallel and a voltage regulator of the kind shown in Fig. 1 being employed. This shows the connection of a twelve-relay regulator having six relays connected to each exciter field

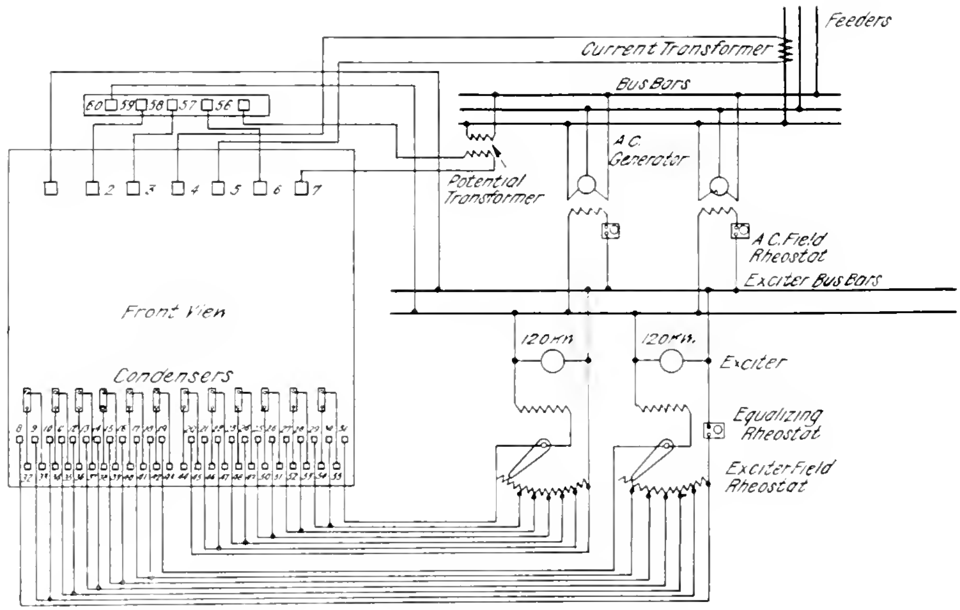


Fig. 1. Connections of Automatic Voltage Regulator with One Arrangement of Two Exciters in Parallel

rheostat, a current transformer being used in the transmission line or feeder, compensating for a non-inductive drop from the generating station to some distant point. This same regulator can also be used for the compensation of the inductive as well as non-inductive drop by the introduction of a line drop compensator, the connections of which are shown in Fig. 2 (external) and Fig. 3 (internal). This compensator is designed with an adjustable resistance and reactance using two current transformers

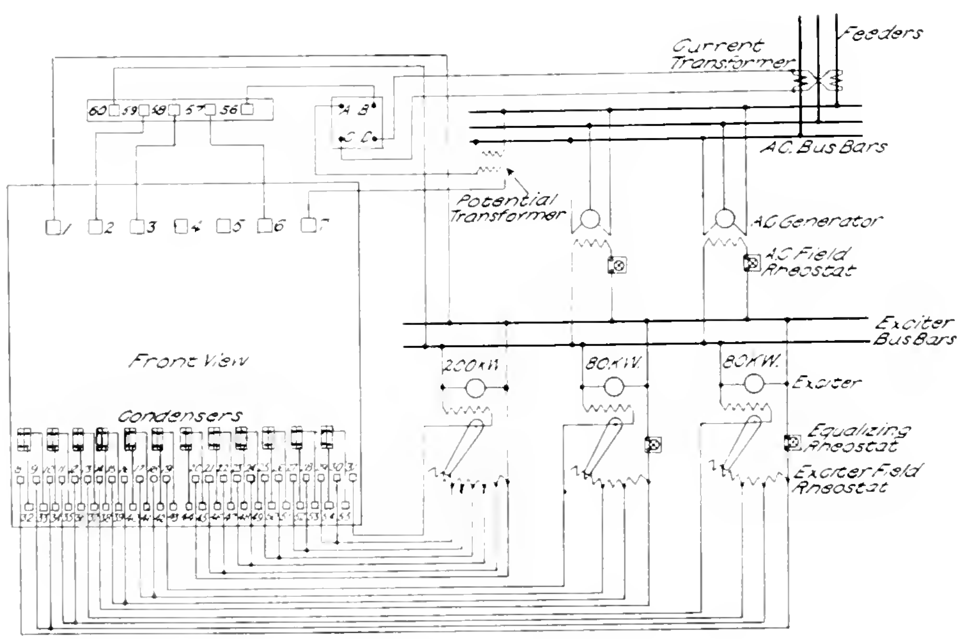


Fig. 2. Connections of Automatic Voltage Regulator with One Arrangement of Three Exciters in Parallel

connected in angular parallel; and a maximum compensation can be accomplished up to 18 per cent. line drop.

With an automatic regulator installed at the generator station as outlined above, an absolutely steady voltage can be maintained at the end of a long transmission line; while, in addition to the voltage regulator at the generating station, a synchronous condenser can be installed at some convenient point on the line, and a standard voltage regulator connected to this condenser. In this way the power-factor of the line can be improved and the energy output of the generator station therefore increased; while, at the same time, automatic voltage regulation is provided under nearly all conditions of load and power-factor. The cost of the condenser will of course be saved in time by increased energy output on the main generators.

In some of the recent power developments it has been decided to operate smaller units with an individual exciter for each generator and an automatic voltage regulator for each unit. The exciters are not operated in parallel, and the generators are usually arranged to be connected to one bus. In some cases the busses are sectionalized for convenience of operation. In general the reason for operating the smaller units with the exciters not in parallel is on account of the possibility of an accident. In the old method, employing one or more large units, the capacity of the entire system is materially affected if one unit is shut down; while in the event of one of the smaller units becoming disabled the capacity of the system is not affected to such a large extent, and there are still one or more separate units which can be easily started up without materially harming the operation of the station. Fig. 4 shows the connection of the two exciters not operating in parallel. A current transformer is connected 90 deg. out of phase with the potential transformer, and is connected to one of the two regulators; so that, if the power-factor tends to change due to the cross current between the generators, the regulator will reduce these cross currents by strengthening or weakening the field of the generator to which the regulator is connected. This admits of running any number of regulators in parallel.

On long transmission lines where synchronous motor-generator sets are used, the

(Continued on page 370)

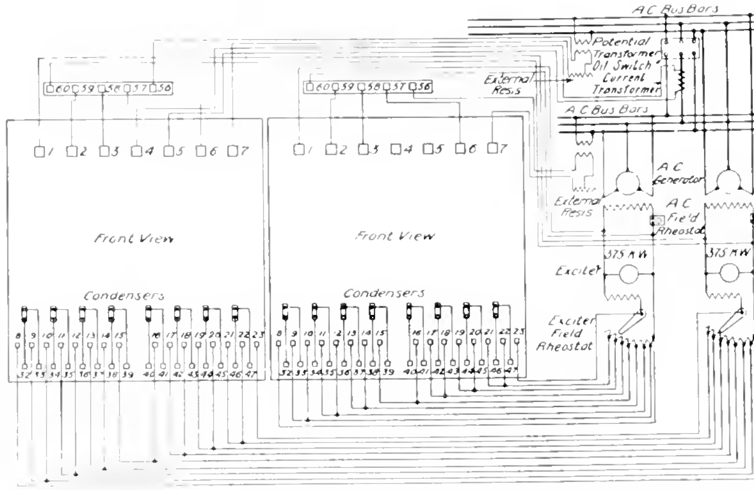


Fig. 4. Connections of Two Automatic Voltage Regulators Operating in Parallel with One Arrangement of Two Exciters not in Parallel

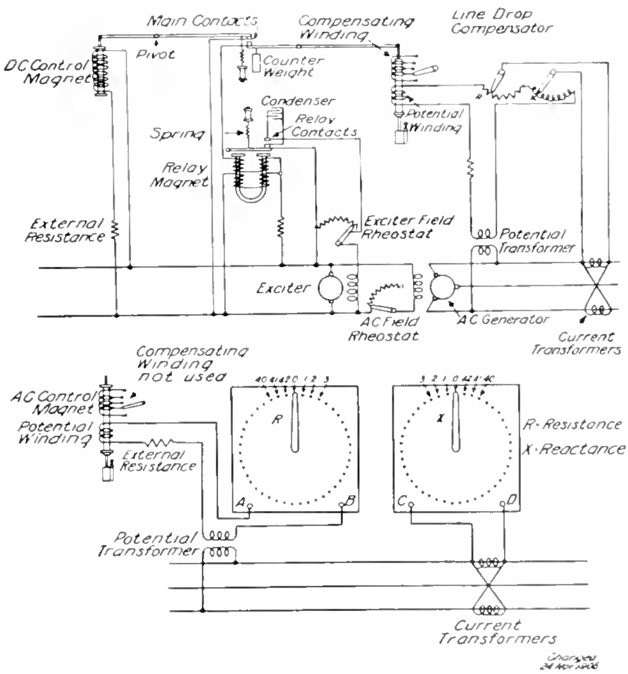
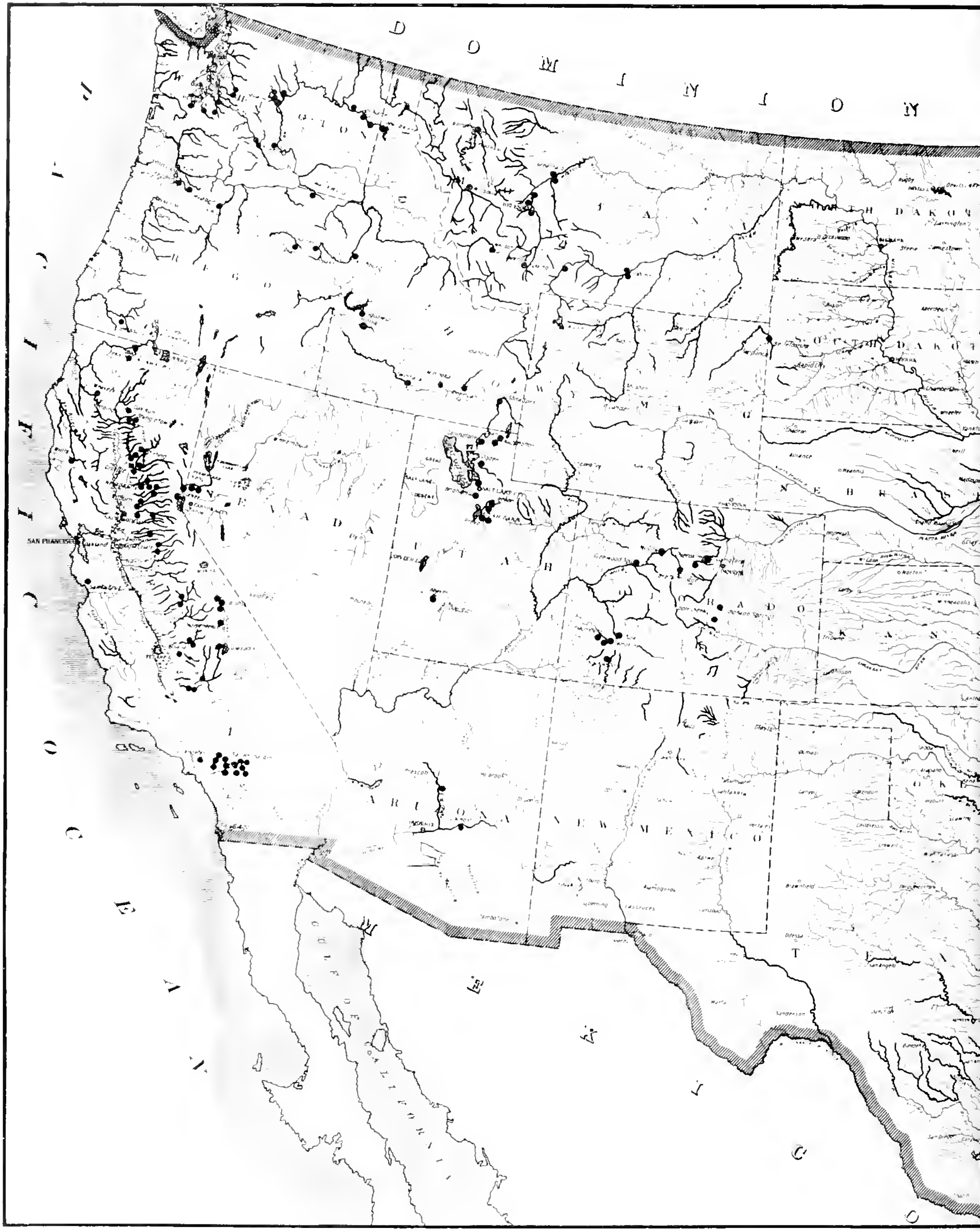


Fig. 3. Connections of Generator and Exciter, with Voltage Regulator and Line Drop Compensator, Automatically Compensating for Non-Inductive and Inductive Drop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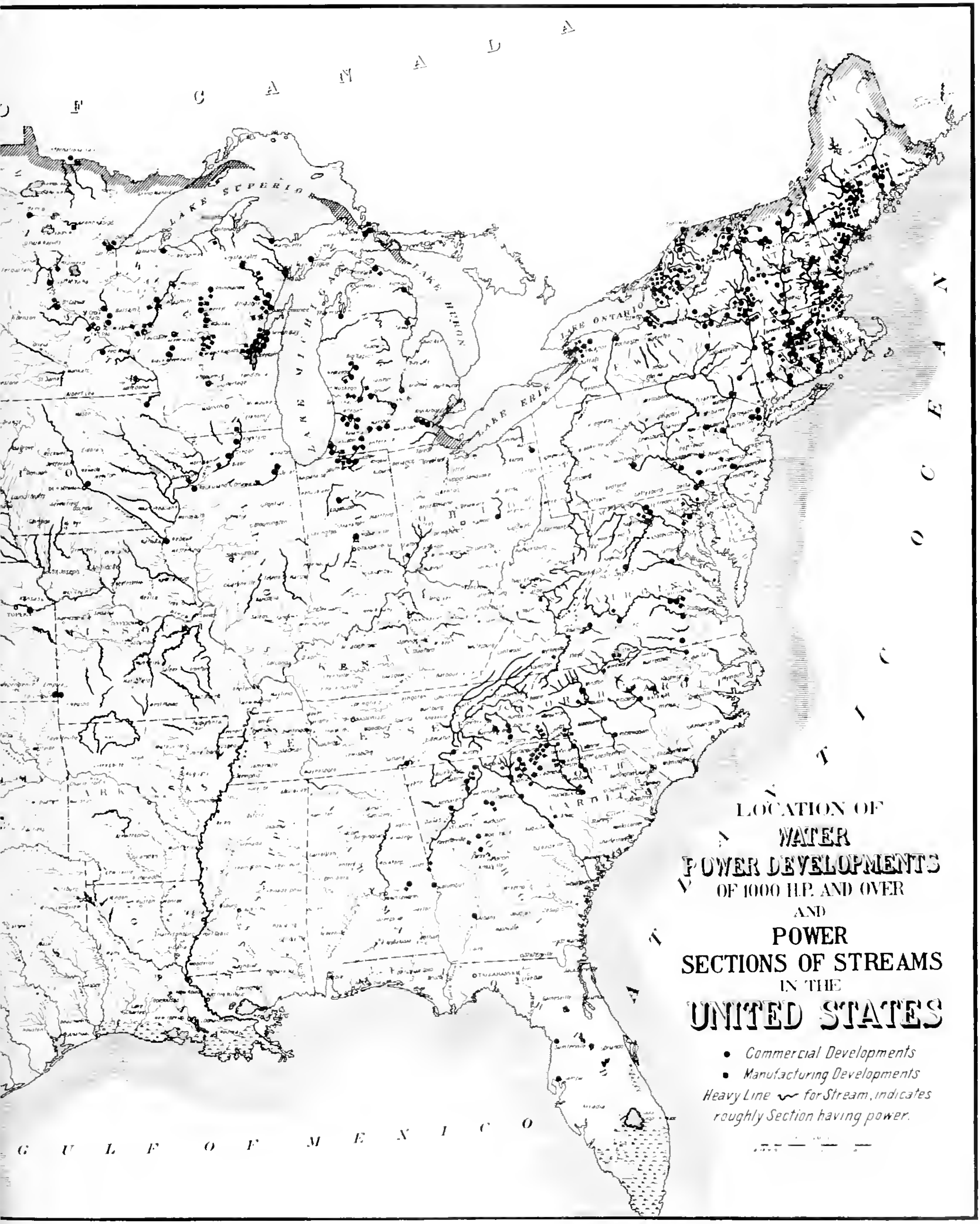

LOCATION OF
WATER
POWER DEVELOPMENTS
OF 1000 H.P. AND OVER
AND
POWER
SECTIONS OF STREAMS
IN THE
UNITED STATES
Commercial Developments
Manufacturing Developments
Heavy Line for Stream, indicates roughly Section having power.
CANADA
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
LAKE ERIE
LAKE ONTARIO
GULF OF MEXICO

generator supplying a direct current for a railway load, if it is desired to hold a leading power-factor on the motors at all times irrespective of what the load may be on the

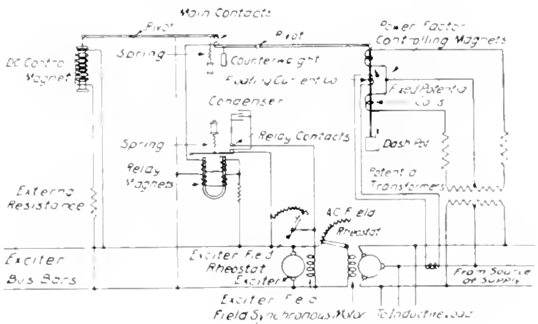

Fig. 5. Connections of Automatic Regulator for Maintaining Constant Power-Factor by Means of Synchronous Motors

generator, a power-factor regulator is employed as shown in Fig. 5. This regulator is designed with two stationary coils, and one moving current coil, the current being 120 deg. out of phase with the potential at unity power-factor. Should the power-factor tend to change in either direction the excitation of the synchronous motor is increased or decreased proportionally, so that the power-factor on the motor or line will be held constant at any desired value. For holding a leading power-factor the adjustable coil is placed at a suitable angle to the potential coil, so that the power factor, anywhere from 80 per cent. leading to 80 per cent. lagging, can be maintained with this regulator.

A short-circuit is frequently a very disturbing element on long transmission lines; and, when the voltage regulator is used and a short-circuit is experienced, the regulator, in order to maintain constant voltage, delivers full excitation to the fields of the exciters and generators. This means that the prime-movers—whether water-wheels or engines—must have their governors wide open in an attempt to hold up the voltage under a short-circuit condition. Should the short-circuit be suddenly relieved the voltage often becomes abnormal, owing to the time the governor requires to close and the fields to be demagnetized. In some instances, therefore, considerable trouble is caused to transformers, lightning arresters, etc. In order to guard against short-circuits or high voltage conditions a relay can be used as shown in Fig. 6. This is designed with a current coil and a potential coil, and will automatically reduce the excitation on the exciters whether due to an excessive load, high voltage, or any other cause whatsoever which would tend to increase the voltage. This relay is designed with a small auxiliary contactor operating across a separate resistance in the exciter field or generator field, and its size depends upon the number of generators or exciters that are installed. The relay can be set for both overload and high voltage, and is a safe-guard against burnouts and other line troubles.

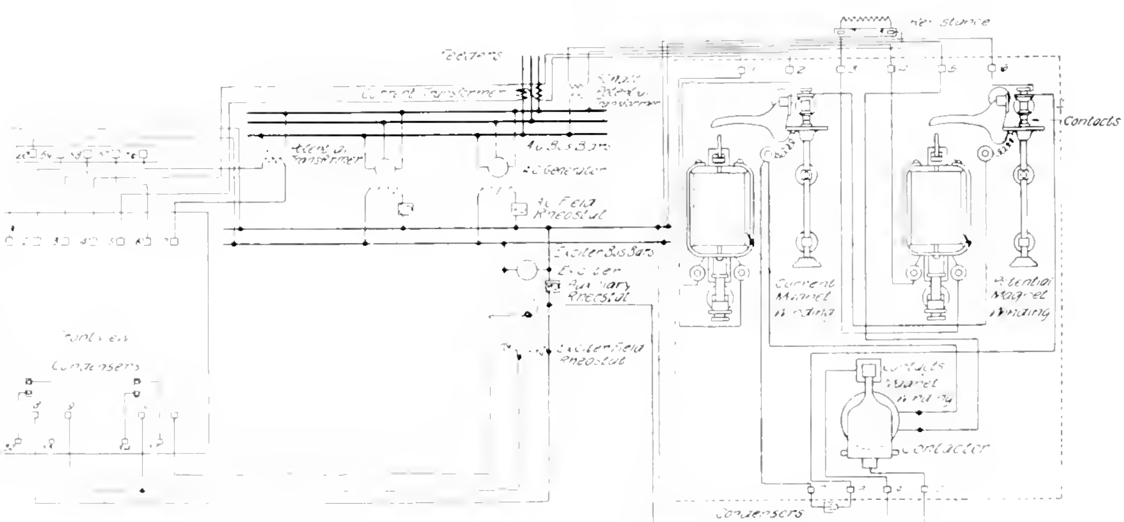

Fig. 6. Connections of High Voltage High Current Cut-out Relay with Automatic Voltage Regulator and One Exciter

SUBSTATION APPARATUS FOR THE GENERATION OF DIRECT CURRENT

By H. F. T. Erben

Engineer, Direct Current Engineering Department, General Electric Company

This article discusses recent improvements in the design and construction of direct current substation machinery, including motor-generator sets and synchronous converters. The sub-division of these two classes of converting apparatus among various lighting and railway services is tabulated. The advance made in direct current machine design through the use of commutating poles is strikingly shown, and further notes are given on other generator details, such as commutator construction, field winding, high grade brushes, etc. The section on synchronous converters, which deals at some length with the means of obtaining close voltage regulation with this class of apparatus, is reprinted from Mr. J. L. Burnham's article in the February, 1912, General Electric Review. The author of the present paper concludes with a note on high voltage converters and series and shunt regulating boosters for use with direct current generators.—Editor.

Modern methods of substation distribution are the natural result not only of the economy effected by the generation of power in large quantities by steam turbine and waterwheel driven alternators, but also of the great advances made during the past decade in the design of transformers, alternating current motors and direct current generators.

Before the advent of the steam turbine and the development of hydro-electric plants direct current was generated and distributed from the same station, engine-driven generators of small size being used. With such units high economies could not be attained, and furthermore, distribution of current at low potentials caused a very large investment in feeder copper. In 1892 there were installed in Milwaukee the first engine-driven direct current generators wound for 600 volts. These generators of 200 kw. output marked such a great advance in central station equipment that they were the subject of many technical articles; and Milwaukee became the Mecca for all contemplating the installation of "large" power generators. Thereafter, for a period of five or six years, the central station system of distribution held its own, the units installed oftentimes having outputs of 2500 kw.; but with the advent of the steam turbine and the development of hydro-electric plants the possibilities of generating power in great quantity became evident, and the building of central stations for distributing purposes practically ceased. Lighting and railway companies now find it more economical to generate alternating current at high voltage, and obtain direct current for lighting and railway service through the medium of either synchronous converters or motor-generator sets. In the early days of alternating current distribution a large variety of frequencies were used; but experience has led to the almost universal adoption of 25 and 60 cycles, although $33\frac{1}{3}$ and 40 cycles are used in certain localities.

As it is my aim to discuss recent improvements in the design and construction of motor-generator sets and converters, the scope of this paper will not permit of a detailed discussion of the reasons governing the selection of either type of machine for various kinds of distribution. Efficiency, first cost, floor space, overload capacity, load factor, station arrangement, etc., are all factors which must be carefully considered before a decision may be reached. This subject has been exhaustively treated by many writers in late years, a paper by Mr. E. W. Allen, read at the twenty-fourth annual meeting of the Edison Companies at Lenox in September, 1908, covering the whole subject very thoroughly. Where unusual conditions of operation are not encountered considerations of economy, efficiency and maintenance dictate a selection of apparatus about as follows:

25 cycles	Railway service	600 volts.	Synchronous converter.
	" "	1200 "	" "
	" "	1500 "	" "
	Lighting "	240 300 "	" "
60 cycles	Railway service	600 "	Converter or motor-generator set.
	" "	1200 "	Motor-generator set or two 600-volt converters in series.
	" "	1500-1800 "	Motor-generator set.
	Lighting "	240 300 "	Converter or motor-generator set.

The apparatus used in direct current substations may be divided into two classes, which we may designate, for want of better terms, as generating and regulating apparatus. Below is given a table showing the various classes of apparatus forming the two general divisions.

Generating Apparatus			Regulating Apparatus
Motor-generators	Synchronous motor sets	240/300 volts. 600 volts. 1200 volts. 1500 volts.	Shunt boosters.
	Induction motor sets	240/300 volts. 600 volts. 1200 volts. 1500 volts.	Series boosters.
Synchronous converters	Commutating pole type		Induction regulator. Reactance. Transformer taps.
	Non-commutating pole type		Induction regulator. Synchronous booster. Reactance. Transformer taps.
	Regulating pole type		None.

It will be noted that motor-generators have again been divided into synchronous sets and induction sets for various direct current voltages. Induction sets are seldom used in large capacities owing to the great importance of power-factor correction in all modern distributing systems. They are, however, built for outputs of from 25 to 200 kw., such sets being as a rule installed in small factories.

MOTOR-GENERATOR SETS

Motor-generator sets consist as a rule of a commutating pole direct current generator, driven by, and mounted on a common bed with, either an induction or synchronous motor. Three-unit sets are at times found to be more convenient for three-wire distribution, in which case the motor is placed between the two direct current generators. Two-unit motor-generator sets in capacities under 1000 kw. have been almost universally provided with three bearings. This policy has been dictated largely by considerations of mechanical design and the problem of ventilation. In motor-generator sets of larger size the general demand seems to have been for the two-bearing design, probably due to the prevailing opinion that minimum floor space may thereby be attained. Actual experience, however, has shown that the handling of two heavy armatures mounted on a common shaft is a difficult task, especially in stations having inadequate crane facilities. In view of this condition it may be expected that three-bearing sets will become generally more acceptable, especially as the overall dimensions are only slightly in excess of the two-bearing type.

The motors used with synchronous sets are designed as a rule to operate at 80 per cent. leading power-factor, there being available, therefore, a considerable margin for phase control. The revolving fields are provided with *amortisseur* windings, for the purpose of relieving any tendency towards hunting and to aid in starting. The field windings of the motors are designed for 125-volt excitation, which is furnished by either a direct-connected or a separate motor-driven exciter. Synchronous motors are as a rule wound for 2300/4000 and 6600 volts, although in many cases 13,200 volt windings are provided. In Figs. 1 to 4 are illustrated some recent motor-generator sets.

GENERATORS

The use of commutating poles in connection with direct current generators is the most important advance in the construction of direct current machines during the past twenty years. Previous to their use it was difficult, if not almost impossible, to construct large direct current generators to operate at high speeds. With commutating poles and improved commutator construction it is now possible to build large high-speed generators possessing the desirable qualifications of high efficiency, noiseless operation and sparkless commutation, even on heavy overloads.

The commonly accepted speeds of motor-generator sets are roughly as follows:

Kw.	Speed	Kw.	Speed
500 –	720	1500 –	360
1000 –	514	2000 –	300

These speeds are uniformly 50 per cent. higher than would have been considered good practice ten years ago on non-commutating pole machines. The increase in speed has naturally brought about a very material decrease in floor space and weight. Commutating poles, in addition to permitting an increase in speed, have made it possible to operate generators with fixed brush position, there being no longer any necessity for shifting the brushes under any condition of load. Fig. 5 illustrates a helically-wound strip copper and a cast copper commutating coil.

There is a close similarity in the electrical and mechanical design of generators for railway and lighting service, the main difference being in the use of a longer commutator for the latter machine, due to the greater amount of current to be handled. The armature windings are thoroughly ventilated, with ample spaces between the upper and lower layers of the windings for the circulation of air. The conductors are held in the slots by means of fibre or wooden wedges, and the end conductors are secured by means of bands. All multiple-wound armatures are provided with equalizers for the purpose of insuring good commutation in the event of there being slight inequalities in the various magnetic circuits. Great improvements have been made in commutator construction by the use of higher grade mica, heavier clamping rings and more careful workmanship. Where formerly it would have been considered impossible to build commutators having surface speeds of 5000 ft. per minute, such commutators are now being regularly used with entire success. It is oftentimes found necessary on machines of large current outputs to construct the commutator in two complete sections, each provided with its own clamping rings. Each section is connected by means of stout copper connectors, which, acting as fans, cause a large volume of air to flow between the two sections. By means of this construction troubles arising from the expansion of bars of undue length are entirely eliminated.

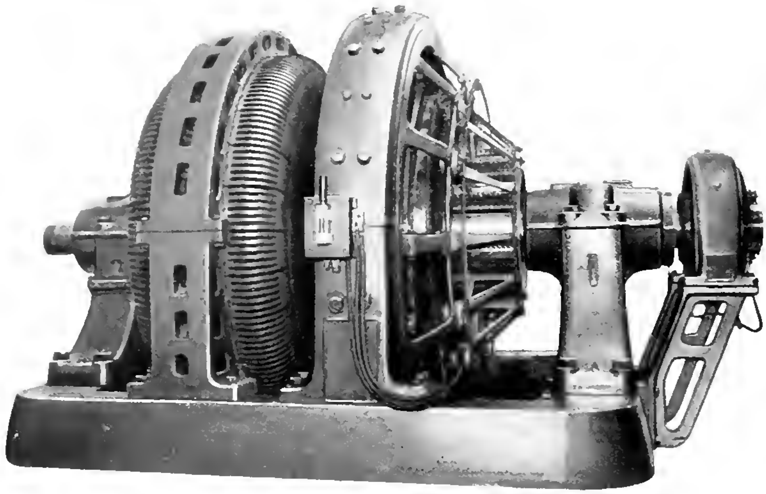

Fig. 2. 1500 Kw. 360 R.P.M. Motor-Generator Set, 11,000 Volt Synchronous Motor and 600 Volt D-C. Generator

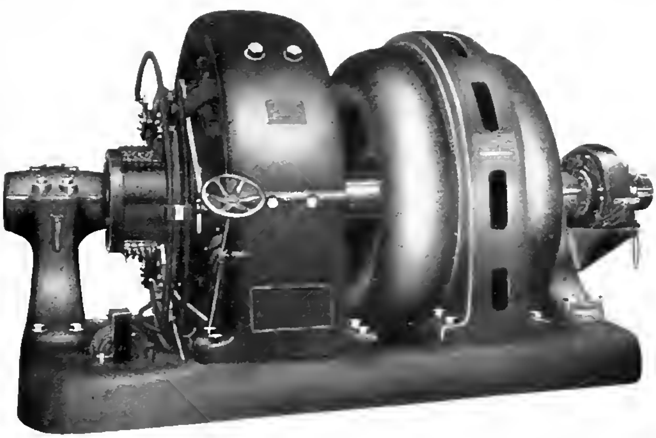

Fig. 1. 500 Kw. 360 R.P.M. Motor-Generator Set, 13,200 Volt Synchronous Motor and 1575 Volt D-C. Generator

Another contributing factor to the successful operation of high speed motor-generator sets has been the development within the past few years of high grade brushes. Where formerly the designer had at his command the choice of only a few grades of inferior brushes, it is now possible to obtain many types of brush, whose characteristics are exactly suited to the machine on which they are to operate. Graphite brushes are especially suited to lighting generators wound for 240/300 volts and large current outputs, as they possess not only higher conductivity than carbon brushes, but, owing to their inherent lubricating properties, the loss due to friction is greatly reduced. In many instances grooving of the mica between segments has been found beneficial in prolonging the life of graphite brushes, as well as promoting a superior commutator surface. It is the universal opinion that brushes should not be operated normally at densities higher than 35 amperes per sq. in.; but investigations carried on during the past few years show that, with the majority of graphite brushes, the minimum commutator loss is attained by operating the brushes at densities as high as 40 to 45 amperes per sq. in. Railway generators, having as a rule higher voltage between segments and greater overload capacities than lighting generators, are of necessity provided with high-resistance carbon brushes.

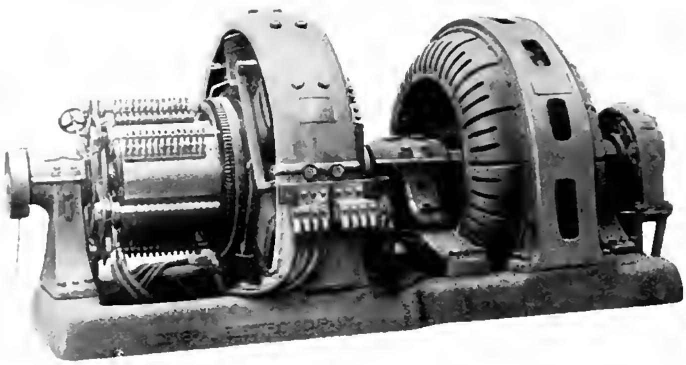

Fig. 3. 500 Kw. 720 R.P.M. Motor-Generator Set, 2300 Volt Synchronous Motor and 275 Volt D-C. Generator

Field Windings

Generators for lighting service are as a rule equipped with shunt fields proportioned to give a range in voltage of 240 to 300. The modern shunt wound, commutating pole generator has such close regulation that scarcely any change is required in the position of the rheostat between no load and full load; whereas with non-commutating pole generators built a few years ago, it was necessary to alter the rheostat adjustment with every slight change in load. Generators for railway service are provided with series windings, so proportioned that the voltage may be held constant over a wide variation of load, or that over-compounding may be attained by an increase in the series field strength.

High Voltage Direct Current Generators

During the past few years there has been an ever-increasing demand for railway generators wound for potentials of 1200 to 1500 volts, capable of carrying three times normal load for periods of from three to five minutes duration. Although such conditions are extremely severe and seemingly difficult of accomplishment, entirely sucessful designs have been developed, and units as large as 500 kw. have been in operation for the past four years. It is entirely feasible to build units of much greater output at these voltages if the demand arises.

Owing to the necessity of carrying such heavy overloads it is usual to provide, in addition to the commutating field, a compensating winding so proportioned as to practically nullify the effect of the armature reaction. This winding, consisting of heavy copper bars, is placed in slots in the pole surface and connected in series with the armature, commutating field and series field. It will readily be seen that the current flowing in these windings will rise and fall at the same rate as the current in the armature winding, thereby preventing flux distortion

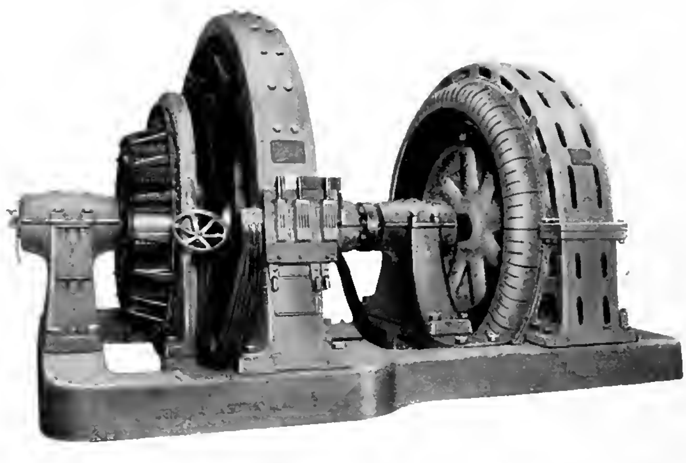

Fig. 4. 2000 Kw. 300 R.P.M. Motor-Generator Set, 3000 Volt Synchronous Motor and 600 Volt D-C. Generator

and resultant sparking. In Fig. 7 can be seen the compensating windings of a 500 kw. field frame.

SYNCHRONOUS CONVERTERS

As the different types and applications of synchronous converters have been thoroughly treated by Mr. J. L. Burnham in the February, 1911, issue of the GENERAL ELECTRIC REVIEW, it seems logical to abstract the following portions for the benefit of those who may not have read the complete paper:

"For the transformation of alternating to direct current, or, less usually, transformation from direct to alternating current, a sychronous converter is a most desirable piece of apparatus where high efficiency and overload capacity are of most importance. The power-factor may be maintained at unity except in cases where voltage control is obtained by change of power-factor. When specially designed, power-factor regulation may be obtained, although it is not usually recommended. At unity power-factor the armature reaction is negligible, and the mechanical torque is only that necessary to overcome losses in the machine. Through the absence of armature reaction and resulting field distortions better commutating conditions on heavy overloads result, and less field copper is required than is the case with a direct current generator, on which counter-excitation corresponding to the armature reaction must be provided. At unity power-factor the armature conductors of a polyphase converter may be made smaller than for a generator, to give the same heating; as the current in the converter armature is the integral of the instantaneous differences of the direct and alternating currents, which are in opposite directions.

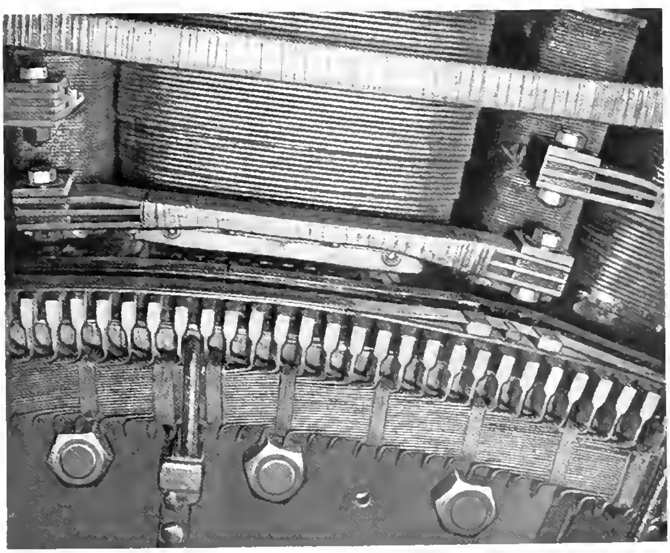

Fig. 6. Involute Equalizer Rings

Fig. 5. Helically Wound Strip Copper and Cast Copper Commutating Field Coils

"Some of the older converters gave trouble from pulsation or hunting, due to the periodic speed changes per revolution of the alternator supplying the power. Troubles from this source are now practically eliminated through improvements in the design of the engines, the present general use of the steam turbine, and improvements in converter pole bridges or magnetic dampers.

"As the ratio of a-c. voltage to d-c. voltage is practically fixed, the standard converter as first built could not be used in all cases for direct current supply on account of requirements of variable voltage, except by the use of an extra piece of apparatus for controlling the a-c. voltage. What little inherent voltage regulation exists is due to the reactance of the armature, and is obtained at a sacrifice of power-factor. By the use of external artificial reactance sufficient range in voltage control may be obtained to hold the d-c. voltage constant, with ordinary resistance drop in the a-c. line voltage, and without excessive variation in power-factor. This method is used at present in railway and other variable load work, to which it is adaptable on account of the usually lower load factors. For work where the load is more nearly constant and the voltage variation required is more than that due to the a-c. line drop, a separate piece of apparatus for changing the a-c. voltage is preferable to the variation of power-factor for securing the required d-c. voltage. It is possible to provide for varying the a-c. voltage by quick-break switches connected to taps on the high voltage side of the transformers, although this is not so desirable as an induc-

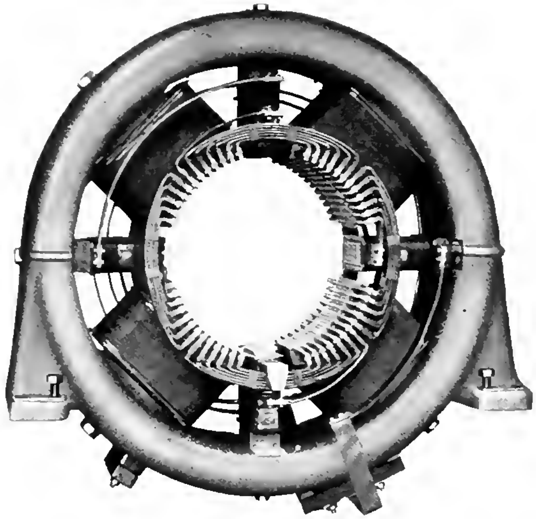

Fig. 7. 500 Kw. Field Frame Showing Compensated Windings

tion regulator, or as an a-c. generator connected as a booster, and driven synchronously either by the converter or by a separate synchronous motor. Of the latter two methods the induction regulator was developed first and is now being used more generally than any other means of voltage control, without change in the power-factor of the converter. Although the synchronous booster combination has many advantages in its favor, it has come too recently into use to have received as yet a very wide application.

"The latest development for obtaining voltage control is the 'split pole' converter, by means of which the ratio of a-c. volts to d-c. volts may be changed within the single armature without auxiliary devices of any kind. The different methods of voltage control now in use will be discussed in detail.

Phase Control

"As indicated above this is most adaptable to variable load work, such as obtains on the smaller railway systems. In general the load factor is low, so that it is possible to adjust the excitations of the fields to give a lagging wattless current at light loads; this lagging current is reduced by the increasing excitation from the series field as the load increases, so that the heating due to the wattless current is reduced to a small value when the heating due to the load current is the greatest. Thus a balance in heating for the light and heavy loads is secured for both the converters and the generator, and the heating for momentary heavy overloads may be kept within safe limits. The artificial reactance that is used to reduce the amount of wattless current required for a given voltage variation, in itself introduces a wattless component (but of smaller value), which makes it impossible to hold unity power-factor on both generator and converter at the same time; and thus the system always has a wattless component equal to the percentage of reactance used. The amount of reactance has therefore been fixed at 15 per cent., which will usually give the desired voltage variation without producing objectionable difference in power-factor between the converter and the generator.

A-C. Voltage Control

"The most obvious means of changing a-c. voltage consists in the use of quick-acting switches connected to taps on the transformers. These have been used but slightly, on account of the complication of the switching mechanism for shifting the tap connections, and the attendant risk of short-circuits started by arcing of the switches.

"The induction regulator avoids the necessity of any switching and gives a smooth variation in a-c. voltage, which is preferable to the step-by-step variation obtained by taps. The induction regulator is a polyphase transformer in which the relation of primary and secondary may be changed by mechanically shifting the primary winding. The primary is excited at constant a-c. line voltage and induces practically constant voltage in the secondary, which is connected in series with the line. By changing the relation of primary and secondary windings, the secondary voltage is changed in phase relation to the line voltage, with which it adds vectorially. It is therefore possible to increase and decrease the line voltage by any amount, up to full secondary voltage of the regulator.

"The synchronous booster, which may be driven either by being direct-connected to the converter or by a separate synchronous motor, has its winding connected in series with the source of supply, so that its voltage may be added to or subtracted from the supply voltage by the required amount, depending on the direction and amount of field excitation. This combination of synchronous booster, direct-connected to the converter, has the advantage over the induction regulator of greater simplicity and reduced amount of station wiring.

The Split Pole Converter

"Until recently it has been assumed that the a-c. to d-c. voltage ratios available in the armature of a converter were fixed within close limits. By dividing the pole into parts, with field winding for each part, so that the flux distribution through the pole face may be changed, it is possible to obtain variable ratios and thus control the d-c. voltage, from a single armature, to the values desired, without any device having corresponding a-c. voltage control. It is possible to obtain variation by using any number of divisions of the field pole; but the simplest and most economical arrangement is to use two sections, which gives the least number of parts and field circuits, and at the same time provides the maximum amount of voltage control. The voltage generated by the regulating pole flux subtracts from that generated under the main pole in the portion of the armature winding between the d-c. brushes. The change in a-c. wave shape also has some influence on the voltage ratios, but its effect is small in comparison to the differential action. Under this condition of excitation the d-c. voltage is not the same as the maximum a-c. voltage, but is of some lower value.

"The split pole converter, like the synchronous booster combination, gives the simplest station layout and wiring. When the split pole converter was first proposed predictions were made that it would produce very undesirable effects upon the system, due to distortions in wave-shape; but after several years of operation these forebodings have proven groundless. The troubles which might have arisen from wave distortions have been avoided by the selection of transformer connections to avoid short-circuiting the third harmonic voltage, which is the largest disturbing factor.

Commutating Poles

"On account of the inherently good commutating characteristics of the synchronous converter, it has not seemed necessary to resort to commutating poles until recently. The limit in the reduction of the number of poles, or the maximum output per pole, has now been reached, and by some manufacturers possibly even exceeded for economical maintenance. To obtain a further increase in the output per pole a rapidly increasing pole pitch is required, in order to reduce the reactance voltage generated in the slot portion of the commutated coil. This increase of pole pitch at the same time increases the reactance voltage of the end connections of coils outside of the slots; so that at a certain output per pole the gain in commutation by increase of pole pitch (and hence the diameter) is slight, and is only realized at greatly increased cost. It is at this point that the commutating pole becomes very useful. Through this means the number of poles may be reduced with corresponding reduction in diameter; while, besides taking care of commutation at the desired loads, the commutating poles will usually cause such a great improvement in commutation that it ceases to be a limitation to the steady output of the machine, and will allow of greater momentary overloads.

"It will thus be seen that, by the use of commutating poles, (1) a machine much smaller in diameter may be built to do a given duty for widely fluctuating loads, and (2) the commutation being now less of a limiting feature, the load factor may be increased so that it is possible more nearly to realize full capacity, as limited by heating. The great advantages which result are, (1) saving of investment in land and buildings, with smaller parts to handle, and (2) saving in cost of converters, especially where very heavy overloads have to be handled.

"The excitation of the commutating pole of a converter is only that required to give the necessary field strength to generate a counter voltage, such as will equal the reactive voltage generated by a reversal of the load current of the coil while passing a brush. Unlike the case of a d-c. generator, it does not require additional excitation to cancel the armature reaction. For these reasons the ampere-turns of excitation required on a commutating pole of a converter are about one-third of those required on a direct current generator having ordinary air-gaps between pole faces and armature. The effect of any disturbance which would unbalance the usual alternating current and direct current relations would therefore give an armature reaction that would be a large percentage of the total excitation of the commutating pole, and which would greatly affect the commutation. To reduce the effects of these unusual disturbances it is of advantage to increase the excitation required. This may be done by the use of large air-gaps. Even with large air-gaps, however, it is not possible to reduce the sparking, when starting from the a-c. side, to the amount obtained when interpoles are not used. To insure low maintenance of brushes and commutator it has therefore been necessary to provide a brush-raising mechanism on machines intended for starting from the alternating current end.

"In order to obtain current for exciting the fields and also to indicate polarity, two narrow brushes, one for each polarity, are allowed to remain on the commutator when starting. Being narrower than the main brushes, these pilot brushes short-circuit a lower voltage than the main brushes, and the sparking is harmless. As there is always some sparking when starting machines without commutating poles from the a-c. end, the brush-raising device with commutating pole machines gives better a-c. starting conditions than obtained in the past.

"An inductive shunt to the commutating pole winding is used the same as with a direct current generator. The inductance of the shunt is made greater than that of the field, in order that the changes of the field strength may be more quickly accomplished. A greater percentage of the current will pass through the commutating pole windings for increasing loads than at steady load, and for decreasing loads the commutating pole current will be less than with the corresponding armature current at steady load."

As Mr. Burnham has thoroughly described the different methods of regulating synchronous converters, I will confine myself to a brief description of those used in connection with direct current generators, under the heading of "boosters."

High-voltage Synchronous Converters

The conditions which have caused a demand for high-voltage motor-generator sets have necessitated the development of converters in voltages of 1200 to 1600 volts; and units as large as 750 kw. have been developed and placed in successful operation. The maximum voltage obtainable with a 25-cycle converter, having the usual factors of safety against flashing required in commercial service, is in the neighborhood of 1600 volts. For 1200 volts the maximum permissible frequency is about 35 with the same factors of safety. Due to the high rotating speeds of 60-cycle converters it is difficult to design successful units for voltages higher than 650 to 700 volts.

BOOSTERS

Shunt Boosters

Shunt boosters are principally used on Edison systems as a means of obtaining different potentials on outgoing feeders. Boosters are usually wound for a range in voltage from zero to 50 volts, and commutating poles are provided in order that they may operate sparklessly with full current throughout the range in voltage. Shunt boosters must have exceedingly good commutating properties, as they may at times be called upon to operate at full current and low voltage for long periods of time. The fields are separately excited and are provided with rheostats of special design in order to obtain very fine gradations in voltage.

Series Boosters

Series boosters are used on railway circuits to compensate for line drop and to maintain approximately constant potential at remote points of distribution. The magnetic circuit of series boosters must be extremely liberal in order that the characteristic may be approximately a straight line between no load and full load, i.e., the boosting voltage should vary uniformly with changes in load. It is usual to provide the fields of series boosters with taps to obtain different amounts of boost with varying conditions. A booster using shunts, except of the inductive type, is liable to be sluggish, and will not respond readily to changes in line current.

NOTES ON THE DESIGN OF WATERWHEEL-DRIVEN GENERATORS

By H. G. Reist

Engineer, Alternating Current Engineering Department, General Electric Company

This article briefly points out what are some of the salient features in the design of modern waterwheel-driven generators. Any waterwheel is liable at times to race, and the designer must perforce be conservative in assigning his allowable stress in the rotating parts. Steel for rotor spiders, grooving of the spider periphery to receive the pole piece, and sectionalizing of the spider are other points touched upon. An improved method of mounting and operating brakes is described. Mention is made of the recent increase in the internal reactance of generators, the responsibility of close regulation being transferred from the generator to automatic regulating apparatus. The author advocates a more liberal rating for this class of machinery with a higher permissible temperature rise.—Editor.

With the advance in the development of water powers the conditions that are being met today are becoming extreme in regard to the speeds—both high and low—of the waterwheels, as compared with the practice of only a few years ago. At present the manufacturers are called upon to build generators in large sizes at almost steam turbine speeds. At the same time low-head water power developments are being made, requiring large generators at very low speeds. Although the speeds required in many cases are great, in nearly all cases projecting poles may be used in the revolving fields; while the copper for the field may be formed in a single coil, allowing the coil to be placed on and removed from the machine as a unit, instead of in sections, as is necessary with the distributed field windings used on steam turbine generators. The form of rotor with projecting poles is somewhat simpler, and is preferred when it can be used without difficulty.

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 installation; but usually it is from 75 per cent. to 80 per cent. over normal speed with the Francis type of turbine, to about 90 per cent. over normal speed with the repulsion type of wheel.

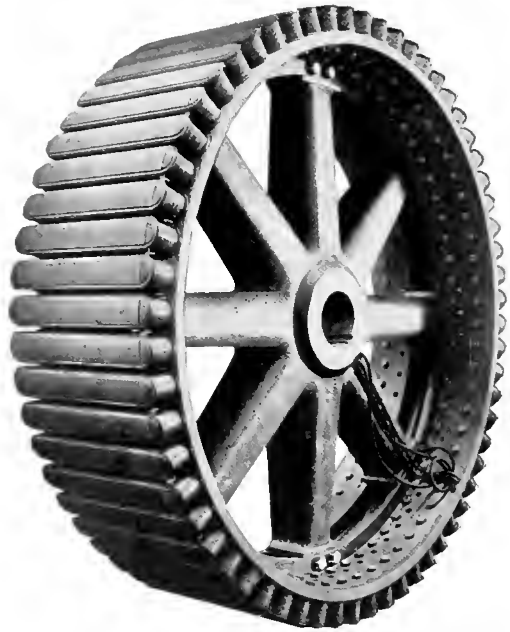

Fig. 2. Revolving Field of 4000 kw., 116 r.p.m. three-phase generator, showing design generally used for moderate and slow speed generators; all castings are made to be free from shrinkage strains

Fig. 1. 9000 kw. 57.7 r.p.m., 11,000 volts, three-phase generator, showing general appearance of a very slow-running large size generator

The manufacturers endeavour to design their rotors so that no part of this portion of the machine (as nearly as can be calculated) has a stress much in excess of half the elastic limit of the material at the runaway speed of the waterwheel. With such conservative design in this respect there is no danger of the parts of the machine yielding under the conditions of extreme speed, due to defects in the material or due to conditions or stresses which cannot

Fig. 3. Field Pole and coil of 10,000 kw. 400 r.p.m. 11,000 volt vertical three-phase generator, showing field pole, form of dovetail and dovetail reinforcement on pole piece

be predetermined. The importance of this safety factor will be appreciated when we remember that all waterwheels are liable to attain the runaway speed, and that in most installations the wheels actually do run away at times from one cause or another.

Most of the waterwheel-driven generators have steel spiders, and on high speed machines the periphery of the spider is grooved to receive a dovetail on the pole piece, shown in Fig. 3. By carefully designing the shapes and proportions of these parts a very strong fastening can be made. The designing of these dovetails is a matter to which the designing engineer must give considerable attention, since a variety of stresses are involved. The calculations are complicated, due to the angles of the parts of the dovetail; to the tendency of the laminations of which the pole piece is generally built up to fail as a column; and to the overhanging winding and other parts of the structure at the ends of the pole. The proportioning of these parts has received very careful consideration, and the actual pieces have been tested in testing machines, to verify the calculations. Consistent designs for all sizes of fastenings ordinarily used have thus been developed, and possible errors in the design of these parts in the construction of new machines have been practically eliminated. I dwell at length on this subject, because the serious character of the damage in case of mechanical failure in the rotating element of a high speed generator makes it of great importance.

It is considered sound practice to make the revolving center of large high speed machines in two or more pieces, division between the pieces being at a right angle to the shaft. Fig. 4 shows a spider made in three sections. This construction allows pieces to be made, even for large machines, that will have a moderate weight for handling; and there is less liability of a large defect in the casting than if the spider were made in one piece. It is also likely that, if there are defects in the casting, the weakness in the rims of the different sections will not come on the same side of the spider; so that the different pieces of the spider may be said to reinforce each other. On some very high speed machines this division has been carried to an extreme and a very reliable design has been adopted by constructing the field centers of rolled steel plates. This construction allows the use of uniform material of a known quality, practically free from defects, which almost always exist and which must be provided for when steel castings are used. There have been recently built several 10,000 kw. generators running at 514 r.p.m., for Tallulah Falls, Ga. which have the plate form of construction in the field spiders. The spider of one of these machines is shown in Fig. 5.

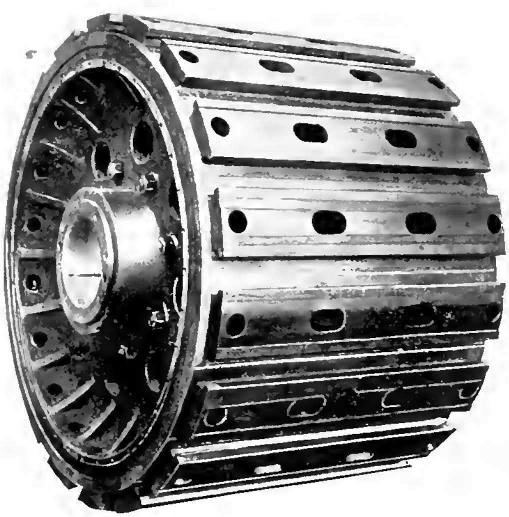

Fig. 4. Field Spider of 10,000 kw., 400 r.p.m., 11,000 volt vertical three-phase generator, showing field spider made in three sections

Brakes

In most of the larger installations it has been thought desirable to apply brakes on the revolving portion of the waterwheel to stop it quickly. Foreign material sometimes obstructs 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. It is usually found more convenient to apply the brakes on the rim of the revolving field than to mount a special brake wheel elsewhere on the shaft. A convenient means of operating brakes is by means of oil pressure which is used in the power house for operating governors, and sometimes for other purposes, and is thus generally available for use for braking when it is necessary to resort to this method of stopping the machines. The wooden face of the brake shoes can usually be allowed to bear directly on the field rim, as the amount of energy that has to be absorbed will heat the metal in contact with the brake shoe only a comparatively few degrees. In designing brakes for waterwheels it is usual to make them of sufficient capacity so that the machine can be shut down in a few minutes even if there is a leakage allowing about 2 or 3 per cent. of the full load water to flow.

Regulation

Our ideas of the regulation of alternating current generators have changed radically during recent years. There is no longer any need for good inherent regulation since we now possess an effective automatic voltage-regulating device for maintaining any condition of potential that may be desired. It performs this function whether the fluctuation is due to a change of load, speed or of power-factor. It is so easy to obtain almost perfect control over the potential by this means, that the regulation as obtained by building generators with low armature reaction is no longer satisfactory. There is a decided objection to close regulation of generators with modern power installations, since, in case of a short circuit, such generators allow a very large current to flow through the machine and through any other apparatus that may be within the circuit enclosed by the short-circuit. This frequently causes great damage to the generator and to the switchboard apparatus. For this reason it is preferable to build generators with poor regulation and high internal reactance, which is frequently supplemented by external reactance in the form of compensators or reactance coils. A generator with poor regulation may be built with lower core losses than if it has close regulation, thus allowing higher efficiency to be obtained in such machines, especially at partial loads. Such a machine is smaller and usually may be built for less money. The revolving part has less weight than the same machine with good regulation. Smaller bearings may thus be employed; and, in consequence, there will be less friction loss. It will be understood that poor regulation in a machine might be carried to an extreme, so that both the losses and cost of the machine might increase beyond the minimum point.

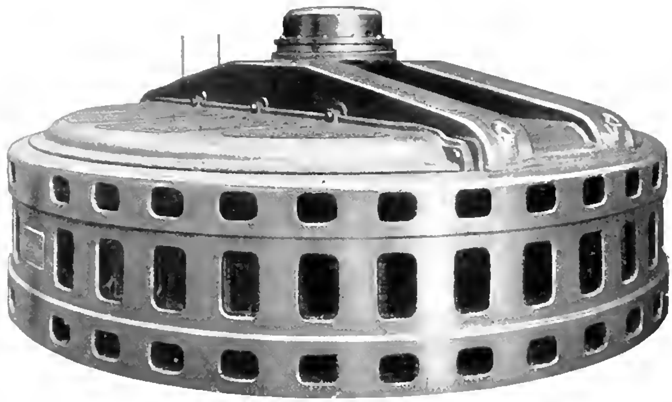

Fig. 6. 2300 kw., 97 r.p.m. three-phase generator, showing the appearance of a slow speed machine with the top bracket provided with a bearing for supporting the weight of the revolving part of the generator and the waterwheel runner

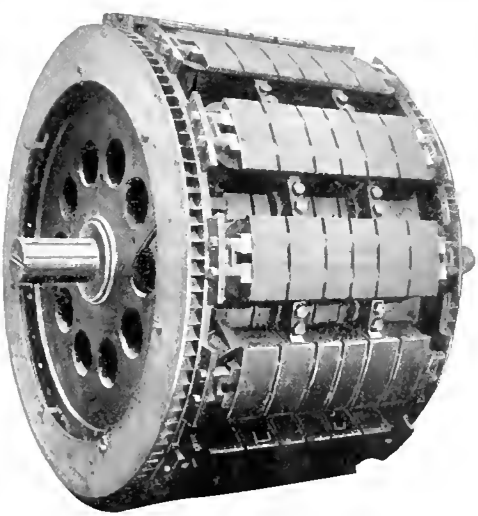

Fig. 5. Revolving Field of 10,000 kw., 514 r.p.m. three-phase generator, showing spider made of plates of rolled steel

Temperatures

Our present system of guaranteeing temperature is cumbrous, and frequently leads to installation of machinery not best adapted for the conditions existing in a plant. The tendency with the present system of guaranteeing temperatures is to install generators of too large a size for the waterwheels, and to operate machines at their normal rating; whereas the efficiency of generators, and frequently of waterwheels, is higher at overloads than at rated loads. I believe that this class of machinery could to advantage be given a maximum rating—as has been adopted with steam turbine generators. In this case the maximum temperature might be perhaps 50 deg. C. rise. Higher rating of the generator would inspire the attendant to operate it at a higher output than is the case by the present system, thus assuring a greater all-round efficiency.

REVIEW OF RECENT DEVELOPMENTS RELATED TO PROTECTIVE APPARATUS

Part I

By Prof. E. E. F. Creighton

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This article forms a review of some of the more important devices that have recently been developed or modified for protecting electrical apparatus against abnormal conditions of service. The first part of the article, which we now publish, deals with the inability of the standard aluminum cell arrester to withstand the discharge of dynamic current that follows a large percentage increase in the normal voltage of the system, due to any one of several causes, and the means that have been employed to overcome the difficulty; changes in the arcing ground suppressor, and its application to underground cable systems in connection with a device for localizing faulty feeders; a discharge alarm and recorder for indicating and registering static discharges of any frequency, potential and amount; and a compression chamber arrester for local protection, which is less expensive than the usual graded shunt resistance arrester.—Editor.

While it is the object of this paper to make a cursory review of the various phenomena relative to electrical protection, it is not desired at this time to more than touch on protective apparatus that has become standard and familiar to all, and electrical phenomena that has been analyzed and investigated by experiment some time in the past. The desire, rather, is to review some of the more recently devised apparatus, and to note not only studies that have been made but also outline in some cases the direction of further progress.

The following subjects are treated briefly:

1. Cause of troubles in Aluminum Arresters and their correction.
2. The latest conclusions regarding the Arcing Ground Suppressor.
3. The Localizer of a Faulty Feeder on circuits which contain many feeders, such, for example, as cable systems.
4. The description of a new type of Discharge Alarm, operating on the principle of Hertzian waves and utilizing in its construction a coherer.
5. The Compression Chamber Lightning Arrester, a new, compact, and inexpensive form of multi-gap arrester involving a new principle.
6. The subject of the Protection of Direct Current Railway Apparatus.
7. Experiments illustrating the local rises of potential in transformer coils with no rise of potential at the transformer terminals. These local rises of potential are due to resonance at certain frequencies.
8. Description of a Multi-Recorder, a new instrument for recording the operation of switches and other things. Records are printed to the second and by successive operations a second may be split into four parts.

The Aluminum Arrester

Inquiries show that the efficiency of this arrester in protecting apparatus against lightning and transient surges in general is so high that little more could be expected of it. The general satisfactory operation of the arrester, it may be presumed, is of less interest to the user than the conditions of limitation or misapplication where the arrester has apparently been a source of concern.

The most notable condition that has caused trouble with the aluminum arrester is its application to long distance transmission systems on which the regulation is excessively bad. Investigations of failures of the arrester have disclosed dynamic potentials of 175 per cent. of normal applied to the arrester when, due to some accidental condition, the power load on the system was accidentally dropped. Such rises of potential were due not only to the effect of the electrostatic capacity of the unloaded line, but also to the effect of the leading currents on the generator; and furthermore, with hydraulic plants, a racing of water wheels at the moment the load was dropped.

A moment's consideration of the function of a good lightning arrester will show the difficulties in meeting this situation. The more nearly a lightning arrester approaches the condition of a safety valve on a boiler, the greater the value of the arrester. A perfect arrester would be one which could be connected continuously to the line without the intervention of a spark gap, and which would take no current or power at normal potentials. Furthermore, the wear on such an arrester should not produce an objectionable expense in its up-keep. This same ideal arrester, on an increase of potential above normal, should be capable of discharging current at an enormous rate without taking dynamic energy from the circuit.

Let us now examine the aluminum arrester with this ideal arrester in view. The arrester can be made for connection to the line without a series gap, but it will take an appreciable amount of energy from the line; and the cost of the arrester and the wear on the plates will be objectionably high. Therefore this one feature of the perfect arrester (connecting it to the line) has to be abandoned. A gap is placed in series, the break-down potential of which is slightly above the line potential in order to prevent the continuous flow of energy into the arrester. We have at once attained the desirable condition of no wear and a sensibility to slight increases in potential; but on the other hand there has been introduced a spark in the circuit which it would be desirable to avoid. This gap also introduces the necessity of reforming the film each day, as it is the natural characteristic of the film on the aluminum plate to slowly but gradually dissolve in its electrolyte. These matters will be taken up further on. Next, let us consider the factors of function at abnormal potentials. The natural conditions of the usual electrical circuit are such that abnormal potentials are of a transitory nature. The energy in these transitory surges is limited to that which can be stored up either in the electrostatic capacity or the electromagnetic circuit of either a part or the whole of the system. This energy is necessarily limited in its amount; as compared to the main power delivered it is infinitesimal. Therefore, in its application, it is required of this arrester to have an energy capacity only sufficient to absorb the transitory discharges. The aluminum arrester has in fact a factor of safety in this regard that can be expressed in thousands. When, however, due to the accidental conditions that have been described above, the generated potential rises to an abnormal value dangerous to the insulation, then, the better the arrester as a discharger of abnormal potentials, the harder will it be hit by the continuous discharge of the energy of a generator through its small bulk.

The important question arises: "How shall we avoid this condition?" This is a problem that is not yet quite satisfactorily solved. The easiest answer to give is: "By requiring that the dynamic potential on the circuit shall never rise to these objectionably high values." To accomplish this on many of the circuits, however, is almost impossible at the present time. From the standpoint of design of the arrester the question may pertinently be asked: "Why not design the arrester to withstand these conditions?" This design, in itself, is very easily made, as it consists initially in putting more cells into the arrester, but the difficulty then arises of keeping the films on these arresters formed up to the maximum value that will occur during accidental rises of generator potential. The arrester is naturally charged at normal line potential. The aluminum cell has the characteristic of dissolving off the thickness of film that is above the thickness produced by the daily charging. Therefore, the arrester is not in a prime condition to take the abnormally high dynamic potentials until after it has reformed its film up to the new value. Meanwhile, tremenduously high currents have been passed through the arrester and a possibility of damage from these currents has been incurred. An arrester could be arranged in parts so that each part could be charged up to line potential separately and subsequently placed in series. This involves a complication in charging that is undesirable, not only on account of the trouble but on account of the extra expense.

A better solution of this problem is to use the extra cells in series that are demanded by the accidental conditions of dynamic potential and introduce a parallel circuit with the main gap containing a limiting resistance. Such a circuit now exists in practice in what is known as a safety horn gap and charging resistance (Fig. 1). This auxiliary horn has a gap setting considerably below the main gap. Consequently, when the dynamic potential on the arrester increases, it is the smaller gap that sparks over, the resistance in series limiting the charging current in the arrester during the early

Fig. 1. One Form of Mounting Charging Resistance for the Aluminum Arrester

period to a value such as to allow the films to re-form with a minimum of risk, and protecting the arrester from the enormous concentration of energy from the generator. Under these conditions the resistance is not at all objectionable from a protective standpoint. The main gap is always present to take the discharge in case the drop of potential through the resistance becomes objectionably high, as it would naturally under the conditions of a heavy lightning discharge. While this solution is not all that could be desired, it promises, in conjunction with ameliorating conditions that can be produced elsewhere in the circuit, to give satisfactory results.

Returning now to the factor of spark at the gaps, it is well known that every spark or arc in any circuit whatsoever is a disturbing element to the continuous regime, and since capacity is always present in every circuit, more or less oscillations are set up thereby. With a normal setting of the horn gaps of the lightning arrester, when a spark takes place little if any dynamic energy follows, and the spark is immediately extinguished. There is, therefore, in this condition little possibility of disturbing oscillations being set up.

If the films of the arrester get in bad condition and the charging current becomes excessive, then under very special conditions of inductance and capacity arcs may produce oscillations which should be considered. In order to avoid damage during the re-formation of the film, a charging resistance limiting the current to a comparatively small value can be used. This charging resistance acts not only as a damper of high frequency oscillations, but protects the lightning arrester from dynamic energy if the arrester is in such condition as to need it. At the same time this charging resistance is low enough in ohmic value not to influence appreciably the charging potential across the aluminum cells in series. The favorable condition is made easy by the fact that the potential across the aluminum cells is practically at right angles to the potential across the resistance, and therefore the electromotive forces combine in a triangle. So long as the charging current is normal, then the drop of potential across the resistance is negligible; but under abnormal conditions the resistance absorbs the dynamic potential until the films are gradually reformed. The potential is thus gradually shifted from the resistance to the cells automatically.

The Arcing Ground Suppressor

The arcing ground suppressor was described for the first time in 1911 at the February meeting of the American Institute of Electrical Engineers. At that time it had been in use very little. Experience, however, has not changed the conclusions that were reached at that time and no material changes

Fig. 2. Ammeter, Stick and Jack for Measuring the Charging Current in an Aluminum Arrester

have been necessary in the design. The only changes have consisted in making the movable part of the electrostatic relay more stable, and in eliminating the glass plates between the insulator and the aluminum disc.

The suppressor has not failed to extinguish arcs around insulators, and where the troubles on the circuit are principally single-phase arcs to ground the suppressor has been able to improve service correspondingly. The suppression of the arcing ground relieves the system of the greatest known source of dangerous electrical surges.

More recently the arcing ground suppressor has been applied to a cable system. Since practically all cable troubles are initially a single-phase fault to ground, the arcing ground suppressor becomes more effective when thus applied than when used on the overhead system. The application of the suppressor to cable systems has been delayed by the lack of a reliable localizer of a faulty cable. It is evident that after the arcing ground suppressor has operated on the bus of a cable system, all evidence of the grounded cable is eradicated. It should be noted that the suppressor applied to a cable system is not arranged to open up automatically, as a fault in the cable is permanent and the cable must finally be disconnected for repair. The conditions on a large cable system are described in a paper by Mr. T. J. Whittlesey and the writer for the annual meeting of the A.I.E.E., June, 1912.

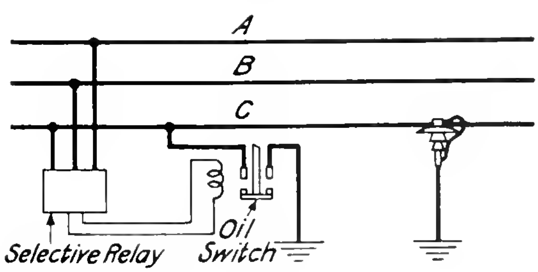

Fig. 3. Simplified Circuit of the Arcing Ground Suppressor

The Localizer of Faulty Feeders

The problem of selecting from a number of feeders the one which has become grounded is made difficult by the fact that the current to ground is variable over a wide range, according to the accidental conditions at the arc. This variation has made it impossible to set a relay which would be selective for both low currents and high currents.

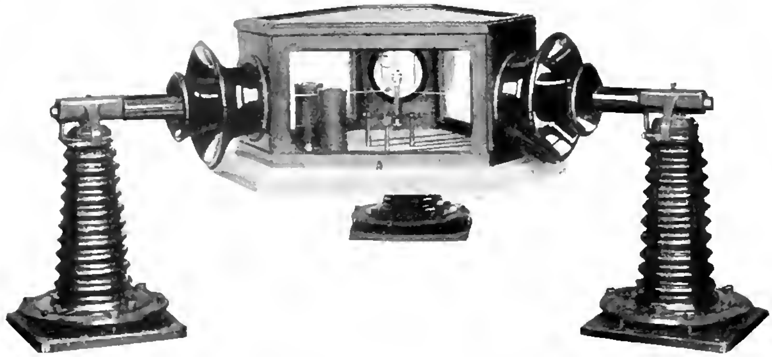

Fig. 4. Side View of the Electrostatic Selective Relay for the Arcing Ground Suppressor

For example, if the relays are all set to be selective when the currents to ground are at their lowest possible value, and an arcing ground takes place, all the relays will show the cables faulty. If on the other hand the relays are adjusted so that they are selective for the highest possible value of grounding current, then no relay will respond when the current to ground happens to be low. In order to overcome this condition, relays have been designed in which all the currents from the cables that are not grounded cancel out, leaving only an unbalanced condition of the current in the grounded cable. This makes the relays selective, no matter what the grounding current is, as the proportionality of grounding current between the different cables is always the same.

Another problem in regard to the localizer of faulty feeders comes from the effects of transient surges, such as are due to switching and other causes. In order to prevent false signals of grounds on a cable from the transient surges, it was necessary to design a retarding relay. The nature of this problem will be understood from the conditions that had to be met. The arcing ground suppressor, as the switches are designed at present, requires one-quarter of a second to suppress the arcing ground; therefore the localizer of the faulty feeder must operate within that period of time. On the other hand, the localizer should not operate within 0.20 of a second, in order to avoid the effects of transitory surges. The solution of this problem is found in the use of a time element which depends upon inertia. The actual form of the relay is shown in Fig 5, while the technical details of the conditions on the circuit are more fully described in a paper by Mr. Archibald Davis and the writer, written for the annual meeting of the American Institute, June, 1912. The general connections of the relay

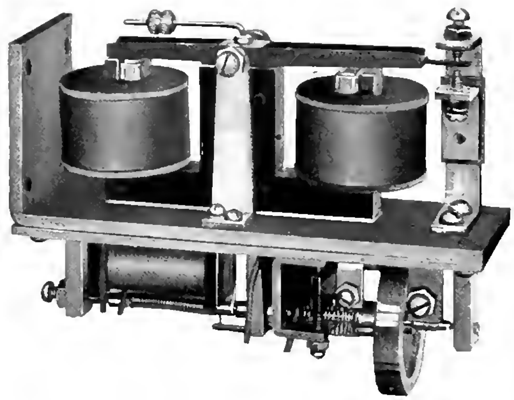

Fig. 5. Relay of the Localizer of Faulty Feeders

and arcing ground suppressor on a cable system are shown in Fig. 6.

New Type Discharge Alarm

While working along theoretical lines of study of lightning phenomena, it became necessary to find some kind of alarm and recorder which would respond to static discharges of any frequency, any potential, and any quantity of electricity, large or small. The more usual devices using the principles of electromagnetic, electrostatic, and heating effects of the currents were tried without good results. Finally, the coherer, as used in the original wireless experiments, was adapted to this class of work. The apparatus for giving an alarm and for recording such a discharge then consists of a Branley coherer connected to a local circuit consisting of a tapper hammer, and interconnected local circuit containing an alarm and recording devices. When the coherer has its circuit completed by discharges of any kind the tapper hammer is pulled back, but unlike the usual connections does not immediately decohere the tube. The hammer is held back until the alarm and recorder work. For example, when the clapper on the alarm bell reaches the end of its stroke it opens up the circuit of the hammer for the coherer tube and allows it to strike the tube, thus opening the coherer circuit. It will be seen that this device is entirely independent of everything but the Hertzian waves. During the past year this device has been applied to lightning arresters and to transmission lines. As applied to several lightning arresters in one station, the discharge alarm is not selective. The alarm is connected to the ground wire of one lightning arrester and will respond to the discharge of any of the lightning arresters in the station. If the coherer is connected to the telephone line under the transmission line it will respond to lightning strokes anywhere in the neighborhood of the transmission line, no matter how far out.

This discharge alarm contains an erratic element in the coherer. Although good results have been obtained during the past it can not be said from an engineering standpoint that we are sure that the development of the alarm is yet in a position where it is absolutely reliable and fool-proof. A wider application will be necessary in greater numbers before we can reach the assurance that the design will fit the peculiar conditions of static field, potential, and oscillations

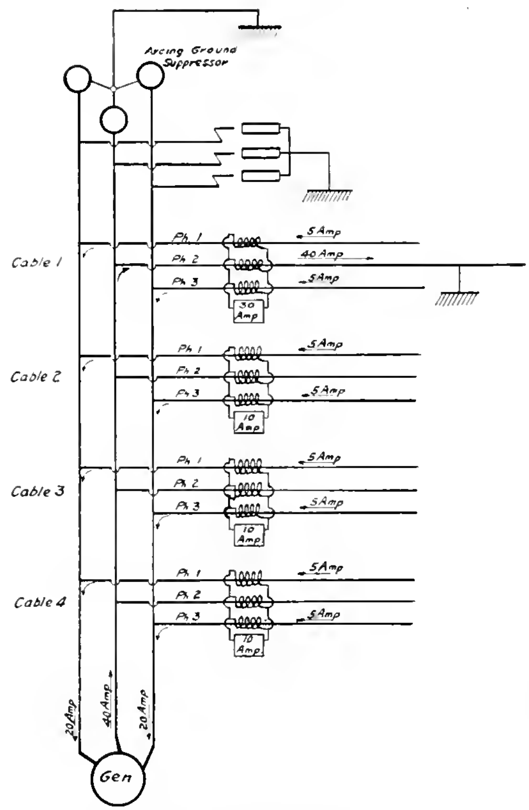

Fig. 6. The General Connections of the Localizer of Faulty Feeders and the Arcing Ground Suppressor

which exist on different systems. This matter, however, has progressed sufficiently to warrant a description of the apparatus. This is given in a paper by Mr. G. F. Gray and the writer, written for the annual meeting of American Institute, June, 1912. The general connections of the circuit are shown in Fig. 7, and the alarm itself is shown in Fig. 8.

Compression Chamber Lightning Arrester

After careful study extending over a number of years the conclusion has been reached that lightning disturbances on transmission lines are very much localized. It has been observed, for example, that on a 2300 volt system a lightning arrester placed several poles away from a transformer would not give adequate protection if the stroke were severe. In recommending the use of a lightning arrester at every small transformer, we were confronted with the commercial side of the problem: namely, that

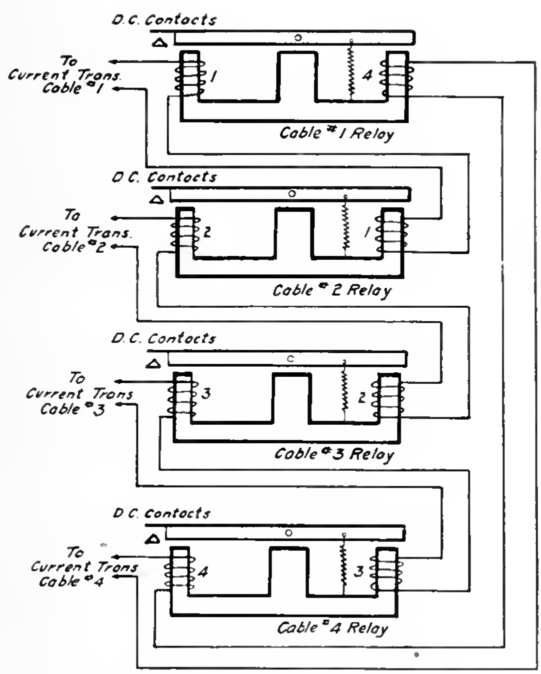

Fig. 6a. Scheme of Connections for Pairing off the Grounding Currents in the Localizers of Faulty Feeders

the value of many small transformers would not warrant the expense of the installation of the well known standard types of graded shunt resistance arresters. It became evident that a less expensive arrester was necessary, even if it had to be obtained by a sacrifice of some of the efficiency of the standard type.

This led to the design of a type of arrester in which two conditions of efficiency are

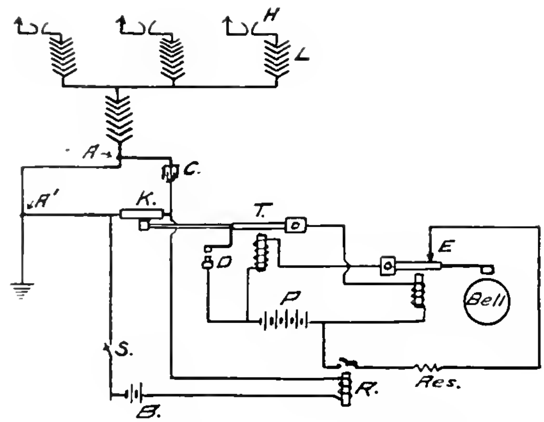

Fig. 7. Circuit Connections of the Discharge Alarm

possible. The new form of design has also allowed the use of a new factor which gives the arrester greater sensibility to lightning strokes and at the same time increases its arc-extinguishing value. This device is known as the antennæ.

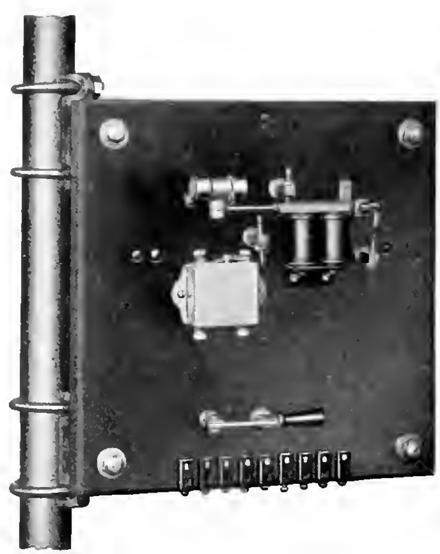

Fig. 8. Discharge Alarm Mechanism

The design of the compression chamber lightning arrester for 2300 volts is shown in Fig. 9, and its application to pole transformers in Fig. 10. In brief, the arrester consists of a porcelain base from which extends a long porcelain tube, making an over-all dimension of about one foot. Between the porcelain tube and the porcelain base a metal sleeve is introduced in the form of a "U", which is the antennæ already referred to. This antennæ increases the electrostatic capacity of each of the electrodes placed inside the tube, and thus, in accordance with the theory given by Dr. Steinmetz a number of years ago, aids in producing a spark across the several gaps. In fact the spark potential with this antennæ in place is the same on 8 gaps as it is on 4 gaps with the antennæ absent. In the actual construction this allows the use of twice as many gaps with the same spark potential. Inside the porcelain tube enclosed by the antennæ are the compression chamber gaps. These gaps consist of a short length of porcelain tubing with inverted metal hats placed over the ends. Between these metal hats is a small gap which the lightning has to jump. The spark thus takes place in a closed chamber, and the increase in pressure in this chamber when an arc follows the spark helps to extinguish the arc.

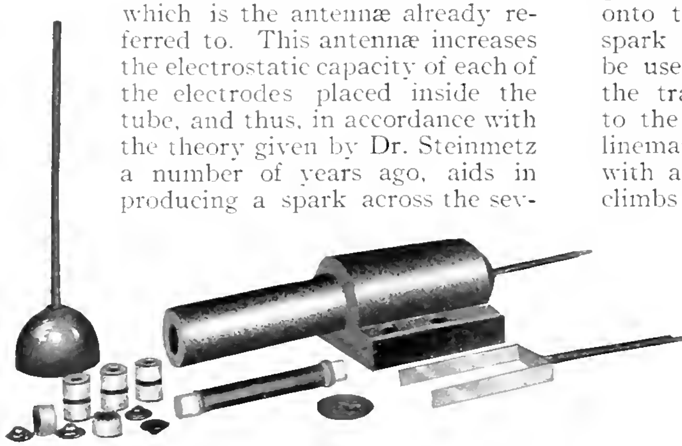

Fig. 9. Parts of a Compression Chamber Lightning Arrester

In series with a number of these gap units is a resistance rod of low value. In the simpler form of arrester this rod is plain. The resistance, however, is so low that there is a discharge rate of 600 amperes at the potential at which the 2300 volt transformers are tested. This discharge rate has been found ample for practically all lightning strokes; however, by the addition of gaps in parallel with this resistance rod it is possible by a slight increase in expense to retain in this arrester the shunting effect used in the design which has been standard for a number of years. The shunting gaps are made very compact by making the electrodes in the form of rings which enclose the resistance rod.

In the application of this arrester a very important feature is the connection between the case and the grounding wire which runs down the pole to a salted pipe earth. Where there is an objection to connecting the ground lead of the lightning arrester directly onto the case of the transformer a simple spark gap of inexpensive construction may be used. In general, however, the case of the transformer can be directly connected to the ground wire. For the safety of the lineman the ground wire can be arranged with a joint which is broken by him as he climbs the pole. With this direct shunting effect of the lightning arrester around the transformer to the case, less attention need be paid to the conductivity of the ground wire and the resistance of the earth connection, as they are no longer in the circuit which produces a potential on the insulation of the transformer. Therefore, cheap iron wire may be used extending down the pole.

The construction and use of the compression chamber arrester is described more in detail in a paper written by Mr. F. R. Shavor and the writer for the Schenectady meeting of the A.I.E.E., May 17, 1912.

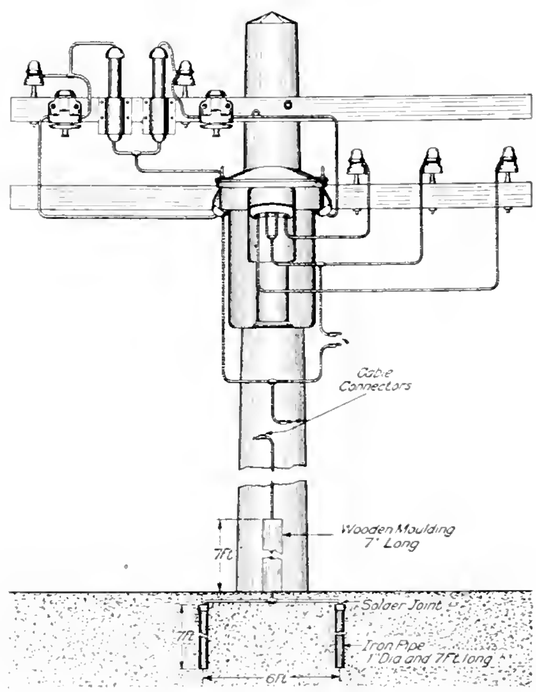

Fig. 10. Application of Compression Chamber Arresters to Protection of Pole Transformer

(*To be Continued*)

THE LINE INSULATOR IN MODERN HIGH VOLTAGE TRANSMISSION SYSTEMS

By F. W. Peek, Jr.

Consulting Engineer, General Electric Company

This paper points out some of the fundamental limiting electrical characteristics of the series suspension insulator used in modern high-voltage lines. The curves shown embody some of the results of extensive tests taken on various types of insulator, wet and dry arc-over voltage being plotted against the number of units in series. Theoretical curves are compared with the test curves. String efficiency is defined. From these test results the author draws some general conclusions regarding voltage balance along a string, the importance of high efficiency and method of making tests. The results and conclusions have a direct practical bearing on the design, testing and selection of high-voltage insulators, as well as on the framing of specifications.—Editor.

The transmission line in the modern hydro-electric development is exposed to many chances of mechanical and electrical failure. For instance, it must cross mountains at high altitude; it must cross rivers over long spans; while it is subject to lightning storms, various weather and climatic conditions, such as high winds, sleet storms, salt storms, snow slides, etc.

In order that any transmission system may be successful, it must, first of all, be reliable. Continuity of service is being demanded more and more as an essential feature of our supply circuits; and the demand for good service has made wonderful development—both mechanically and electrically— a necessity in the transmission line. One has but to compare the old wooden pole line to the modern steel tower to realize the truth of this assertion.

In electrical transmission the conductors are immersed in the most universal insulating material—air. This material is not subject to design, but must be taken as it comes, and the conductor diameter and spacing so proportioned that loss does not occur as corona at the operating voltage.* As the air cannot support the conductors, solid dielectric must be used at given points. This supporting dielectric is known as the line insulator.

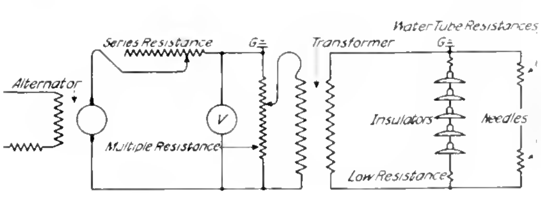

Fig. 1

The insulator, too, must be designed so as not to electrically over-stress the air at any part; while the solid dielectric of which the line insulator is composed must itself be so designed that none of its parts are over-stressed.

The object of this paper is to point out some of the fundamental limiting electric characteristics of the modern high voltage insulator—i.e. the series suspension insulator—with a view, possibly, of limiting line troubles and of helping in the selection of insulators.

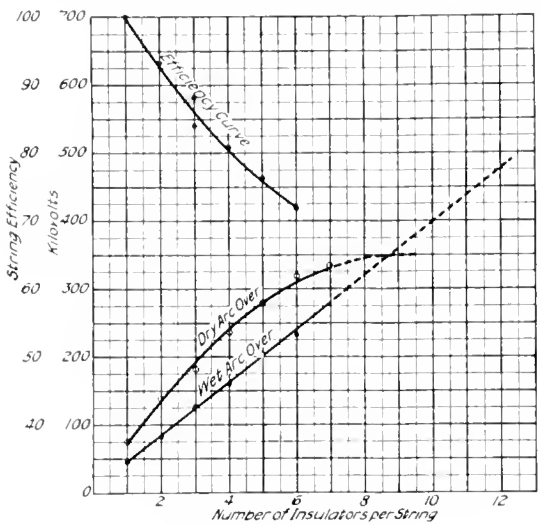

Fig. 2. Test Characteristic Curves of Suspension Insulators

Tests and Test Characteristics

Tests were made on a number of insulators of different types and manufacture. A few characteristic tests are given; and it should be mentioned that the method of test is very important. Although it is not possible to go completely into details of the testing arrangements at the present time, it may be said, briefly, that the A.I.E.E. standardization rules should be followed; and in addition, the connections and voltage control, as shown in Fig. 1, should be used. Voltage control is effected in this method by the series resistance, while the multiple resistance should

* "The Law of Corona and the Dielectric Strength of Air," A.I.E.E., July, 1911, and "The Limiting Effect of Corona on Electrical Transmission," General Electric Review, October, 1911, by F. W. Peek, Jr.

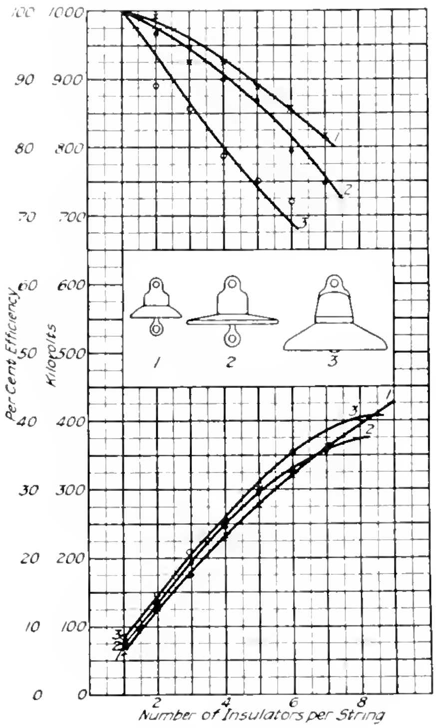

Fig. 3. Test Arc-Over and Efficiency Curves for Different Sizes and Types of Insulators

always by-pass from three to ten times the exciting current of the transformer. The object of the multiple resistance is to prevent distortion of the generator wave at the transformer terminals. The use of four low-voltage coils on the transformer for multiple series connection, and alternator field control over a short range, † in combination with the potentiometer resistance method as above, will generally be found most convenient. The potentiometer method of control should be used in all careful work. The generator wave should be close to a sine wave. Water-tubes for resistance (see A.I.E.E. rules) should be used in series with the needle points to prevent oscillations. It is also sometimes advisable to use a low resistance in series with the insulators. ‡

Fig. 2 shows the wet and dry arc-over voltages for different numbers of units in series; these are characteristic curves of the suspension insulator. Considering the dry test: One unit arcs over at 85 kilovolts; two units at 140 kilovolts; seven units arc over at 335 kilovolts, and not at 7×85, or 595 kilovolts. Hence if a single unit alone arcs over at e volts, we cannot say that n units will arc over at ne volts. This is because the insulator nearest the line takes more than its share of the voltage, and the voltages across the successive units decrease as the tower is approached; or, in other words, the voltage along the string is not balanced. One method of noting this unbalance of voltage is to observe the corona glow on the metal caps of the insulator as the voltage is increased. Glow can generally be noticed first on the insulator nearest the line. When the voltage is increased to a certain point the arc-over voltage of the line unit is reached. This insulator arcs over and the others follow in rapid succession, the arc appearing to take place simultaneously over all the units. It has also long been observed in practice that most of the insulator failures—as, for instance, by lightning—occur on the units nearest the line.

It is convenient, when comparing the suitability of different types of units for connection in series, to use the ratio of the actual arc-over voltage, to n times the arc-over voltage of a single unit. This may be

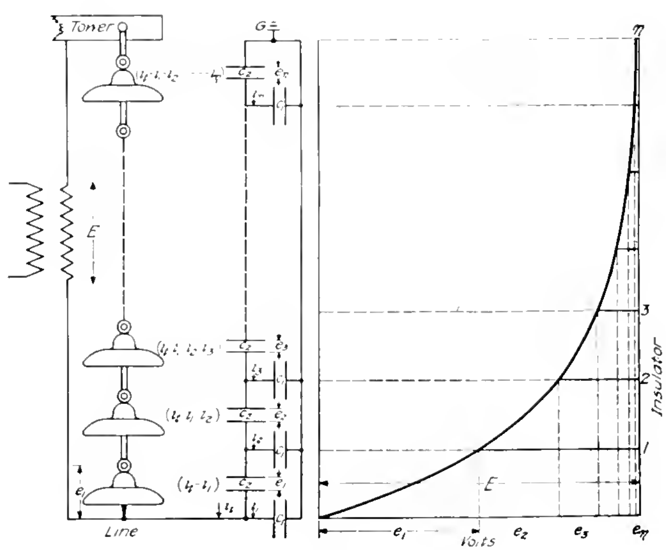

Fig. 4

† If field control is used over a wide range of voltage, at low voltage the alternator field is very weak, and wave distortion and unstable conditions result.
‡ For a more complete discussion of tests, etc., see "The Electrical Characteristics of the Suspension Insulator," by F. W. Peek, Jr., A.I.E.E. Proceedings, May, 1912.

called *string efficiency*. If the units are very close together arc-over will take place from line to tower. This will mean a low efficiency, but not necessarily due to unbalance. A condition of this kind may sometimes be advantageous if the balance is good. It will be considered, for convenience in comparing, that

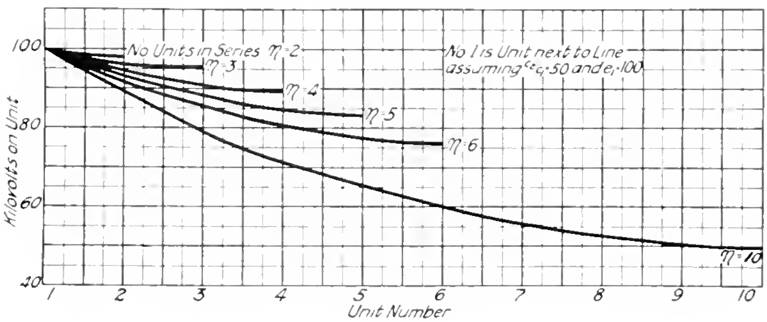

Fig. 6. Calculated Voltage Across Different Insulators in a String of n Units

$$\text{string efficiency} = \frac{\text{arc-over voltage of } n \text{ units}}{n \times \text{the arc-over voltage of one unit}}$$

The efficiency curve plotted in Fig. 2 shows that the efficiency rapidly decreases as the length of the string is increased.

The rain tests in Fig. 2 show that the current through the wet surface resistance has a balancing effect. This is especially so when a spray is used that completely wets both sides of the units. The balancing is accomplished in a manner somewhat similar to that which would take place if an autotransformer were placed across the string, with equal voltage taps brought out to each unit. Because of the balancing effect of the moisture, in this particular case, after nine units are placed in the string, the wet arc-over

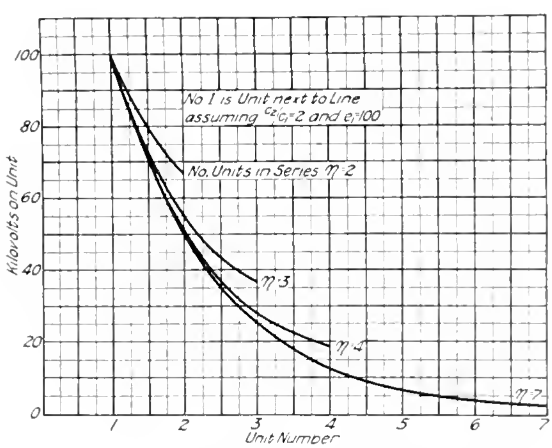

Fig. 5. Calculated Voltage Across Different Insulators in a String of n Units

voltage is higher than the dry arc-over voltage.

Fig. 3 shows test characteristic curves on three different sizes of units. It should be observed that the smallest unit (1), on account of its better design for string balance, has a higher arc-over voltage than Nos. 2 or 4, after nine insulators are placed in series.

Theoretical Characteristics

The cause of the unbalance is this: Looking at Fig. 4, each unit is a condenser with a mutual capacity c_2, and each cap and connecting link is a condenser with a capacity to ground c_1. The capacity currents of all the c_1 condensers pass through the line unit. All of the c_1 currents but one pass through the second unit; all but two pass through the third unit, and so on. Hence the "drop" across the first unit is greatest, and the "drop" decreases across each successive unit as the tower is approached. Thus if i_t is the total capacity current, the current through the first unit is $(i_t - i_1)$

The voltage across the first unit is

$$e_1 = (i_t - i_1)\left(\frac{1}{2\pi f c_2}\right);$$

across the second unit it is

$$e_2 = (i_t - i_1 - i_2)\left(\frac{1}{2\pi f c_2}\right);$$

across the third unit it is

$$e_3 = (i_t - i_1 - i_2 - i_3)\left(\frac{1}{2\pi f c_2}\right); \text{ and}$$

across the nth unit it is

$$e_n = (i_t - i_1 - i_2 \ldots\ldots i_n)\left(\frac{1}{2\pi f c_2}\right)$$

Where there is no surface leakage, as at operating voltage, the following relations can be easily shown to hold.* The total capacity of a string of n insulators

* For complete discussion see "The Electrical Characteristics of the Suspension Insulator." Proceedings A.I.E.E., May, 1912.

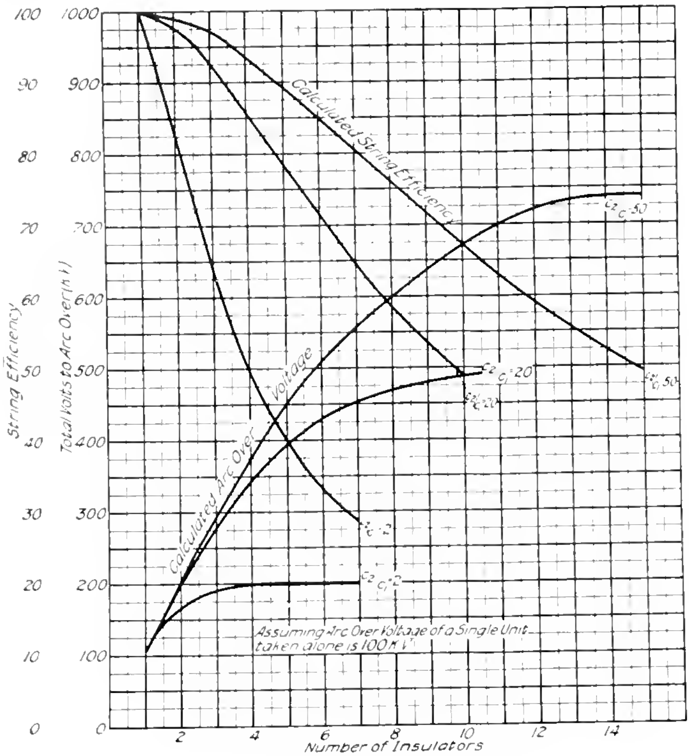

Fig. 7. Calculated Arc-Over Voltage and String Efficiency of n Insulators in Series

(1)

$$k_n = c_1 + c_2 - \cfrac{c_2^2}{2c_2 + c_1 - \cfrac{c_2^2}{2c_2 + c_1 - \cfrac{c_2^2}{\cdots \over 2c_2 + c_1}}}$$

Write fraction to $(n-1)$ of the $(2c_2+c_1)$ terms.

(2) The voltage across the first, or line, insulator of a string of n is

$$e_1 = \frac{E}{x}(k-1), \text{ where } k = \frac{k_n}{c_1} \text{ and } x = \frac{c_2}{c_1}$$

(3) The voltage across the mth insulator of a string is

$$e_m = e_{m-1} + \frac{e_{m-1} + e_{m-2} + \ldots\ldots e_1 - E}{x},$$

when E is the total voltage across the string.

(4) $$E = \frac{e_1 x}{k-1},$$

(4-a) $e_a = \dfrac{c_a x}{(k-1)}$ = arc-over voltage of string, when the arc-over voltage of a single unit alone e_a is taken for e_1.

(5) String efficiency

$$= \frac{E_a}{nc_1} = \frac{x}{n(k-1)}$$

Comparison of Test and Theoretical Characteristics

The curves in Figs. 5 and 6 are calculated from the above equations, assuming always 100 kilovolts on the line unit. In Fig. 5 where the ratio $c_2 : c_1$ is low, i.e., the capacity to ground c_1 is high in comparison with the mutual capacity c_2, the balance is very bad. In Fig. 6 where $c_2 : c_1$ is assumed to be 50, the balance is very much better. If 100 kilovolts is the arc-over voltage of a single unit alone, a string of such units will arc over when the total voltage is high enough to place 100 kilovolts across the line unit. As an example, take the curve $n=3$ in Fig. 5. If 100 kilovolts is the arc-over voltage of a single unit alone, the arc-over voltage of the string of three in this case is

$$100+55+37=192 \text{ kilovolts.}$$

Hence the efficiency is

$$\frac{192}{3\times 100} = 0.64.$$

The calculated total arc-over and efficiency curves, for $c_2/c_1 = 2$, 20 and 50 respectively, and $c_1 = 100$, are plotted in Fig. 7.

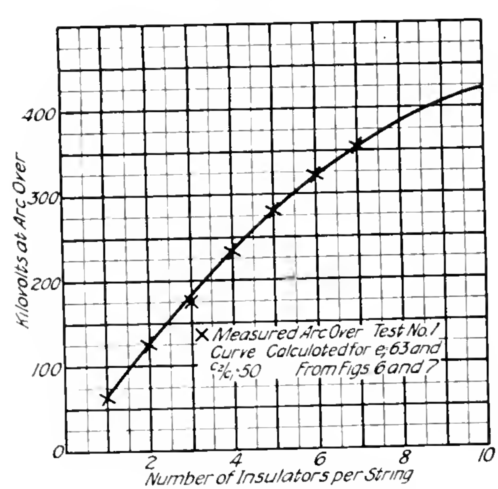

Fig. 8. Comparison of Calculated Curves and Test Curves

The drawn curve in Fig. 8 is calculated from the equations on the assumption that $c_2 : c_1 = 50$, and taking 63 kilovolts the measured arc-over voltage of a single unit alone (Test 1, Fig. 3), as the voltage on the line insulator. This curve can be obtained directly from Fig. 7, by taking 63/100 of the voltage values given there. The crosses are actual measured values from the test in Fig. 3. The check is much closer than would be expected, as when the voltage is brought nearly to arc-over, corona appears first on the line insulator. This generally increases c_2 in greater proportion than c_1, and hence tends to improve the balance. In this way a sort of automatic grading seems to take place. Test values show this in Fig. 9, where the measured points shift to better ratio curves as the string length is increased.

It can thus be seen that, on account of this automatic grading effect, high arc-over voltages do not always mean good balance at operating voltages. It is important to have a high efficiency, or good balance, before leakage starts; otherwise it seems that in case of lightning or surge the porcelain of the line unit is likely to be punctured. Automatic grading would not help in this case, as puncture would probably occur before the formation of corona.

Conclusions

(1) Where the mutual capacity c_2 of an insulator is small compared to its 'to ground' capacity c_1, the voltage balance along a string of such units will be bad. The line unit will take the greatest voltage, and the tower unit the least.

(2) Good string balance or high string efficiency is important, as without good balance the line unit is likely to be punctured by surge, or by lightning. In selecting insulators a high string efficiency should therefore be sought or specified.

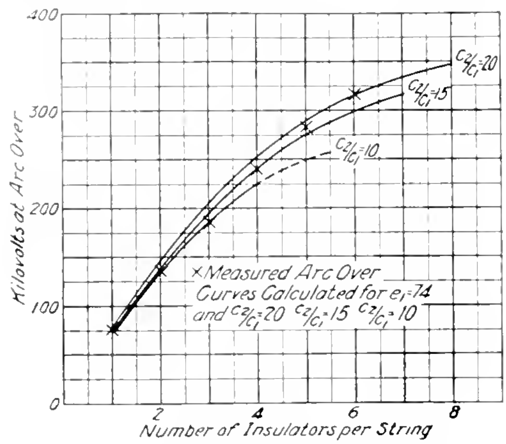

Fig. 9. Comparison of Calculated Curves and Test Curves

(3) The arc-over voltage will generally indicate (due to automatic grading) a somewhat better balance than actually exists. The voltages at which glow starts on successive units from line to tower may sometimes help in determining the balance.

(4) The method by which tests are made is of the utmost importance. Unless certain precautions are taken the tests are valueless. In making tests for balance or string efficiency one side of the transformers should be grounded.

THE POWER-FACTOR OF LOW-SPEED POLYPHASE MOTORS

By H. M. Hobart, M. Inst. C. E.

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The arguments and data given in this paper may assist power users in determining the suitability of synchronous and induction motors for low-speed drives. The author shows how advantage may be taken of the "Field" effect (i.e., variation in the apparent resistance of a slot-embedded conductor with varying periodicity) in designing a squirrel cage motor to combine high starting torque per ampere with high efficiency and low slip at full load. The paper also shows the gain in power-factor which may be achieved by selecting a high-speed motor and interposing mechanical gearing where the induction motor is required for a low-speed drive.—Editor.

The circumstance that a type of apparatus possesses particularly attractive features is liable to occasionally lead to disappointment, owing to its use under conditions for which it is inappropriate through its possession of other less-well-known features, which, under the conditions in question, are undesirable.

In the squirrel cage induction motor an undesirable attribute is that of the low power-factor, inevitable when the rated speed is low and the periodicity relatively high. In Figs. 1 and 2 are drawn curves which give a rough indication of the way in which the power-factor of the polyphase induction motor varies with the speed for which the motor is designed. While *qualitatively* identical conclusions will be reached by an examination of the data of the product of any large manufacturer, the *quantitative* values may be materially different, since each manufacturer's product is characterized by variations in the degree to which good properties in various respects are sacrificed in the effort to arrive at the best all-around result. It is for this reason that instead of employing data of the designs of any particular manufacturer, the curves in Figs. 1 and 2 have been deduced from the results of an investigation published by Dr. Ing. Rudolf Goldschmidt, of the Darmstadt Technische Hochschule, in an excellent little volume which he has published under the title: "*Die normalen Eigenschaften elektrischer Maschinen.*" Whereas from the 50-cycle curves of Fig. 2, it will be seen that, at low speeds, motors of from 50 to 500 h.p. rated output, have power-factors of less than 0.80, the curves in Fig. 1 show that the power-factors of equivalent 25-cycle motors are quite satisfactorily high.

It is desirable to again emphasize that the precise values employed in the curves in Figs. 1 and 2, have, considered individually, no binding significance. Thus, by sacrificing desirable features in other directions and by increased outlay in the construction of the motor, slightly better power-factors may sometimes be obtained. On the other hand, the power-factors on which the curves are based, are, in most instances, already representative of fairly extreme proportions in this respect; and few manufacturers find it commercially practicable to list low-speed motors with such high power-factors as are indicated by these curves. The purchaser would rarely be willing to pay a price which would leave any margin of profit were these power-factors provided; and consequently it is only relatively to one another that these curves are of interest. They teach the lesson that for periodicities of 50 or 60 cycles, it must be

Curves Showing the Gain in Power-Factor of 25-Cycle Over 50-Cycle Squirrel Cage Motors, for Three Standard Sizes and Speeds up to 1500 R.P.M.

Fig. 1. 25 Cycles

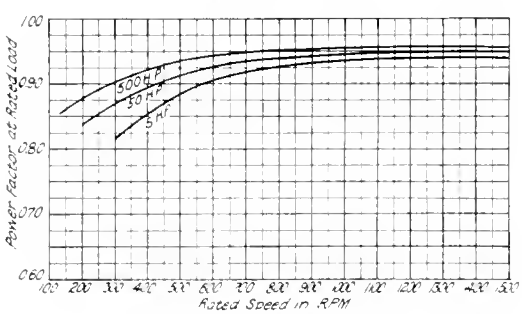
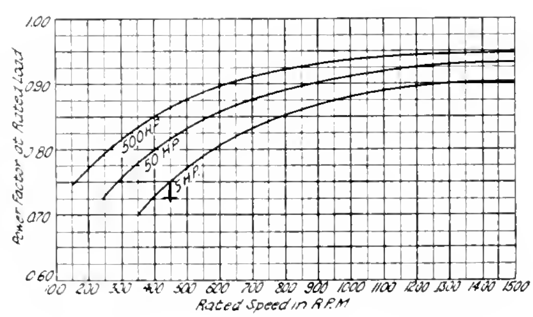


Fig. 2. 50 Cycles



carefully kept in mind that, if slow speed induction motors are used, either the price paid must be disproportionately high, or else the purchaser must be content with motors of exceedingly low power-factors. The power-factor, furthermore, decreases rapidly with decreasing rated output.

On the other hand, for a 25-cycle supply, these considerations become of but slight importance. With a clear recognition of this state of affairs, a power user desiring slow speed motors for a 60-cycle circuit will do well to take into careful consideration the alternative of employing synchronous motors. If he resorts to this alternative he can maintain his power-factor at unity, irrespective of the rated speed of his motors; but he must put up with the slight additional complication of providing for a rotor which, in addition to the squirrel cage winding, is also equipped with field windings excited through brushes and slip-rings from a source of continuous electricity. The precise circumstances of any particular case will require to be considered, in order to decide whether or not this alternative is preferable.

Attention was called in the March, 1912, number of the GENERAL ELECTRIC REVIEW (see p. 166), to the circumstance that the properties of synchronous motors lend themselves admirably to the provision of high starting torque; and means were described whereby a synchronous motor may have not only high starting torque, but may also automatically run close up to synchronous speed, so as to fall quietly into synchronism immediately upon the application of the field excitation from the continuous-electricity source. Not only may we resort to the means described in that article; but there is also available the phenomenon described by Mr. A. B. Field, in a paper entitled "Eddy Currents in Large Slot-Wound Conductors," presented in June, 1905, before the American Institute of Electrical Engineers (Vol. 24, p. 761).

Mr. A. B. Field analyzed the manner in which the apparent resistance of slot-embedded conductors varies with the periodicity. Subsequent investigations show that the Field phenomenon, while harmful in stator windings exposed constantly to the full line periodicity, may be employed to considerable advantage in the proportioning of the conductors of the slot portion of a squirrel cage system. Both in synchronous and in induction motors, this is an important step. Take, for instance, the case of a 60-cycle induction motor. At starting, the periodicity of the currents in the squirrel cage system is 60 cycles, and the Field effect may, with properly-proportioned conductors, be sufficient to occasion an apparent resistance very much greater than the true resistance. The motor thus starts with very much more torque per ampere, than

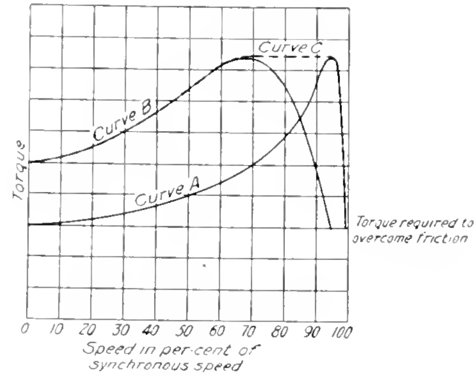


Fig. 3

were the Field phenomenon absent. As the motor speeds up, the periodicity decreases and the Field effect dies out, the apparent resistance of the squirrel cage gradually dying down to the true resistance. Thus, whereas the full-load running slip of an ordinary squirrel cage motor must be high, its heating high and its efficiency low, if it is to develop high starting torque, we may, by using the Field effect, construct high-starting-torque motors with low slip and high efficiency. Excellent results have already been obtained by this method.

In Fig. 3 are shown respectively the rough characteristic shape of a curve in which torque is plotted as a function of the speed for: *first*, a permanently low-resistance squirrel cage motor; *second*, a permanently high-resistance squirrel cage motor; and, *third*, for a squirrel cage motor in which the apparent resistance gradually changes from a high to a low value as the motor runs up from rest to synchronism. As regards the application of these curves to a synchronous motor, it will be seen that, in the first case, the starting torque is rather low; but that the torque increases, passes through a maximum, and falls slowly, remaining quite high until the speed is close to synchronism. This motor, while unsatisfactory at starting, has the property of pulling easily into synchronism on the application of the excitation from the continuous-electricity source. In the second case, while the synchronous motor *starts* with high torque, the torque falls away much more rapidly; and when the torque has fallen to the value necessary to overcome the friction of the motor, the speed is several per cent below synchronous speed, and the application of the continuous excitation, if it suffices to pull the rotor into synchronism, will do so only at the cost of an abrupt and considerable instantaneous drain of power from the line. In the third case, however, there are present the good attributes of the first two cases, the bad attributes being completely eliminated.

It is thought that with these data, the user will be assisted in determining, in any particular case, whether it is more desirable to take advantage of the extreme simplicity and toughness of the low-speed squirrel cage induction motor, notwithstanding its poor power-factor, or whether he should employ the slightly more complicated synchronous motor in order to have the advantage of high power-factor.

Another way of dealing with the situation, which in certain cases of a low-speed drive is preferable, is to employ a high speed induction motor (which will consequently have a high power-factor), and to gear it down to the low-speed load. Thus, from the curves in Fig. 2, we see that, if we require to drive a load at 200 r.p.m., a 50 h.p. motor will have a power-factor of 0.70 or less; whereas, if the motor were to drive the load through 5 to 1 gearing, the motor's own speed would be 1000 r.p.m., and its power-factor would be 0.90 or higher. Not only would the induction motor be characterized by a 20 per cent higher power-factor at full load, but its efficiency would be higher and it would be much smaller, lighter and cheaper. At half load the advantage of the high speed motor in respect to power-factor is still more striking, the two values being of the following order:

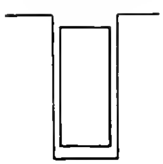


Fig. 4

Rated Speed	Power-factor at Half Load
200 r.p.m.	0.50
1000 r.p.m.	0.78

Returning to the Field effect it may be of interest to describe a test made on a bar 25 mm. high and 8 mm. wide. The bar, together with the slot in which it was located, are shown in Fig. 4. Measurements of the energy loss were made on a length of 32 cm. of this bar, with currents of 500 and 300 amperes, and the following results were obtained:

Periodicity in Cycles per Second	Loss in Bar When Carrying: 500 Amp.	300 Amp.
60	22.0 watts	8.2 watts
40	17.6	6.5
25	13.1	4.9
0	7.2	2.6

For bars and slots of this order of size and shape, Field's curves may be simplified down to be roughly represented by the formula:

$$\text{Multiplier} = 0.15 \times (\text{depth of bar in cm}) \times \sqrt{\text{periodicity}}.$$

For the case examined, and the periodicities employed, the multipliers as obtained from this formula are respectively:

2.90 for 60 cycles
2.37 " 40 "
1.88 " 25 "

Consequently the watts at the three periodicities should, at 500 amperes, have been:

$7.2 \times 2.90 = 20.9$ The observed value was 22.0
$7.2 \times 2.37 = 17.1$ The observed value was 17.6
$7.2 \times 1.88 = 13.5$ The observed value was 13.1

At 300 amperes the results should have been:

$2.6 \times 2.90 = 7.55$ The observed value was 8.2
$2.6 \times 2.37 = 6.16$ The observed value was 6.5
$2.6 \times 1.88 = 4.90$ The observed value was 4.9

Corresponding tests were made with this bar located in a partly-closed slot (the slot opening being 4 mm.). The results were practically identical with those obtained with the wide-open slot.

THE ELECTRIC MINE HOIST AS A POWER STATION LOAD

By F. L. Stone

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From the standpoint of the power station, the problem of the big mine hoist is summed up in the question, "How can the peaks be kept from the line?" This article discusses several methods. (1) Flywheel motor-generator set driven from the line, the input to the motor being automatically controlled by a regulating rheostat, and the generator feeding the hoist motor; (2) an induction motor on the hoist, and a synchronous converter with a balancer flywheel motor; (3) motor-generator set driven from the line and feeding the hoist motor, belted to an air-compressor which comes into action as the load goes off the hoist. (4) A flywheel induction motor with automatic slip regulator driving the hoist through ropes or gearing, the load being picked up by clutches. Actual installations are described as examples of the first three schemes.—Editor.

The ever-increasing use of electricity in mining operations has brought with it an increasing demand upon the central station for power. Many of these loads, such as pumps, crushers, conveyors, screens, fans, etc. are of a most desirable nature from the vendor's standpoint. The haulage locomotives too are not objectionable since they are usually quite numerous and their individual peaks are usually lost.

The question now being forced upon the power companies is, what about the big hoists, whose demands run from zero to several hundred horse-power and back to zero in very short periods of time? Fig. 2 furnishes a good example. The average input to this cycle is but 518 h.p. while the peak goes over 100 per cent. above this. The power plant must have equipment to handle the peak. This means large investment in

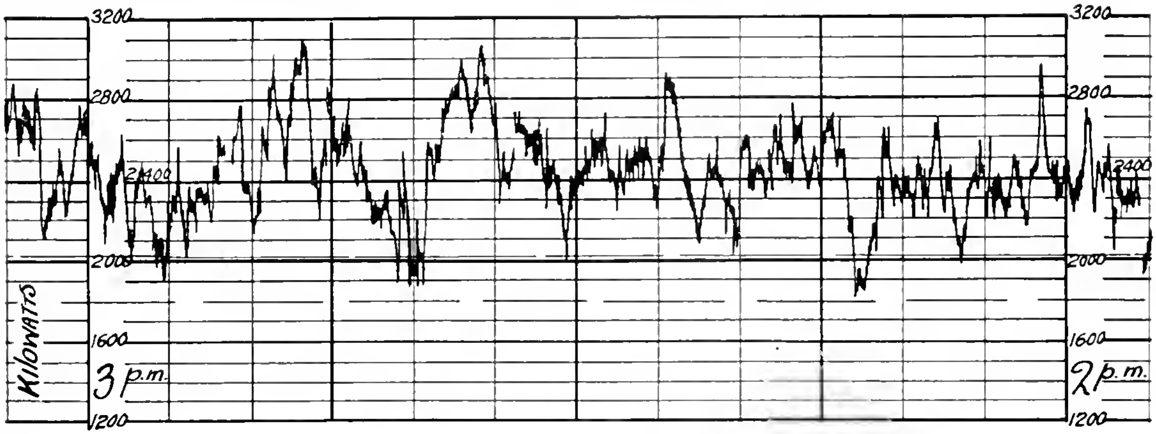


Fig. 1. Load Curve from Large Mine Power House

Small hoists may almost be said to come in the same category as haulage locomotives, and, where their individual loads are a small percentage of the whole, should not be objected to. Fig. 1 shows a portion of the load curve of a large mining power system. The total connected horse-power is 9212, of which 4982 is alternating current and 4230 direct current; while the total hoisting loads, both alternating and direct current, amount to 3232 h.p., the rest of the load being made up of mining locomotives, pumps, fans, breaker machinery, etc. The rated capacity of the plant is 2500 kw. It will be noted that an exceedingly high load factor is obtained, which illustrates the fact that ordinary mine loads, exclusive of the large hoists, represent a very desirable business.

station capacity and lines which must be idle a large part of the time. It is therefore necessary and fair that some extra compensation be received for this fluctuating load.

In order to minimize, or prevent altogether this fluctuating load, a regulating set may be used consisting of a motor-generator set driven from the line with a flywheel coupled thereto, the hoist motor being driven from the generator of the set and controlled by varying the field of the generator. The input to the motor of the motor-generator set is limited by an automatic regulating rheostat. The regulating set is so designed that the maximum torque required by the hoist is in excess of that which the motor of the regulating set can exert. The set will therefore begin to slow down when this demand appears, and in so doing the flywheel will give out energy. The flywheel may be so designed that sufficient energy will be given

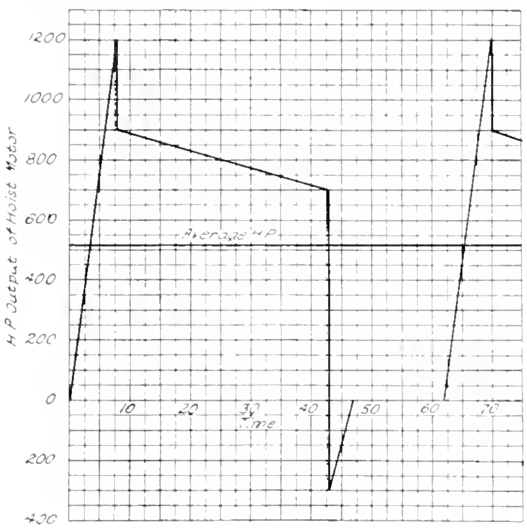


Fig. 2. Load Curve of Mine Hoist

out with comparatively small slip to carry the hoist over its peak. The motor of the regulating set then begins to restore the energy to the wheel so that at the beginning of the next cycle the set is up to full speed again.

Fig. 3 shows a section and Fig. 4 a view of the automatic regulating rheostat. This is of the liquid type, and its operation is as follows: The leads A are connected to the slip rings of the induction motor of the motor-generator set. The variable resistance in the armature circuit of the induction motor is that due to the column of water in the pipe below the plate C. The plates C of the various phases are short-circuited at the top by the bar D. The induction motor (regulating motor) operating the rheostat is connected in series with the primary of the main induction motor. The weight of the moving parts in the rheostat is balanced by the torque of the regulating motor, which acts in the direction shown by the arrows; and the counter-balancing weight B is so adjusted that, in conjunction with the torque of the motor, it just balances the weights of the moving parts in the rheostat when the line current is at its normal value. Increasing the counter-balancing weight tends to lower the current required to operate the rheostat, i.e. to further limit the current taken by the main induction motor and *vice versa*.

Let us assume that the counter-weight is adjusted for 90 amperes. As the load comes on the direct current generator, the current taken by the main induction motor increases. When this current exceeds 90 amperes, the torque of the regulating motor *plus* that of the counter-weight raises the plate C. This introduces resistance in the main induction motor armature, causing it to slip and allowing the flywheel to take the peak. The introduction of the resistance in the main induction motor armature reduces the current to 90 amperes, making a new balance. As the load continues to increase on the generator, the regulating motor continues to increase the armature resistance; while as the load drops off, the reverse action takes place. The hand-wheel shown at the left is for use in starting up the motor-generator set, and by it the plates can be raised a considerable distance. The regulating motor serves as a starting device

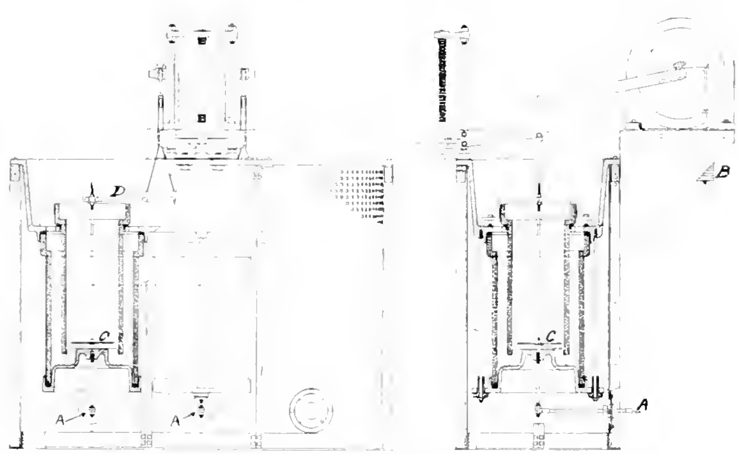


Fig. 3. Section of Automatic Slip Regulating Rheostat

as well as a regulating device. After the motor has started the hand-wheel may be turned down rapidly, the regulating motor preventing the dropping of the plates faster than that corresponding to full load current on the motor. The general wiring connections of such an arrangement are shown in Fig. 5. Many such sets are in operation in Europe, while there are also a number in this country, perhaps the most noteworthy being those of the Winona Copper Company and the Kendall Gold Mining Company. It may be of interest to describe these sets in some detail.

The Winona Copper Company is located at Winona, Mich., a mining town on the Keneenaw peninsula. The power plant consists of one 250 kw., 2080 volt, 60-cycle generator, driven by a cross-compound non-condensing engine. The flywheel motor-generator set is located in the engine house of the Winona No. 4 shaft, 2900 ft. along the transmission line from the power station. This set is shown in Fig. 6; and consists of two 170 kw., 600 r.p.m., 575 volt shunt wound generators, driven through flexible couplings by a 450 h.p., 2080 volt slip ring induction motor. The generators are separately excited, excitation being furnished by two 125-volt exciters rated at 7 kw. and direct-connected to either end of the shaft. Two flywheels, 10 ft. in diameter and weighing approximately 40,000 lbs. each, are employed in order to prevent a shut-down of both shafts in the event of trouble with one of the generators. Forced lubrication is used in the bearings of the motor-generator set. The oil pumps used with the set are of the ordinary reciprocating type driven from the coupling hub.

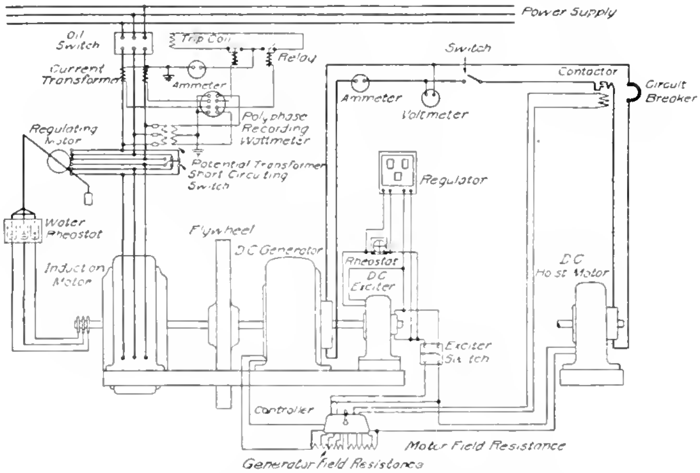


Fig. 5. Connections of Flywheel Motor-Generator Hoisting Equipment with Regulating Motor in Main Line

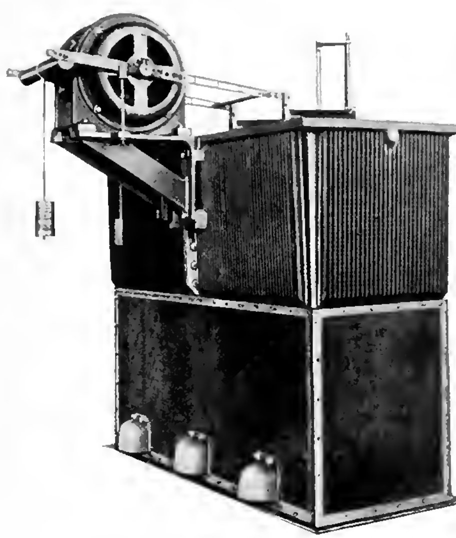


Fig. 4. Automatic Slip Regulating Rheostat

These generators furnish power to two hoist motors, one located at Winona No. 4 shaft (in the engine house with motor-generator), and the other at King Phillips No. 1 shaft, a transmission distance of 1900 ft. from the motor-generator set. The hoist motors are 200 h.p., 500 volt shunt wound machines running at 430 r.p.m. The hoist is a single drum hoist driven by the motor through a double gear reduction. When first installed the equipment ran unbalanced, and this was the cause of the excessive overloads. The duty for which the hoisting equipment was designed is as follows:

Single run, balanced hoist, with no tail rope.

Depth of shaft—1500 ft.
Incline of shaft with horizontal—70 deg.
Hoisting speed—1200 ft. per min.
Weight of skip—2500 lbs.
Weight of ore—5000 lbs.
Diameter of rope—1⅛ in.
Time of acceleration—10 sec.
Time of hoisting at full speed—68 sec.
Time of retardation—5 sec.

The hoist motors are capable of carrying heavy overloads. It has, in fact, been said that the input to one of these motors has reached as high as 360 kw., (corresponding

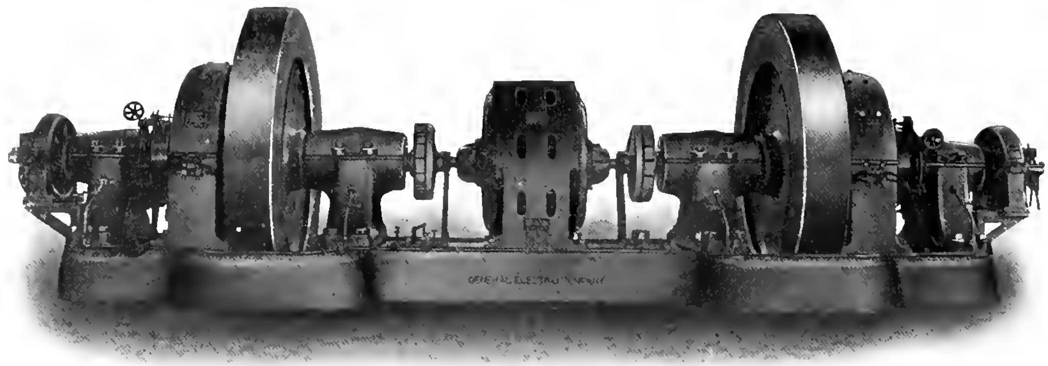


Fig. 6. Two 170 Kw., 575 Volt Shunt Wound Generators Direct Connected to 450 H.P. 2080 Volt Induction Motor, Winona Mines

to an overload of approximately 160 per cent.) without any sign of trouble.

At the time the contract was let it was intended to install a 500 kw. turbine, thus increasing the power house capacity from 250 kw. to 750 kw. The turbine, however, was never installed, and the 250 kw. generator alone was called upon to carry the hoists. This is a good example of the great advantage to be gained by the use of the flywheel equipments, since the hoists are able to perform their service under conditions which require 350 to 375 kw. at each shaft, with a total station capacity of 250 kw. In addition to the hoist loads a 50 h.p. pump motor is also driven from the generator.

As a second example we may mention the set installed at the Kendall Gold Mines located in the North Moccasin Mts., of Montana. This set (shown in Fig. 7) has a normat speed of 720 r.p.m. and is made up of a 500-volt direct current generator, a 440-volt slip ring induction motor, a cast steel flywheel, 8 ft. in diameter weighing approximately 12,000

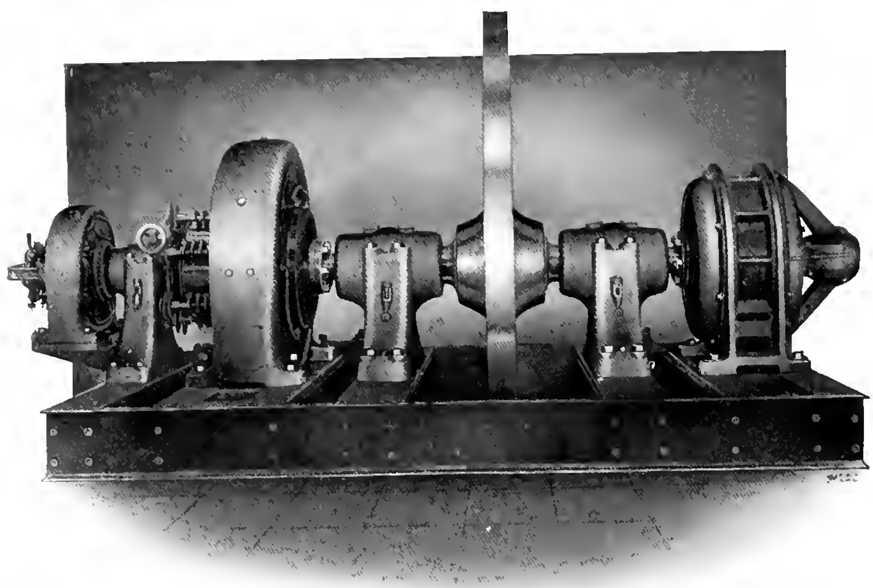


Fig. 7. 90 Kw., 500 Volt Generator Direct Connected to 75 H.P. 440 Volt Induction Motor, Kendall Gold Mines

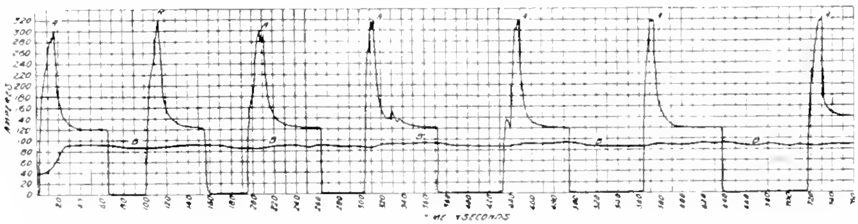


Fig. 8. Load Curves on Flywheel Motor-Generator Hoisting Equipment. Curve A = Current Input to Hoisting Motor. Curve B = Current Input to Induction Motor of Motor-Generator Set

lbs., and a 6 kw. direct connected exciter. An automatic water rheostat for controlling the speed of the induction motor is included in the equipment. The hoist motor, geared to the hoist, is a 100 h.p. shunt wound machine running at 600 r.p.m. No commutating poles are used on either motor or generator. The control of the hoist motor is effected by the usual Ward Leonard system through the field of the generator. The hoisting equipment was designed to handle 2000 lbs. of ore from a depth of 1000 feet, at the rate of one trip in $1\frac{3}{4}$ minutes when operating balanced. Each skip weighs approximately 1400 lbs. and has a capacity of 2000 lbs. of ore. Fig. 8 shows the input to the hoist motor and input to the induction motor of the motor-generator set. The equipment has been in operation approximately two years.

Another arrangement consists in using an induction motor on the hoist, and a synchronous converter with a balancer flywheel motor. The general arrangement of this scheme is shown in Fig. 9. With the converter and balancer running at normal speed the hoist motor is started. As soon as the input from the line exceeds a certain predetermined value, the balancer field is strengthened to such an extent that the balancer becomes a generator, feeding through the converter to the hoist motor. While acting as a generator the balancer slows down, and the energy stored in the wheel is given out until the peak has been passed. When the load has fallen below the value above stated, the balancer field is weakened; the wheel is brought up to speed, and its energy restored, the generator receiving its power as a motor from the converter. The regulation of the balancer field is taken care of in practice by the use of a resistance in

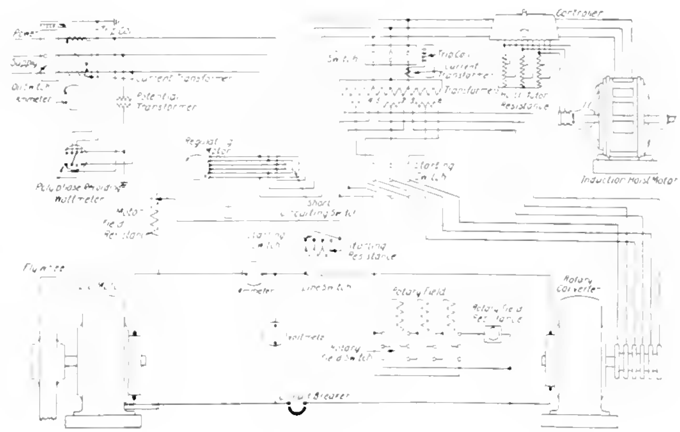


Fig. 9. Connections of Induction Hoist Motor with Flywheel Synchronous Converter Equalizer Equipment

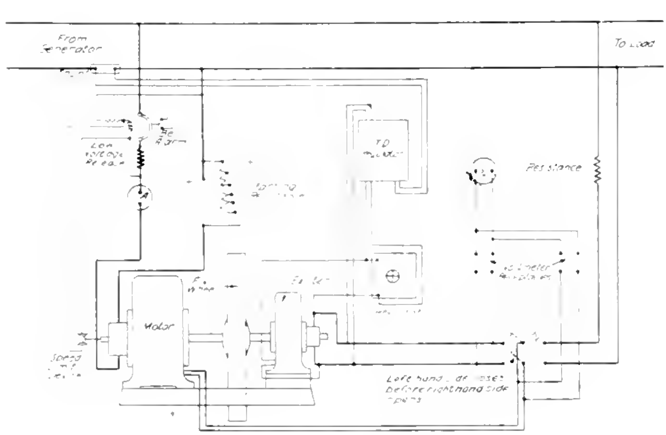


Fig. 10. Connections of Flywheel Equalizer Set with Automatic Voltage Regulator

the main line, with an automatic voltage regulator tapped across it. While this arrangement does not save any of the acceleration losses as does the direct current motor

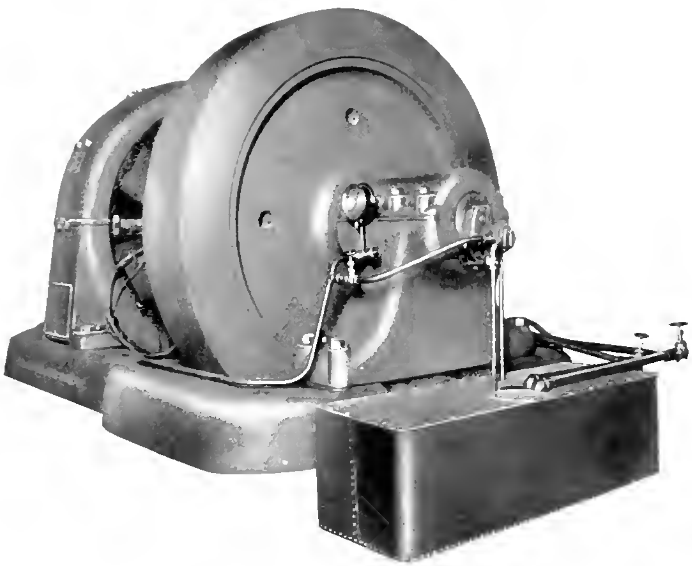


Fig. 11. 500 H.P. Flywheel Balancer Installed at Kolar Gold Mines, Showing Forced Lubrication System

with generator field control, the size of the balancer and converter need only be such as to take the peaks; whereas in the case of the flywheel motor-generator set the generator must be large enough to handle the complete motor load. The application of this system is somewhat special, and very few cases have arisen where any advantage can be shown for it. A modification of the system, however, is shown in Fig. 10 where the supply is direct current, and here it is only necessary to use a balancer with suitable control. There are many cases where this arrangement could be and is used. In this instance a transmission line feeds a substation, upon which there is, together with some steady load, an intermittent hoist load which would cause disturbance on the line. A glance at Fig. 10 will show clearly how the desired result of keeping constant output of the substation is obtained. When the peak comes on, the regulator, operating from the line shunt, increases the balancer field so that it acts as a generator driven by the flywheel. When the peak is passed, the field is weakened and the flywheel is again brought up to speed.

Fig. 11 shows a view of such a balancer, installed at the Kolar Mines in India. There are several of these sets in use in this country notably on ore unloading bridges.

Another illustration of a method of keeping peak loads from a line is the installation at the Iron Blossom Mine in Utah. Here a hoist motor of 300 h.p. capacity is driven from a 165 kw. generator, and is controlled by the Ward Leonard system. The generator forms part of a motor-generator set, the motor being of the synchronous type. Belted to the motor-generator set is an air-compressor. When the hoist is in service an unloading valve on the compressor is open. As soon as the hoist controller is in the "off" position, the unloading valve closes and the compressor comes into action. The duty cycle showing the line load is approximately represented by Fig. 12. In this particular instance it was of the utmost importance to keep the load factor up; and, with this in view, the synchronous motor was furnished with an automatic foolproof compensator panel with current limits. The control of the hoist motor possesses an additional feature of interest in that, even with the sensitive Ward Leonard system, the operator cannot as a rule accelerate or retard the hoist faster than a predetermined rate. In this instance the end is accomplished by interlocking the controller with the hoist drum. After the first few notches of the controller have been passed, dogs on the

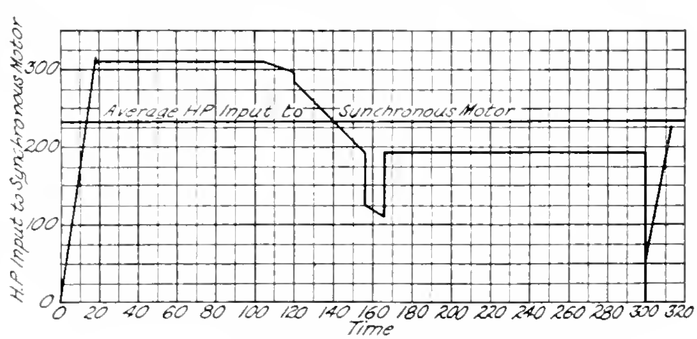


Fig. 12. Horse-Power Input Curve Showing Alternate Operation of Hoist and Compressor

controller shaft engage with ratchet wheels driven from the hoist, and the forward motion can only be made as fast as the moving ratchets will allow. The forward motion of the controller can be stopped at any position for slow running. This device is operative from any level, and, in fact, at any time the motor is started or stopped. The whole can be thrown out of gear by the handle at the side as shown in Fig. 13. For small hoists the acceleration peaks can be limited to a large extent where desirable by current limits and contactor control, although this method increases the time of acceleration.

A scheme has suggested itself to the writer whereby the greater part of the virtues of the flywheel motor-generator set system can be obtained without the actual use of the motor-generator set. This would consist of a hoist driven from an induction motor of the slip ring type by either rope drive or gearing. The motor would run constantly and the loads be picked up by means of friction clutches. This much has been done successfully, as is seen in the hoist at Ray and the D. L. and W. water hoist at Hampton. The idea may be carried further, however, and a flywheel put on the motor shaft and a slip regulator in the motor circuits, whereby a straight line input to the hoist motor would be obtained. Any difficulty with the clutches would be obviated by the employment of multiple-disc clutches of ample surface. The only difference between this method and the Ward Leonard method is that one-half the acceleration energy is lost in heat of the friction clutch; while, on the other hand, the acceleration of the hoist motor armature is saved.

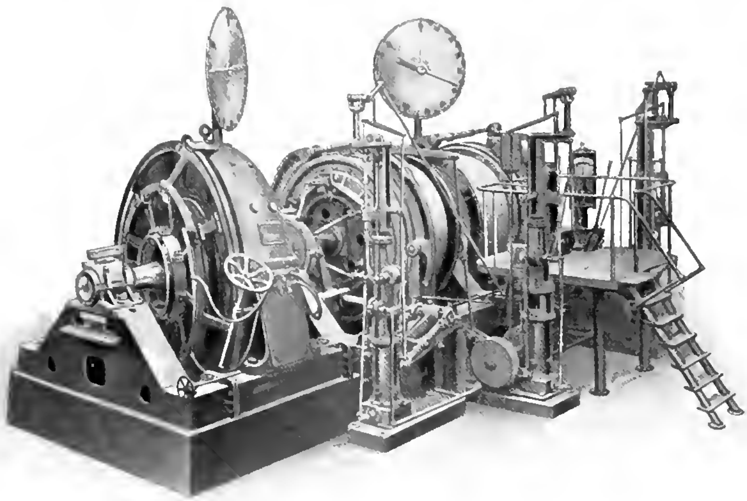


Fig. 14. Electrically Operated Hoist at Iron Blossom Mine, Utah

Fig. 13. Drum Controller for 300 H.P. Hoist Motor, Showing Mounting of Mechanical Acceleration and Retardation Limit Device

There have been installed in this country in the past few years some 50 electric hoists of 200 h.p. and larger. In South Africa there are about 120 hoists of from 200 to 3000 h.p., while in Europe there are approximately 200 hoists of similar capacity. The great majority of the large European hoists operate on the principle of employing a flywheel motor-generator regulating set, the ratio being about 98 to 137. These figures show the very rapid increase which is taking place in the hoisting business. Quite recently the Christopher Coal Company has contracted for a power station to operate their mines. The equipment will consist of two 750 kw. turbines; three 300 kw. synchronous motor-generator sets for the locomotives and cutters, etc.; a hoist motor of 1150 h.p. at 109 r.p.m.; and an 885 kw. flywheel motor-generator set with a wheel weighing approximately 25,000 lbs.

ELECTRIC POWER IN RAILWAY AND MARINE TERMINALS

By R. H. Rogers

Power and Mining Engineering Department, General Electric Company

Freight is rushed over continents and oceans by the most efficient methods of transportation, only to encounter distressing delays at the terminals through the continued use of the crude methods of handling which have come down from the middle of last century. Cities which can cut out these delays through the provision of adequate freight-handling facilities will divert to themselves all kinds of traffic from distant points involving miles of extra haul. This article shows what Seattle is doing to prepare itself for the trade boost which is due to follow the opening of the Panama Canal; and shows how electricity can, and must, be applied to all the details of the terminal business if they are to overcome their great and growing handicap.—Editor.

The progress that we, as a nation, are making in every line of activity may be graphically shown by means of a composite curve which runs along quite straight during the '30's, '40's and '50's of the nineteenth century, rises gracefully during the '70's, 80's and '90's, and turns up abruptly like a sled runner so far in the twentieth century. We are increasing our efforts in hundreds of different lines in a geometric ratio that is startling in its possibilities, and productive of peculiar conditions in its present state.

The accumulated weight of all these increments rests heaviest on transportation, which is required to play its part repeatedly in almost every line of human activity. To follow a single line of thought, it brings ore to the smelter, it brings coal to smelt it, then takes the iron to the manufacturer and carries away the machine he has made. Then it must bring raw material to the machine for years to come, and carry the product by many successive stages year after year to a multitude of consumers. Thus increased activity along a single line bears upon transportation from a hundred different angles. How great then is the burden thrust upon it by the present rate of business acceleration!

Railway and marine transportation is carried on by a great system of machinery consisting of railroads, ships and terminals. The railroads and ships are economical, capable and adequate. The present terminals are now well understood to be so inadequate and inefficient as to form the limiting feature in the inevitable increase in traffic. If the predictions of men prominent in the commercial world come true, the terminals must soon bear a tremendous overload due to the impetus that will be given to commerce by the opening of the Panama Canal. Not only will the routing by sea be changed; but land traffic will also be largely re-arranged, so that both marine and railway terminals will experience great changes in the volume and character of their business. Being the weakest link in the chain, already strained by a steadily increasing load and soon to be subjected to a severe test, the present status of the terminal is to be deplored.

That this grave situation is understood and appreciated by some great communities is evidenced by recent events. Take, for example, the energetic work that is going on in Seattle at the present time, in anticipation of the greatly augmented domestic and foreign trade which will be attracted by Seattle's superior geographical location and its status as a railroad terminal, and which will be made possible by the Panama Canal.

Fig. 1. The Railroads and Freight Elevators are in Alternate Streets Between the Bush Factories

On March 5th the voters of Seattle authorized a bond issue of $8,100,000 for terminal improvements; and the total sum now pledged for expenditure during the next five years from bond issues, Federal Government, the State and private sources, is $20,000,000. This sum will give the city adequate means for co-ordinating its present and future steamship lines, its seven trunk railroad lines and its numerous manufacturing interests. Seattle's foresight and energy, which stand first, and its magnificent harbor, which is second in its qualifications, will soon determine its permanent place in the rearranged commerce of the world—a place that will be envied by other cities who must inevitably take similar action when they awake to the new order of things.

Fig. 2. Six of the Nine Fully Occupied Bush Factories Now Having 210 Tenants

The most important single project in the hands of the Port Commission is known as the Harbor Island Project, which involves building a complete terminal in the broad sense as represented by the Bush Terminal in Brooklyn. The Port Commission, acting jointly with the Pacific Terminals Co., whose president, Mr. R. F. Ayers, was vice-president and manager of the Bush Terminal Co., will build six 1400 ft. by 150 ft. piers, four 6-story manufacturing buildings 700 ft. by 75 ft. and eight 6-story warehouses, all adjacent to paved streets and all inter-connected by adequate railroads, which in turn connect with every trunk line entering the port. Upon the completion of the above preliminary layout Seattle will be equipped with a thoroughly complete steamship, rail, storage and industrial terminal, located on a deep unhampered harbor.

Buildings, piers and railroad connections alone, however, do not make a complete terminal; for here merchandise in vast quantities must be repeatedly moved through short distances, and every provision made to expedite these minor movements, and to reduce the friction incident to breaking bulk, changing character of the carrying agent, and putting the goods into storage. The almost universal use of hand labor to care for all this complex interwoven movement of freight has been responsible for the backward state of terminals. Note what fifty years has done for the navigator, and note also the half-century's progress in the railroad equipment. Then turn to any railway or marine terminal, and see the exact system of fifty years ago in operation on a larger scale and at a greater expense. There is a limit to the number of men that can work in a given space; so that, to handle more work without congestion and prohibitive cost, more space must be acquired or machinery substituted for men. In order to perform more work in a given time in the same space there is no recourse but to adopt machinery. Despatch is the essence of nearly every commercial transaction; and the terminal that establishes a reputation for despatch will divert to itself traffic that involves many miles of extra haul to avail itself of this great advantage.

Commerce equalizes the potentials of supply and demand along the lines of least resistance. An inadequate terminal interposes more resistance than a 500-mile railroad haul, and more than 1500 miles of ocean travel. In the old sailing-ship days facilities for unloading 100 tons per day were considered good. To-day 1000 tons per day is ordinary, and 5000 tons is striven for. With a stand-by charge of $300 per day a ship can travel far to be unloaded so rapidly. Because of leisurely loading and unloading by hand, our two million freight-cars average only twenty-four miles per day, and we frequently face serious car shortages. With adequate terminals there would always be a large car surplus.

Electricity, with its elasticity of application and control, lends itself more readily than any other source of power to the multiplex requirements of the great terminal. Thus we are seeing to-day, in the industry of package freight handling, a direct transition from the slow, expensive and cumbersome hand methods of fifty years ago to the economical electric methods of to-day, without, as is usual in other industries, the intermediate resort to other power. Eliminating free-flowing bulk freight, such as grain, ore, coal, etc. in the handling of which electricity is well established and generally understood, we will look over the field of package freight handling. Both in railway and marine terminals the complexity of the "marks," representing various consignees, brings about an amazing amount of handling and rehandling of both incoming and outgoing freight. An incoming ship's cargo must be removed to the pier, distributed into many piles, and held in temporary storage until certain transactions have been concluded and the disposition of each pile decided upon. The present intermittent method of unloading a ship by means of slings and the steam-winch at the rate of, say forty "drafts" per hour per hatch is giving way to continuous motor-operated apparatus. When merchandise is let down to the pier floor-level it is seldom raised again into piles more than five feet high, since it is cheaper to truck out to a great distance than to pile high by hand. Various means are at hand and in use to economically distribute and tier up cargo in piers. The overhead monorail, or "telpher" system, the portable moving belt, and the battery truck crane (all, of course, electrically operated) are used for this work. For simple distribution without tiering there are frequently used small storage battery platform trucks.

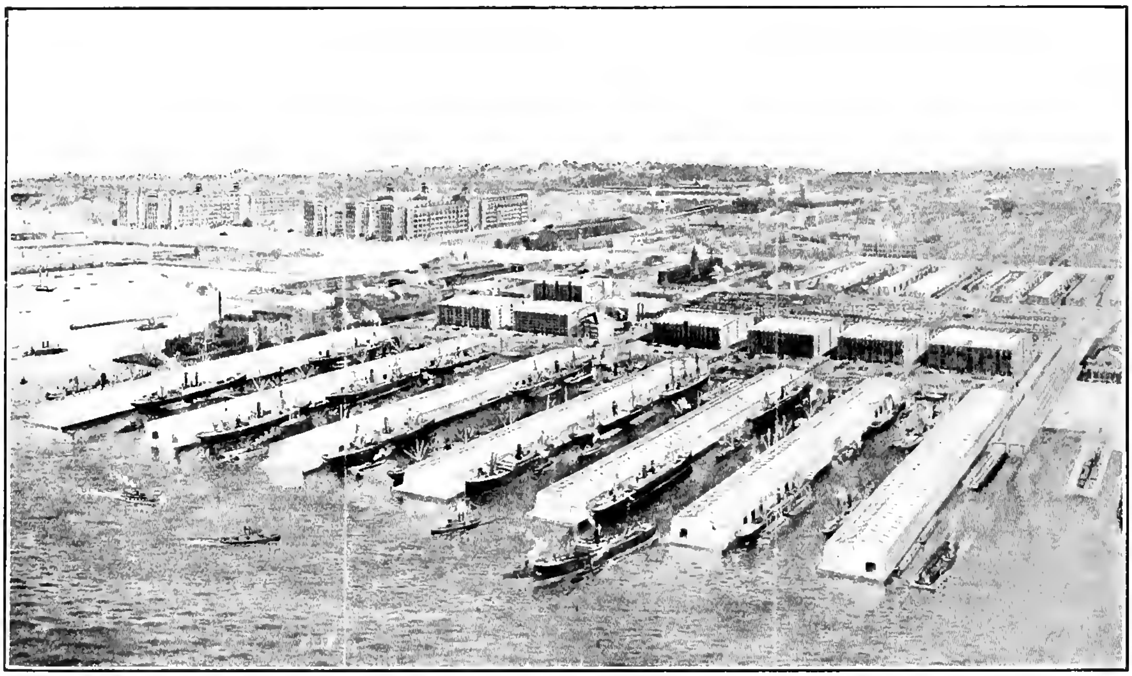


Fig. 3. The Bush Terminal, Brooklyn, Co-ordinates, Railroads, Steamship Lines, Warehouses and Factories

The cargo may now be disposed of in various ways, such as by lighters, by freight cars or by drays. Lighters are loaded by motor hoists, cars and drays by portable electric cranes. A large percentage of a cargo will go to outside storage—"on the farm" as it is called—or to the adjacent warehouses. This traffic runs high in tonnage and the distances are as great as 4000 feet. The same class of work includes the removal of the merchandise from storage to various carriers when the market calls. This work is actively carried on at the Bush Terminal by means of the battery truck cranes previously mentioned, in connection with fleets of trailers which are towed by the machines in trains of three or four. One such machine with twelve trailers has a capacity of 15 ton-miles per hour. Electric hoists in great numbers are employed for elevating merchandise into and out of the warehouses, as are the ordinary electric freight elevators. At the Bush Terminal may be seen an ingenious arrangement, whereby a single hoist, motor and drum serve the eight fire-proof compartments of the six-story warehouses. The hoist is located in a shed about 100 feet from the face of the building. From it radiate eight hoist ropes to the pulleys on the sections. The rope from the drum which ends with a hook may be attached to any one of the eight hoist ropes that end in loops at the shed. When it is required to transfer from one compartment to another it is only necessary to throw the loop over a pin and pass the hook to another loop and start work. By this means 40 doors in the warehouse front are served by one hoist and operator.

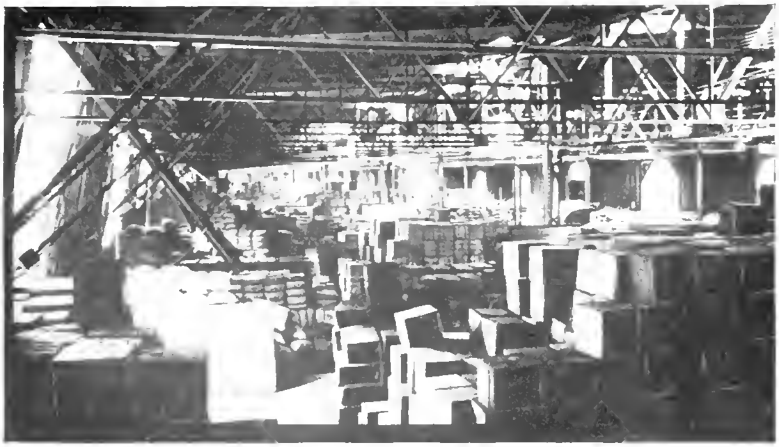


Fig. 5. A Bush Pier with One-fourth of 10,000 Ton Oriental Cargo

Fig. 4. Bulkhead, Slip and Pier with 10,000 Ton German Freighter at Bush Terminal

The electric locomotive is almost a necessity in the modern terminal, performing the function of shifting, spotting, making up, etc. economically; for it is claimed that a pound of coal burned in the central station produces twice the draw-bar pull of that burned under a locomotive boiler. Yard engines, too, are subject to a very intermittent service where electric power has a great advantage, to say nothing of the high starting power and nicety of control possessed by the electric locomotive. Electric commercial vehicles form a prominent part of a terminal company's equipment, especially where manufacturing concerns are catered to. By combining all the drayage of, say, two hundred industries and wholesale concerns great economy is attained, as such a combination tends to keep all the electrics busy during working hours and with full loads, while the maintenance and administration charges are greatly divided.

Electric power is distributed throughout the factories, warehouse yards and piers at the usual voltages for trolleys, hoists, factory motors, charging panels, etc. Outlet boxes are distributed along the piers, bulkheads and yards at intervals of 150 ft. or less, so that portable apparatus can be plugged in to the service lines wherever required. Terminals, such as the Bush Terminal in Brooklyn and the Harbor Island Terminal in Seattle, require a tremendous amount of current for lighting. Flaming arc lamps are generally used in the piers. Portable banks of incandescent lamps, called hatch lights, are used in the holds of the ships alongside. Along the bulkheads and all about the warehouses arc lights are used, while incandescent lamps are used throughout the warehouse interiors. Both arc and incandescent lamps are used in great profusion in the factory buildings. The terminal company acts as distributer for its numerous tenants; thereby getting for them a low wholesale rate, and in turn relieving the central station of a multitude of moderate accounts.

Fig. 6. Proximity of Ample Warehouses Double the Value of Bush Piers

Electricity will find its greatest usefulness in the minor movements of package freight in the terminals; for, to quote Woolley: "Here the human worker still reigns supreme in all his primitive wastefulness. He rolls up an annual pay-roll of millions, and congests traffic by his complex and cumbersome motions. He strikes when he pleases and ties up whole harbors." Mr. Henry R. Towne, of Yale and Towne, before the Inter-State Commerce Commission, said: "Millions of tons of material are moved every day by the crudest kind of labor. I am absolutely sure that mechanical appliances could be successfully employed for the greater part of the work."

Fig. 7. One of the Electric Locomotives that Work in the 2200 Car Yard of the Bush Terminal

While the use of electricity in handling package freight is in the pioneer stage the same may be said of modern terminals themselves, for we have only one Bush Terminal so far, with another planned for at Seattle. Other cities are, however, waking up to their shortcomings, especially Boston, with its $9,000,000 appropriation for harbor improvements, Los Angeles, San Francisco, New Orleans and Chicago. New York State, with its $20,000,000 Canal Terminals appropriation, and the Government Terminals at Panama, which will be the largest in the world, show at the trend of the times. Terminal building activity must be swiftly accelerated, in order to overtake and hold its own with traffic which is almost due for an unprecedented boost from the Panama Canal. The terminals must turn to and adopt wholesale the use of electricity as a powerful aid to overcome their great and growing handicap. On the other hand, electricity must be made to rise to the occasion, that it may not be found wanting at the critical time.

Fig. 8. Battery Truck Crane and Trailers Trafficking Between Piers, Bulkhead and Warehouses

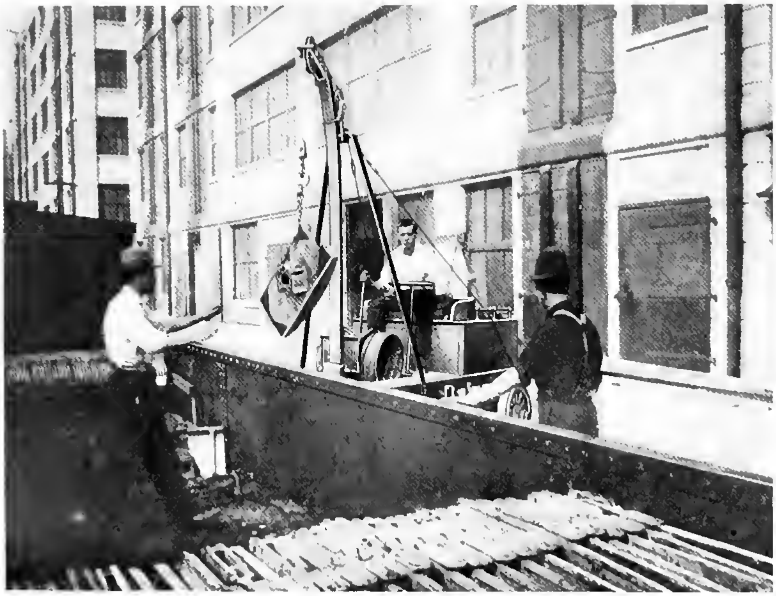
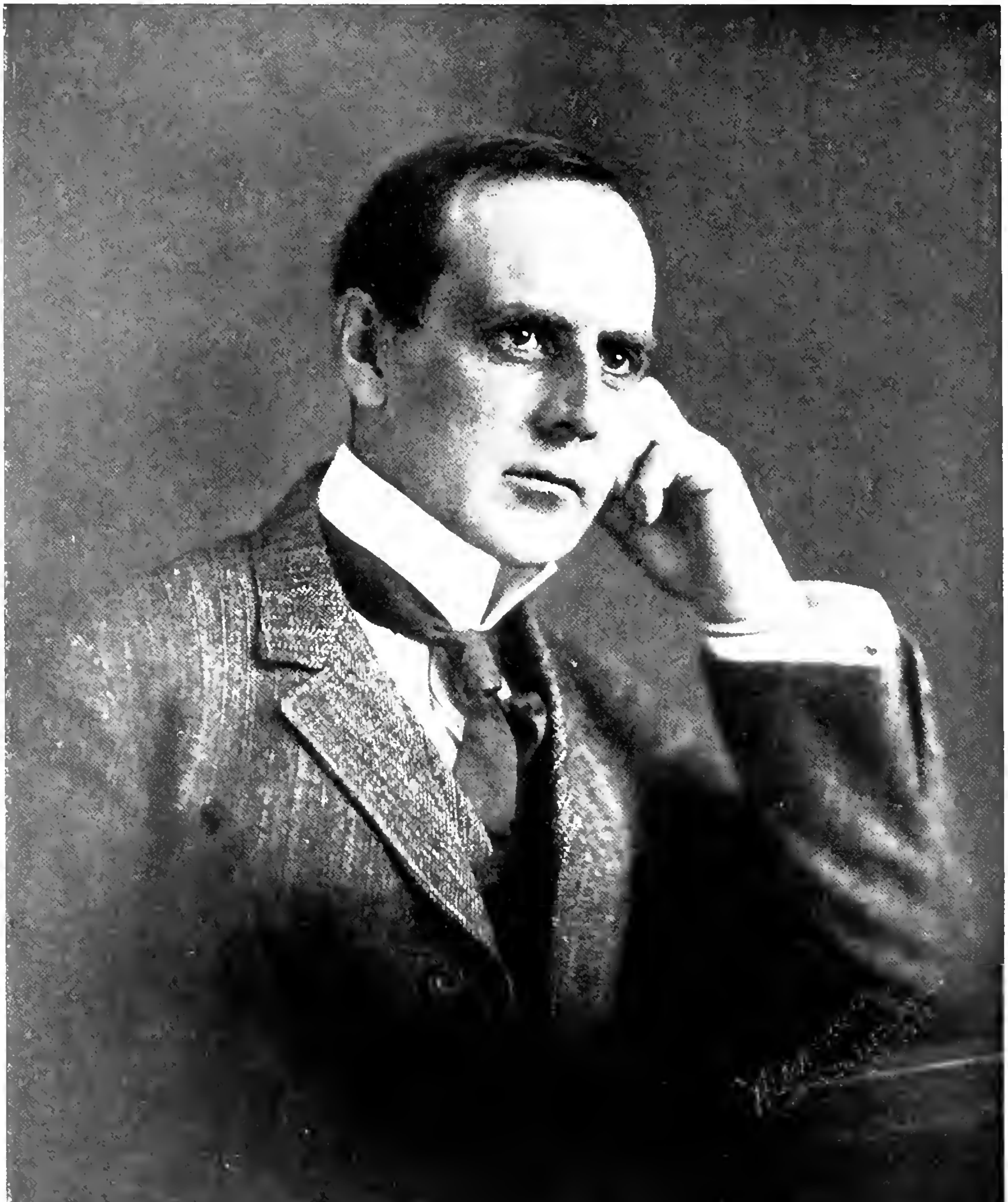


Fig. 9. Unloading Gondola Car Load of Mining Machinery for Foreign Shipment, Bush Terminal



Hinsdill Parsons.

IN MEMORIAM

HINSDILL PARSONS

When the history of the electrical industry in this country comes to be written, and especially the history of the great electrical manufacturing organizations, a worthy place will be found for the men who performed the great work of establishing these concerns on a firm and substantial corporate basis, of directing their commercial and financial activities during their period of growth, of protecting the inventor by the just and equitable safeguards of the patent law, and of finding a solution to the multitude of perplexing legal problems which inevitably attended the growth and development of these organizations to a point where they rank among the great industrial corporations of the country. From January, 1894, when he entered the employ of the General Electric Company, until the time of his death, when he occupied the position of vice-president and general counsel, Hinsdill Parsons was a great factor in this work; and the tragic accident of April 28, 1912, has robbed the Company of one of its ablest and most brilliant leaders, the value of whose years of service it is difficult to gauge and almost impossible to overestimate.

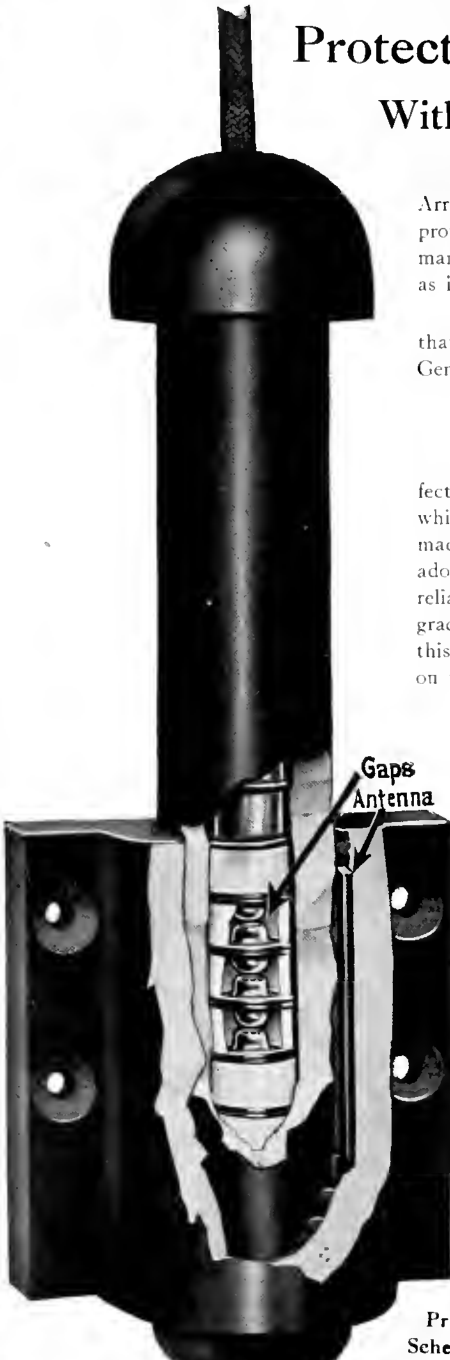
The son of J. Russell Parsons, of Hoosick Falls, N. Y., Hinsdill Parsons was born on February 10, 1864. After completing his common school course he entered Trinity College, Hartford, Connecticut, graduating in 1884. He then attended the Albany Law School, where he was graduated in 1885. At Trinity College he was a member of Delta Psi fraternity and the honorary fraternity, Phi Beta Kappa. At Albany Law School he was a member of Phi Delta Phi. He was admitted to the New York State bar in 1885, and in 1889 was appointed patent attorney for the Walter A. Wood Harvester Company, of Hoosick Falls, his father then being vice-president of that corporation.

In 1894 Mr. Parsons came to Schenectady and joined the staff of the General Electric Company. His first position was that of counsel, and in May, 1901, he was elected vice-president and given charge of the Company's legal business as general counsel. He was also made president of the Schenectady Railway Company, retaining the position until July 26, 1905, when the line was sold to the New York Central and the Delaware and Hudson railroads. The remarkable development of the Schenectady Railway Company was largely due to his enterprise and genius. At the time of his death he was also president of the Schenectady Illuminating Company and the Mohawk Gas Company. He was a director of the Electric Bond and Share Company, the Washington Power Company, and the Schenectady Power Company. Subsequent to the panic of 1907 he was largely instrumental in effecting the successful readjustment of the affairs of the suspended Knickerbocker Trust Company, of New York City. He was a member of the St. George's Episcopal Church, of the Mohawk Golf Club, and of the Mohawk Club, all of Schenectady, and was deeply interested in many other local organizations. He was also a member of the University, Metropolitan, St. Andrews, and St. Nicholas Clubs, and of the Down Town Association, of New York City. In 1889 Mr. Parsons married Miss Jessie Mary Burchard, whose brother, Anson W. Burchard, is now Assistant to the President of the General Electric Company.

The story of Mr. Parsons' career with the General Electric Company is one long record of brilliant achievement. The panic of 1893 had laid bare the inadequate financial basis upon which local electrical enterprises had been capitalized; and the energies and experience of the most able men in the Company were utilized in replacing them on their feet and extracting from their slim resources cash, promises and securities, anything available, for the satisfaction of their debts. In this work, Mr. Parsons took a leading part, and early disclosed to his associates the traits of character that led to his subsequent promotion in recognition of his ability and success. To his brilliant hereditary gifts, he added an intuitive penetration of mind and the power of incisive concentration on the work in hand, until he had achieved complete and exhaustive mastery of the subject of study. No point or figure was so minute as to escape him, and the easy solution of many a difficult problem was promptly accomplished by his having in the first instance arrived at all the facts. He did not possess the forensic ability of a great advocate, but he had an instinct for correctly appraising the legal merits of a case, and the ability and persistence for acquiring intimate knowledge of its smallest details. Unusual traits were exercised in effecting an adjustment of all matters of controversy without having recourse to the Courts, achieving this on a fair and reasonable basis of conciliation and settlement. His knowledge of the intricacies of corporation law was comprehensive and exact.

The industrial and commercial world will mourn his loss. The great corporate interests, in which he was becoming a more and more vital and necessary factor, will find it difficult to adjust themselves to the changed conditions without him. But however much his loss may mean to business and professional interests, it is as nothing to the burden of sorrow borne by his friends. It is given to few men in this world to have friends greater in number or devotion—friends in the broadest sense of the word, and it is they who mourn his loss with a grief too genuine and too deep to find ready expression in words. His warm, lovable nature endeared him to all those with whom he came in contact. Generous, liberal-minded, whole-souled, no one could feel his personality without succumbing to its irresistible charm. He possessed the wonderful gift of making subordinates feel that they were met on a plane of equality, of listening intently to whatever they had to say, and finally of leaving with them the impression that it was they who had conferred a favor upon him.

It was a tragic ending to a brilliant career, not yet at its zenith; but the world, we know, is better off that such men as Hinsdill Parsons have lived in it, and those who have come in contact with him have felt in a measurable degree the inspiration of his high character and nobility of mind.



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Dr. W. R. Whitney

Dr. Whitney is the Director of the Research Laboratory of the General Electric Company at Schenectady. An article on page 415 gives an account of the work which is carried on there under his direction, and some of the more important "new" things and processes which have been discovered in the laboratory during the last few years. In one main building there are thirty-one separate rooms given over to research, with smaller laboratories elsewhere in the Schenectady plant; the equipment is complete and costly; while the staff includes many picked clever men. The responsibility devolving upon the Director is a heavy one. His instructions are virtually no more explicit than "Go ahead and invent!"

GENERAL ELECTRIC REVIEW

THE ECONOMIC VALUE OF RESEARCH IN ELECTRICAL MANUFACTURE

In an editorial article on "Electrical Progress in Britain and America," in the April issue of this paper, an attempt was made to show that the big manufacturing corporation is an indispensable part of the industrial machinery of any country which desires to be in the forefront of electrical progress. It may be that, for various reasons (some similar, some dissimilar) it is also an economic necessity in the supply of a nation's food and clothing; but many of the conditions in the electrical manufacturing business are peculiar to that business and are to be reproduced in no other industrial field. Electrical progress calls for experiment and research to obtain the fullest knowledge of natural laws, "in order that the greatest economic gain may result from the application of these laws. Individuals may divide the work of investigation and of application; but the gain to the industry will be greatest when the activities of the investigator are directed along lines indicated by economic necessity or expedience. This conservation can only be achieved if the manufacturer, the party who has to meet commercial needs, is able to go after and obtain the necessary scientific knowledge upon which to base the design of his apparatus."

It may be of interest to enter a little more specifically into detail in order to show how the research facilities which are maintained by the electrical manufacturer do actually justify their existence, in making possible from time to time some of the big discoveries which are milestones in the path of progress, and in the production of a continual output of lesser work which, while attracting little attention outside, enables the manufacturer to reduce his price or to improve his product, or both. Other respects in which the research faculty plays an important part will be referred to later. A few weeks ago Dr. W. R. Whitney, Director of the Research Laboratory of the General Electric Company at Schenectady, gave an address before the District Engineers of the Company assembled for the annual meeting. Into sixty minutes' time he compressed a mass of detail with regard to the reasons which called the laboratory into being, the story of its growth, a few of the more important "new things" which it had unearthed, the present extent of its resources in equipment and personnel, and the wide range of its activities. It was a rapid and concise review, intensely interesting. Those present learned much, and received food for thought concerning much more. We cannot reproduce Dr. Whitney's remarks verbatim, but can recount some of the salient facts with additional information since obtained from the laboratory.

The expedient of sinking hundreds of thousands of dollars a year in scientific work has paid, as the men who resorted to it knew it would pay. Financial gain was the object in view; but, having said that, it may be mentioned that it was also with the very real hope that this country might climb to a higher place in the list of nations which had actually pioneered and invented, that resort was made to this costly expedient. At the end of the nineteenth century, the only notable new things credited to the United States in the field of applied electricity were the traction motor, the telephone and the glow lamp. All the others came from Europe. Since that time two of the most important (as far as we are able to see at present—the distance is too close) have been the squirted tungsten and the drawn wire tungsten lamps. The latter comes from the Schenectady laboratory; and future years may possibly show that this one thing alone were worth all the money sunk in the up-keep of the place for 10 years. The central stations have profited enormously; and it is impossible to gauge the benefits which have accrued to the individuals of the nation, the millions who are crying for cheap light. Before that the metallized filament had been forthcoming from the same source, (as a fact this was the personal invention of Dr. Whitney himself) pulling down the watts-per-candle from 3.1 to 2.5; whence the tungsten has since made a further reduction to 1.25. Thousands of experiments were performed before the drawn wire filament was produced—many of them perhaps such as might, to the uninitiated, appear as fool experiments, foredoomed to failure so far as immediate result was concerned. But at this point another and most important aspect of the research laboratory appears. In making these endless experiments with tungsten, an intimate knowledge of the metal was obtained; from which it became evident that the substance was admirably suited for a variety of purposes connected with the electrical manufacturer's business. Today tungsten contacts are being turned out for magnetos and spark coils, vibrators and relays, at the rate of hundreds of thousands per year. Tungsten and molybdenum are replacing platinum in resistance-wound furnaces running up to temperatures of 2000 deg. C.; while as the target or anti-cathode in the X-ray equipment, tungsten, substituted for platinum, will withstand higher temperatures, will thus increase the power of the apparatus, and at the same time greatly enhance its stability. Such knowledge, thus gained and thus applied, represents one of the collateral or incidental benefits for which the existence of the research faculty is responsible.

The vacuum furnace with carbon resistor for obtaining temperatures up to 3000 deg. C. is another of the laboratory's offspring, and the mercury arc rectifier was first produced here. Dr. Steinmetz is responsible for the magnetite lamp; but a great deal of very valuable work upon it has been carried out in the research laboratory under the direction of its inventor. Poplox—the name given to a popped water-glass—used as a heat insulator in electric ovens, comes from the laboratory; and the calorizing process, if not actually discovered, certainly underwent its practical development there. Looking for a moment at carbon brushes, it may be said that here for the first time an attempt was made to make a brush to suit a service. Carbons in different forms—graphite, coke, lamp-black and so on—were mixed in different proportions, until results were obtained which made it possible to put any desired degree of hardness or softness, resistance, toughness and density, into the brushes for any given machine. A number of cases of persistent trouble with railway motors have been cleared up; while in designing the commutators of stationary machines it has often been possible to allow a reduced commutator length or to obtain improved commutation. Turning to metals, we find that over 150 alloys have been worked with and produced for various purposes; much has been achieved in casting copper by the use of a boron-suboxide flux (discovered by Weintraub of Lynn and the subject of a separate article in this issue); great improvements have been made in the selection and preparation of sheet steel for the iron circuits of electrical machines, while greater knowledge of the laws of magnetism has incidentally resulted; and a lengthy set of tests have been performed on various tool steels. This last point is interesting. It might be imagined that the shops of the electrical manufacturer alone would provide insufficient market for a steel plant; but it will be immediately obvious that great saving in production costs may be accomplished, by making exact specifications for the tool steel best adapted for machining any of the various grades of iron or steel for which the designer may call in the building of his machine.

We have only mentioned a few of the directions in which the research laboratory is putting in very valuable work. In many other cases electrical apparatus is installed and running before the laboratory is called upon. A turbine was found to be corroding when the machine was opened up. The research man found that the water was actually deficient in alkalis. Lime was added and the trouble disappeared. Mention of lime calls to mind the 1200-volt enclosed fuses in which lime was used as the packing. The substance was good on 600 volts, but slagged up at the higher voltage. A substitute was quickly found in the laboratory and satisfactory service obtained. It may easily be imagined that some of the special apparatus, maintained primarily for use in research work, can be made of the greatest assistance in various special manufacturing processes and tests which may be demanded from time to time. In testing compensating dashpots in the Signal department, for instance, a very low temperature was required—something around 40 deg. below zero, which is impossible in the factory, but easy of attainment when the laboratory's liquid air outfit is brought to bear. And again, various manufacturing departments performing the oxy-acetylene welding process used to buy oxygen in great quantities from outside. The laboratory installed an oxyhydrogen plant—a move which enabled them to supply the works with oxygen at a cost reduced by 80 per cent., and gave the laboratory their hydrogen free as a by-product.

There are now 120 employes engaged along these and similar lines in the Schenectady laboratory, 45 of whom are graduates of technical colleges. Besides their direct and indirect contributions to the mass of technical data furnished to their employers, considerable scientific value attaches to the papers which are forwarded from the laboratory staff to the various learned societies and technical journals. Few of these are concerned solely with electrical topics, many with electrochemical, and perhaps a majority with purely chemical matters. The following titles of papers which have emanated from the research room in the past 12 months in this manner will give an indication of the nature of the material: Thermal Conductivity and Convection in Gases at Extremely High Temperatures; Dissociation of Hydrogen into Atoms; Transformation of Other Forms of Carbon into Graphite; Solubility of Wrought Tungsten and Molybdenum; Carbon Brushes; Some Applications of Wrought Tungsten and Molybdenum; a Modification of the Periodic Table. The foregoing papers are to be found in such publications as the Proceedings of the A.I.E.E., the Journal of the American Chemical Society, the Physical Review, the Transactions of the American Electro-chemical Society, and the Journal of Industrial and Engineering Chemistry.

We cannot conclude this brief review of the activities of the Schenectady laboratory without mentioning some of the other units which constitute very important parts of the complete research scheme of the Company. Separate organizations, each under its individual director, are to be found at the Harrison lamp works, and at the Lynn and Pittsfield plants. These laboratories are smaller and the scope of their activities somewhat more restricted than that of the Schenectady research room; but each has the advantage of being in close touch with the engineers and factory at the particular plant at which it is located, and is therefore in an extremely advantageous position for handling many problems more or less peculiar to that factory. At Harrison work is specialized on incandescent lamps; at Lynn, arc lamp electrodes and materials for meters, small motors, etc. are the principal matters of study; at Pittsfield sheet steel and insulations, such as impregnating compounds, varnishes and oils are being studied and improved. The several laboratories cooperate by the exchange of visits and reports in order to give to each as far as possible the benefit of the others' work and to prevent overlapping, except where such overlapping is desirable. It is impossible to over-estimate the value of such a system to the manufacturing concern. To quote Dr. Whitney. . . . [leaving aside direct commercial gain] "the experience and knowledge gained in a general research laboratory is a positive quantity. I am firmly convinced that proper scientific research is practically required by the existing conditions of our technical age."

THE POSSIBILITIES OF THE EXHAUST STEAM TURBINE

Although the exhaust steam turbine has for some time ceased to be a novelty to the steam and electrical engineer, its possibilities are often not realized, and the lay mind is frequently sceptical of the claims made for it. Considerable misconception still exists as to the theoretical and practical operation of a mixed-pressure turbine. An ordinary low-pressure Curtis turbine, reduced to its fundamental elements, consists of the low-pressure half of a high-pressure condensing turbine. For example, a four-stage high-pressure turbine of 1000 kw. might be converted into a low-pressure turbine of 500 kw. by using the last two stages. This is evident when it is considered that normally the first two stages utilize something like half the total available energy of the steam, which brings the pressure to about atmosphere, while the remaining two stages abstract the remaining half of the available energy in the expansion range from atmosphere to vacuum. This would similarly apply to a machine with any other number of stages, although evidently an odd number would not normally produce exactly atmospheric pressure in any one stage.

A low-pressure machine, then, is primarily constructed with nozzles and buckets correctly proportioned for the expansion of steam from about atmosphere pressure to the available vacuum. A mixed-pressure turbine is similar in so far as the buckets and nozzles are concerned, but is also equipped with additional nozzles, and corresponding governing device, for the expansion of high-pressure steam. It should be remembered that in any Curtis turbine the nozzles cover an increasing arc of the circumference from stage to stage, until the entire periphery is covered toward the low pressure end. Thus even in a low-pressure turbine the first-stage nozzles do not occupy the entire circumference. It is therefore possible to fill the remaining arc, amounting to 90 deg. or more, with high-pressure nozzles designed to expand steam to the same discharge pressure as the low-pressure nozzles, but from an initial pressure corresponding to the boiler supply. Thus if both high and low-pressure steam is being simultaneously utilized, the actual discharge pressure from both sets of first-stage nozzles is practically the same, and the combined steam takes the same course through the remainder of the turbine.

This process is not to be confused with simple throttling, in which the steam is reduced to atmospheric pressure before entering the turbine. On the contrary, boiler pressure steam is expanded through correctly designed nozzles; and the resulting economy when running on high pressure steam alone, while, of course, not as good as that of a machine primarily designed for high pressure, is very much better than where the steam is simply throttled.

The process of decreasing the pressure by throttling superheats the steam somewhat, since no heat has been added or taken away, and the total heat consequently remains the same. But the actual number of heat units available for conversion to mechanical work, between the limits of the throttled pressure and vacuum, has been reduced by nearly one half. In fact the difference in available energy between steam throttled to atmospheric pressure, with resulting superheat, and normally dry saturated steam at the same pressure, is comparatively small. For example, dry steam at 150 lb. gauge (165 lb. absolute) if throttled to 16 lb. absolute would be superheated about 91 deg. F., which, however, would increase its available energy over that of dry steam to a 28 in. vacuum only by about 6 per cent. The following comparative figures show this relationship more clearly.

Initial Pressure Lb. Absolute	Superheat 0 Deg. F.	Final Pressure Lb. Absolute	B.T.U. Available Energy per Lb. of Steam	Equivalent Foot-Lb.
165	0	1 *	321	250000
16	91 deg.	1	182	142500
16	0 deg.	1	172	134400

* About 28 in. vacuum.

It will be noticed that the available energy of the high-pressure steam is about 75 per cent. greater than that of the low-pressure superheated steam. It is, of course, true that the mixed-pressure turbine cannot utilize high-pressure steam as economically as low-pressure; so that the difference in economy is not proportional to the available energy in each case. But even after allowing for lower efficiency on high-pressure operation the net economy is much higher than where the steam is throttled. This arrangement also permits the machine to carry a considerable part of its capacity non-condensing. Thus, if the condenser is for any reason out of service, the turbine may still operate, and a complete shut-down may be avoided. Where the steam is throttled to atmospheric pressure before entering the turbine, non-condensing operation is evidently impossible. It is, therefore, self-evident that where an exhaust steam turbine may be expected to operate for any considerable time directly from the boilers, either with or without its condenser, it should be of the mixed-pressure type with separate nozzles for high-pressure steam, rather than merely equipped with a reducing valve to throttle the steam to low pressure before it enters the turbine.

Some excellent articles appear in this issue of the REVIEW, describing typical exhaust turbine installations. These are of particular interest, not only because of the successful results accomplished; but because they relate to machines operating in stations of widely different character, yet typical of two of the most important applications of electricity —industrial and railway power. The article by Mr. B. E. Semple on page 451 shows how a large part of the power of a great steel mill is developed from a single exhaust turbine; while that by Mr. E. G. Morgan on page 448 refers to a system in which a vast net-work of interurban railways is supplied from a similar machine. In both cases the steam is derived from several independent sources of supply, e.g., engines, pumps, etc., thus differing from some of the earlier installations where the low-pressure turbine took all its steam from a single engine, and the combined engine and turbine were generally operated as a single unit. In both cases the machines are of the mixed-pressure type. It is needless to add that the heavy and variable demands of both the steel mill and the traction service require machines of liberal mechanical construction, and capable of economical operation over wide fluctuations of load.

The new mixed-pressure turbo-generator station recently installed at the works of the Tennessee Coal, Iron & Railroad Company, at Ensley, Alabama, described on page 444 by Mr. Best, is notable as being the largest installation of mixed pressure turbo-generators and equipment, concentrated in one power house, for the utilization of exhaust steam from rolling mill engines.

G. R. PARKER

THE SECOND LAW OF THERMODYNAMICS AND THE "DEATH" OF ENERGY, WITH NOTES ON THE THERMODYNAMICS OF THE ATMOSPHERE

CHARLES P. STEINMETZ

CHIEF CONSULTING ENGINEER, GENERAL ELECTRIC COMPANY

Expressing the second law of thermodynamics in the words: "Without expenditure of some other form of energy heat flows only from higher to lower temperature," the author shows that the logical sequence from this is the conclusion that eventually all energy transformation will stop, i.e., all motion will cease and the universe will be dead. The conclusion is not a reasonable one and the author sets out to disprove the general applicability of the law. Adopting as his line of reasoning the thermodynamics of gases, he shows how, attending the escape of molecules from the attraction of earth into cosmic space, there is a heat energy flow from a temperature of 10 deg. C. to one of 60,000 deg. C. Even within the earth's atmosphere, and without considering what happens in cosmic space, he shows that there is a transference of heat energy from lower to higher temperatures, or rather against the thermodynamic temperature equilibrium; and leads us to the conclusion that this law of thermodynamics is not of universal application, but applies only within the limited range of thermodynamic engines from which it has been derived.—EDITOR.

The second law of thermodynamics may be expressed in the form: "In any cyclic process, the sum total of unavailable heat energy increases." Thus, if we transform electrical to mechanical energy and backwards, we do not get back the total amount of energy, but some of it is converted into heat. Of this heat energy at least a part can never be re-transformed into any other form of energy, i.e., it has become unavailable. Or the law may be expressed: "Without expenditure of some other form of energy, heat flows only from higher to lower temperature;" that is, from a higher heat level to a lower heat level. In this form the law is easiest to grasp; just as water, without expenditure of outside energy, flows only from higher to lower level.

The result thereof is that the total heat energy can never be used in any case; but that amount which is still heat energy when the lowest heat level or temperature has been reached can not be transformed except by the use of additional energy, i.e., it has become unavailable. Thus of the total heat energy in the superheated steam issuing from the boiler, only that corresponding to the temperature range from admission temperature to the temperature of surrounding space can be used; but the much larger amount of heat energy which is still contained in the steam exhausting into the condenser at atmospheric temperature is unavailable.

To some extent availability is relative. The heat energy in the steam exhausting into the condenser at atmospheric temperature, which is unavailable under ordinary conditions, would be available in part if we could exhaust at the temperature of liquid air; and of the heat energy remaining in the exhaust at liquid air temperature, a further part could be transformed by exhausting at the temperature of liquid hydrogen, etc. Even between the limits of atmospheric temperature appreciable variations of available energy, and with it differences in the efficiency of steam turbines, etc., are noticeable. However, the total heat energy could be made available only by dropping down to the absolute zero of temperature, and as this can not exist, all the energy, which is still heat energy at the minimum temperature of the universe, has become absolutely unavailable, i.e., it can never be used without the expenditure of some other form of energy.

An analogy is given by water power. Of the energy of a water course, only that represented by the difference in height between the upper level and the lower level is available at the point of development. However, some miles distant, a still lower level may exist, and further hydraulic energy made available by it; but finally the ocean level is reached. Here the water still contains an enormous amount of gravitational energy —that corresponding to its distance from the center of the earth. This, however, is now absolutely unavailable, since no lower level exists into which the water can be discharged, and outside energy would have to be expended to make such a lower level.

The result of this functioning of the second law of thermodynamics is that the temperature crests in the universe are leveled off, the temperature valleys filled up, the amount of unavailable heat energy (that below the bottom of the temperature valleys) is increased; in other words the temperature of the universe tends towards a uniformity, at which all the heat energy has become unavailable. The temperature differences in the universe are thus maintained only through the expenditure of other forms of energy, and other energy is thus continuously poured into the gulf of heat energy in producing available heat energy through temperature differences, which again are continuously leveled off and the heat energy made unavailable by the functioning of the second law of thermodynamics; but no return path exists from the unavailable heat energy to other forms of energy.

The outcome of this unidirectional transformation law must be that finally all the other forms of energy will have been converted into heat energy, and all the heat energy have assumed a uniform temperature level, i.e., become unavailable. This means that all the energy of the universe must finally be converted to unavailable heat energy, and if the second law of thermodynamics holds universally, no return exists from this state; hence, the universe must finally run down, just like a clock. All energy transformation will stop, i.e., all motion will cease and the universe will be dead. The energy will still be there, — the law of conservation of energy will not have been offended,—but as unavailable heat the energy will be dead. It is true that if we define energy as that entity which can do work, it is questionable whether the unavailable heat energy of the dead universe, which can never do any work, can still correctly be called energy.

The second law of thermodynamics is well founded on our experience. The reasoning from this law as to the death of the universe is logical. At the same time, the conclusion that the universe must run down is not reasonable. If the universe is eternal, has existed since infinite time, then it should have run down an infinite time ago. But if it is not eternal, but had a beginning, what was before? How could energy begin without offending the first law, that of the conservation of energy? Thus, in the final reasoning, we arrive at a contradiction.

The explanation may be either that we have attempted to reason beyond the limits of the capacity of the human mind, which, being finite, always fails in the attempt to reason into the infinite, or it may be that the second law of thermodynamics is not of universal application, is not a general law of nature, but is of limited application only. In the following pages I wish to show that the latter is the case. A single exception obviously would be sufficient to show that the second law of thermodynamics is not a universal law, and that the conclusion regarding the death of the world, based on this law, are thus not justified. As the thermodynamics of gases is far simpler and more completely known than any other branch of thermodynamics, it would offer the most promising field of study.

The kinetic theory of gases is probably as fully and conclusively proven as anything can be by the inductive method of science. According to this theory, the heat energy of a gas is the mechanical energy of the irregular molecular motion: the $\frac{1}{2} m v^2$ of the molecules and the atoms in the molecules. The second law of thermodynamics then is nothing but the application—the natural consequence of the operation—of the law of probability. If we bring together two gases of different kinetic molecular energy, i.e., of different temperature, such as a liter of air at 30 deg. C. and a liter of air at 10 deg. C., in such a way that the molecules can exchange their motion, i.e., heat can flow between the gases, it is obvious that, in an interchange of velocity between the molecules, one having a velocity above the average is more likely to lose than to gain velocity; a molecule with less than average velocity is more likely to gain than to lose velocity. The result of the interchange of velocity—or rather of kinetic energy, in accordance with the laws existing between bodies, probably the law of gravitation—thus is an averaging of the kinetic energy, i.e., an equalization of the temperature—in the above instance to 20 deg. C. for both liters of air. However, the result of the operation of the law of probability cannot be a perfect equalization of the molecular energies so that all the molecules have exactly the same energy, but sometimes a fast molecule may still gain energy (although it is more probable to lose), or a slow molecule may lose. The result thus would be a distribution of the kinetic energies between all the molecules in accordance with the probability law; and the temperature then represents, or is, the average kinetic energy of the molecules—is represented by an average molecular velocity. This is the velocity found most frequently amongst the molecules; but all higher and lower velocities exist, becoming, however, more and more rare the further they differ from the average velocity, in accordance with the probability law.

Causing heat to flow from a lower to a higher temperature then means separating the faster from the slower molecules

Experience, expressed by the second law of thermodynamics, says that this can be done only by the expenditure of outside energy. However, such a separation of the fast from the slow molecules without expenditure of outside energy would in no way contradict the law of conservation of energy, as Maxwell has shown. Assume that we have a volume of gas at constant temperature—the two liters of air at 20 deg. C. resulting from the previous illustration—and have a partition to divide the gas volume in two parts. This partition may be perforated by numerous minute doors, which we assume to have no weight and to move without friction, so that no energy is required to open and close them. Assume now that at every such door we place a demon, who opens the door whenever a fast molecule comes from the right, or a slow molecule from the left, and lets this molecule through; but does not open the door for a slow molecule from the right, or a fast molecule from the left. The result would then be, that gradually the fast molecules would accumulate in the left, and the slow molecules in the right section of the space; that is, without expenditure of outside energy, but through the intelligence of the demons, heat energy would flow from the lower temperature on the right to the higher temperature on the left side of the partition, against the second law of thermodynamics.

Now these demons exist in nature. Every cosmic body is such a demon, and separates the fast from the slow molecules, keeping the latter and sending the former out into space, and thereby causing heat energy to flow into space at a temperature far above its own temperature. Consider for instance our earth. In the uppermost regions of the atmosphere, assume a molecule which happens to be moving in an upward direction, and does not happen to approach another molecule so closely that its direction of motion is changed. Such a molecule will move upwards, until its motion is stopped by the force of gravity, by the attraction of the earth, when it falls back again. If, however, the upward velocity of the molecule is sufficiently high—above a certain critical value—then this molecule escapes from the attraction of the earth into space, and never comes back. This critical velocity at which a molecule escapes from the earth is 11,000 meters per second.* Assuming the average velocity of the molecules of the air, corresponding to an average terrestrial temperature of 10 deg. C. or 283 deg. abs., as 750 meters per second, then the velocity of 11,000 meter seconds corresponds to a temperature of $283 \times \left(\frac{11{,}000}{750}\right)^2 = 60{,}000$ deg. C. That is, the molecules which the earth sends out into the universe have a kinetic energy corresponding to a temperature of 60,000 deg. C.; or as we may say, by the escape of these molecules heat energy flows from the temperature of the earth, 10 deg. C., into a temperature of 60,000 deg. C.

This brings up an interesting feature. Since the temperature of the earth steadily decreases with increasing altitude, we usually think of cosmic space as extremely cold—near the absolute zero of temperature. Empty space obviously has no temperature, since temperature is an attribute of the matter in space. Judging the temperature of cosmic space by the kinetic energy of the molecules which have escaped into space from the larger cosmic bodies and which traverse space in irregular motions, we would be led to the conclusion that, far from being extremely low, it would on the contrary be of an inconceivably high value, probably several hundred thousands degrees centigrade. This conclusion would better agree also with the very simple line spectra of gaseous matter in space, as shown by the nebulæ.

We may ask, however, whether the kinetic energy of a molecule which, due to its high velocity, has escaped into cosmic space, can still be considered as heat energy. Heat energy is the kinetic energy of irregular molecular motion. The difference between the heat energy of a gas and mechanical energy thus lies in the irregularity of the motion and the size of the moving particles, which is such that only the resultant effect of the mechanical motions of large numbers of moving particles can be perceived. Irregularity of motion, however, is relative; for, if we consider a single molecule which has escaped into space by reason of its high velocity, we can not attribute any irregularity to its motion. That is to say, its kinetic energy cannot further be considered as heat energy; but the kinetic energy of the molecule, which was heat energy while the molecule moved in a mass of gas together with other molecules, is mechanical energy of cosmic motion, and the molecule is a cosmic body, traversing space under the laws of gravitation, but not subject any more to the law of proba-

* Calculation see in the appendix.

bility of mass action, i.e., to the second law of thermodynamics.

This brings us to the question of the limitation of the conception of heat energy, but for this purpose we do not need to go to cosmic space. If we consider the vacuum tube, and go to the highest vacua—the cathode ray vacuum and beyond—the distances between the molecules become so large that the free path of each molecule becomes appreciable, and the action of the kinetic energy of the individual molecule becomes noticeable. But as soon as this is the case, the kinetic energy of the molecule cannot well be considered as heat energy any more, and the laws of thermodynamics, which after all are the laws of probability of a mass of moving bodies, begin to fail in their application. Thus Crookes proposed to recognize this condition of a high vacuum, where the molecules act as individuals, as a fourth state of matter. This again throws a side light on the question of the temperature of the cathode ray tube, or the mercury arc in a vacuum. At these very high vacua we may say that we cannot speak of a temperature at all, and heat energy, as the resultant mechanical energy of molecular motion, ceases to exist with the separation of the molecules to such distances that their resultant effect vanishes when compared with their individual actions. When, however, the kinetic molecular energy ceases to be heat energy, the second law of thermodynamics, which is the application of the law of probability, also ceases.

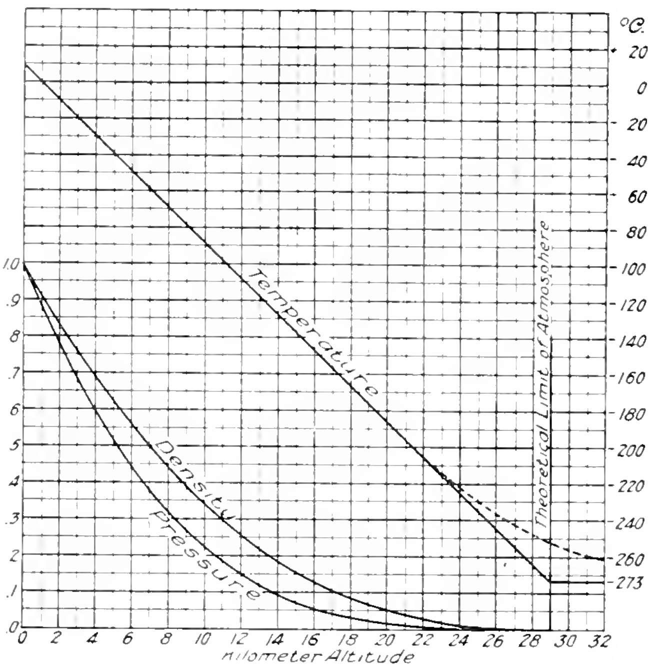

Fig. 1. Curves Showing Theoretical Conditions for Equilibrium of Temperature, Air Pressure, and Air Density, Assuming a Surface Temperature of 10° C.

Spontaneously, heat energy flows from a higher to a lower temperature, until equality of temperature is reached, and most methods of temperature measurements are based on this law. However, even this law is correct only within certain limitations. For instance, in the atmosphere of our earth, where there is continuous interchange of heat energy and the air is never at rest, nevertheless no equalization of temperature occurs, and there is no tendency to a condition of equilibrium at constant and uniform temperature—the condition of equilibrium is a definite and very decided decrease of temperature with increase of altitude. If we assume that no heat energy is supplied to or withdrawn from our atmosphere, and that the atmosphere is very thoroughly mixed so as to reach equilibrium condition, then (if for a moment we leave out of consideration the effect of condensation of moisture) the equilibrium condition would be a uniform decrease of temperature with increasing altitude, down to the absolute zero of temperature at an altitude of about 29 km. (about 18 miles). As function of the altitude, the theoretical equilibrium condition of temperature, air pressure and air density are shown in Fig. 1 assuming 10 deg. C. as surface temperature.* The reason for this is obvious. In the equalization of temperature, whether by the molecules in bulk, in air currents, or by the motion of individual molecules in heat conduction, any upward motion of a molecule is accompanied by a retardation due to the attraction of the earth, and thereby a decrease of kinetic molecular energy, i.e., of temperature. Any downward motion is accompanied by an acceleration by gravity, and consequently by an increase of kinetic molecular energy and therefore of temperature, and equality of temperature throughout the entire atmosphere is thus impossible with freely moving molecules: the theoretical con-

*See derivation of these curves in appendix.

dition of equilibrium is the temperature distribution with the altitude, in accordance with the adiabatic law.

In accordance with this theoretical law of atmospheric equilibrium, the atmosphere would have a finite limit at about 29,000 meters, at which limit air pressure, density and temperature fall to zero. We know, however, that an appreciable atmosphere extends very far beyond these limits, and for the upper regions of the atmosphere, this theoretical law of equilibrium thus fails. However, this equilibrium condition is based on thermodynamic relations, i.e., is that corresponding to the average velocity of the air molecules. The molecules which have a higher velocity than the average corresponding to the temperature are capable of reaching up to correspondingly higher altitudes—beyond those that would limit the extent of the atmosphere if all its molecules had the same average velocity. Thus even in our own atmosphere, and without going beyond it into cosmic space, the law of gravitation is doing the work of Maxwell's demons in separating the faster and the slower molecules, and collecting the former in the higher regions of the atmosphere. Thus the second law of thermodynamics does not apply to the atmosphere of the earth, since kinetic molecular energy is transferred from the regions of lower molecular energy to regions of higher energy; that is, heat energy flows from lower to higher temperature, or rather flows against the thermodynamic temperature equilibrium. Furthermore, this phenomenon is not beyond the limits of heat energy—that is, in the range where the molecules act as separate masses—and their kinetic energy thus is not heat energy but mechanical energy. In the present case, however, the phenomenon applies to the resultant kinetic molecular energy, that is, to the temperature. The average kinetic energy, and thus the temperature of the upper regions of the atmosphere, must be higher than that which corresponds to the theoretical thermodynamic equilibrium.

Thus we are led to the conclusion that the second law of thermodynamics is not a universal law of nature, but applies only within the limited range of thermodynamic engines from which it has been derived. It does not apply to the universe as a whole; and the conclusions derived from it, that the universe must finally come to a standstill, are not justified.

APPENDIX

A. *Critical Velocity of the Escape of Molecules from the Attraction of the Earth, into Cosmic Space.*

Let:

$g = 9.81$ meter sec. = acceleration of gravity at surface of earth.

$r = 6.37 \times 10^6$ meters = radius of earth.

At an elevation x above the surface of the earth, the gravitational acceleration, which is inversely proportional to the square of the distance from the center of the earth, then is:

$$\frac{d^2x}{dt^2} = -\frac{gr^2}{(r+x)^2} \tag{1}$$

this gives:

$$\frac{d}{dt}\left(\frac{dx}{dt}\right)^2 = -\frac{2gr^2}{(r+x)^2}\frac{dx}{dt}$$

and is integrated by:

$$v^2 = \left(\frac{dx}{dt}\right)^2 = \frac{2gr^2}{r+x} + c \tag{2}$$

where c is the integration constant, and v the velocity of the molecule at the elevation x.

Let:

v_0 = initial upward velocity of the molecule at the surface of the earth, or for $x = 0$. Substituting this into (2) gives the integration constant:

$$v_0^2 = 2gr + c$$

$$c = v_0^2 - 2gr$$

and, substituting in (2):

$$v^2 = v_0^2 - 2gr\left(1 - \frac{r}{r+x}\right) \tag{3}$$

The critical velocity of escape into the universe is then given by the condition that v becomes zero for $x = \infty$. This, substituted in (3), gives:

$$v_0^2 = 2gr$$

$$v_0 = \sqrt{2gr} \tag{4}$$

or, substituting the numerical values, approximately:

$$v_0 = 11{,}000 \text{ m sec.}$$

B. *Thermodynamic Equilibrium of the Atmosphere*

The general thermodynamic gas equation is, with sufficient approximation for the present purpose:

$$pV = \frac{r_0 T}{M} = RT \tag{5}$$

where:

p = pressure,

V = volume per unit weight,

T = absolute temperature,
M = molecular weight, approximately 29 for air, and
r_0 = a constant, = 848

and:

$$R = \frac{r_0}{M} = 29.$$

The adiabatic relations between pressure and volume are:

$$pV^a = p_0 V_0^a \tag{6}$$

where:

$a = 1.4$ for air, with sufficient approximation.

If then:

w = weight per unit volume, the pressure distribution in the atmosphere is given by:

$$dp = -w\,dx \tag{7}$$

where:

x = height above the surface of the earth.

It is:

$$w = \frac{1}{V} = \text{weight per unit volume} \tag{8}$$

and since by (6):

$$\frac{V_0}{V} = \left(\frac{p}{p_0}\right)^{\frac{1}{a}} \tag{9}$$

it is:

$$w = \frac{1}{V_0}\left(\frac{p}{p_0}\right)^{\frac{1}{a}} \tag{10}$$

substituting (10) in (7):

$$dp = -\frac{1}{V_0}\left(\frac{p}{p_0}\right)^{\frac{1}{a}} dx \tag{11}$$

or:

$$p^{-\frac{1}{a}}\,dp = -\frac{1}{V_0} p_0^{-\frac{1}{a}} dx$$

this is integrated by:

$$\frac{p_0^{1-\frac{1}{a}} - p^{1-\frac{1}{a}}}{1-\frac{1}{a}} = \frac{1}{V_0} p_0^{-\frac{1}{a}} x$$

or:

$$\left(\frac{p}{p_0}\right)^{1-\frac{1}{a}} = 1 - \frac{1-\frac{1}{a}}{p_0 V_0} x \tag{12}$$

or by (5):

$$\left(\frac{p}{p_0}\right)^{1-\frac{1}{a}} = 1 - \frac{1-\frac{1}{a}}{RT_0} x \tag{13}$$

where the values T_0, $p_0 V_0$ are those corresponding to the surface of the earth.

From (13) follows:

$$\frac{p}{p_0} = \left[1 - \frac{1-\frac{1}{a}}{RT_0} x\right]^{\frac{1}{c}} \tag{14}$$

where:

$$c = 1 - \frac{1}{a} = 0.285$$

From (6) and (5) follows:

$$\frac{v_0}{v} = \frac{\delta}{\delta_0} = \left(\frac{p}{p_0}\right)^{\frac{1}{a}} \tag{15}$$

where δ = air density

and:

$$\frac{T}{T_0} = \left(\frac{p}{p_0}\right)^c \tag{16}$$

hence:

$$\left.\begin{aligned}
\frac{p}{p_0} &= \left[1 - \frac{1-\frac{1}{a}}{RT_0} x\right]^{\frac{1}{c}} = \left[1 - \frac{x}{29{,}000}\right]^{3.5} \\
\frac{\delta}{\delta_0} &= \left[1 - \frac{1-\frac{1}{a}}{RT_0} x\right]^{\frac{1}{ac}} = \left[1 - \frac{x}{29{,}000}\right]^{2.5} \\
\frac{T}{T_0} &= \left[1 - \frac{1-\frac{1}{a}}{RT_0} x\right] = \left[1 - \frac{x}{29{,}000}\right]
\end{aligned}\right\} \tag{17}$$

where the average surface temperature of the earth is assumed as 10 deg. C., or $T_0 = 283$.

The values (17) are plotted in Fig. 1.

CENTRIFUGAL COMPRESSORS

PART IV

BY LOUIS C. LOEWENSTEIN

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By way of illustrating the application of the formulæ and curves published in the first instalment (March REVIEW), the author works out in this issue a few problems typical of those that occasionally present themselves in the commercial operation of centrifugal compressors. The performance of a given compressor, as regards range in capacity and pressure and the power required, when operated under conditions not quite those for which it was designed may be readily determined.—EDITOR.

Rating of Centrifugal Compressors

Table II gives the standard sizes of single- and multi-stage centrifugal compressors. The single-stage units are direct connected to either alternating or direct current motors or steam turbines. The multi-stage units of large size are direct connected to Curtis steam turbines, and some of the smaller units to alternating current motors.

With the aid of Table II and the formulæ given it is possible to ascertain the range of capacities and pressures and also the power required when any of these units are to be used for conditions or speeds not quite standard, or when they are used for compressing gas instead of air. The rating of each unit is given in cubic feet of free air per minute at sea level (14.7 lbs. per sq. in. abs.). Several examples will now be given to illustrate the application of the formulæ and curves previously mentioned.

Power Required

What is the power required to adiabatically compress 20000 cu. ft. of air from atmosphere to 30 lbs. per sq. in. pressure when the efficiency of the compressor is 75 per cent.?

Apply formula 12*a* for the theoretical power.

$$P = 0.2620\, Qp \quad \ldots \quad 12a$$

The mean effective pressure rise p is obtained from the curve in Fig. 3. For 30 lbs. discharge pressure the mean effective pressure is 19.25 lbs. per sq. in. (When discharge pressures of 3 lbs. or less are used no correction is necessary for mean effective pressure; hence for single stage compressors let p equal actual pressure rise.)

Q is the quantity in cu. ft. per sec., hence $Q = \frac{20000}{60}$, or the theoretical horse power required is

$$P = 0.2620 \times \frac{20000}{60} \times 19.25 = 1685.$$

This can also be obtained from the curve in Fig. 4. The theoretical power required to compress 100 cu. ft. of air to 30 lbs. pressure is 8.4 h.p. To compress 20000 cu. ft. of air we require $200 \times 8.4 = 1680$ h.p. If the efficiency of the compressor is 75 per cent., the actual power required is

$$\frac{1685}{0.75} = 2250 \text{ h.p.}$$

Equivalent Suction Pressure

What suction can be obtained by a standard compressor rated 2500 cu. ft. of air per minute against 2 lbs. per sq. in. pressure?

From formula 17 we find that if the wheel speed u_a remains constant the value $\frac{p_2}{p_1}$ is constant, as none of the other values of the formula are variable if the initial temperature remains constant. Therefore the ratio of the absolute final pressure to the absolute initial pressure will remain constant for any compressor if the speed is kept constant.

For the above example the initial absolute pressure is 14.7 lbs. per sq. in. and the final absolute pressure is 16.7 lbs. per sq. in. The ratio $\frac{16.7}{14.7}$ must remain constant, and hence must equal the ratio of final pressure divided by the initial pressure when the compressor is operating against suction.

This can be expressed by $\frac{14.7}{p_1}$

$$\text{Hence } \frac{16.7}{14.7} = \frac{14.7}{p_1} \text{ or}$$

$$p_1 = \frac{14.7 \times 14.7}{16.7} = 12.94 \text{ lb. per sq. in.}$$

Therefore this compressor will compress from 12.94 lbs. per sq. in. to 14.7 lbs. per sq. in., or produce 1.76 lbs. per sq. in. suction.

Equivalent Rating at Altitudes Above Sea Level

What pressure can be obtained by a standard compressor rated 3800 cu. ft. of air per min.

against a pressure of 3.25 lbs. per sq. in. when installed 3000 ft. above sea level?

From Fig. 7 we find that the barometer at 3000 ft. altitude is 13.16 lbs. per sq. in. Hence as before $\frac{17.95}{14.7}$ is the ratio of $\frac{p_2}{p_1}$ for standard conditions. This ratio being constant, it must equal $\frac{p_2}{13.16}$ for the compressor at 3000 ft. altitude.

Therefore

$$p_2 = \frac{13.16 \times 17.95}{14.7} = 16.07 \text{ lbs. per sq. in. abs.}$$

or the compressor will deliver 3800 cu. ft. of air per min. against 2.91 lbs. per sq. in. at an altitude of 3000 ft.

Equivalent Pressure when Compressing Gas

What pressure can be obtained when compressing water gas with a standard unit rated 25000 cu. ft. of air per minute against a pressure of 15 lbs. per sq. in.; and what power will be required if it requires 2000 h.p. to compress the air to 15 lbs. pressure?

From Table I we find the following analysis by volume of water gas, and multiplying by the densities we obtain the density of water gas.

	Volume.		Density.		
CO_2	.04	×	.1168	=	.00467
N_2	.04	×	.0742	=	.00297
CO	.25	×	.0740	=	.01850
H_2	.35	×	.0053	=	.00186
CH_4	.18	×	.0426	=	.00767
C_3H_6	.14	×	.1143	=	.01600
Density of water gas				=	.05167

If the specific gravity of air having 0.0764 lbs. per cu. ft. density is taken as unity, the specific gravity of water gas is $\frac{0.05167}{0.0764} = 0.677$.

In equation (10) we find that $\frac{p}{\rho}$ remains constant for any compressor if the wheel speed u_a remains constant. The value p stands for the mean effective pressure rise. (For single stage compressors of 3 lbs. pressure and under, p can be taken as the actual pressure rise.) Referring to the curve in Fig. 3, the mean effective pressure for the standard condition of 15 lbs. per sq. in. discharge pressure is 11.44 lbs. per sq. in. Therefore $\frac{p}{\rho}$ for standard conditions (air) is $\frac{11.44}{0.0764}$. As this ratio is constant for any compressor as long as the speed remains constant, it must

TABLE II

STANDARD SIZES OF CENTRIFUGAL COMPRESSORS, SINGLE- AND MULTI-STAGE

Capacity in cu. ft. of air per min.	Normal Pressure in lb. per sq. in. gauge	Normal No. of rev. per min.	Maximum pressure in lb. per sq. in. gauge	Maximum No. of rev. per min.	Nominal h.p. rating of driver	No. of stages	Dia. of impeller In.
800	1	3450	1.25	3850	5	1	20
1600	1	3450	1.25	3850	10	1	20
3200	1	3450	1.25	3850	20	1	20
4500	1	3450	1.25	3850	30	1	20
7200	1	3450	1.25	3850	50	1	20
10200	1	3450	1.25	3850	75	1	20
750	2	3450	2.5	3850	10	1	27
1600	2	3450	2.5	3850	20	1	27
2500	2	3450	2.5	3850	30	1	27
4200	2	3450	2.5	3850	50	1	27
6200	2	3450	2.5	3850	75	1	27
1250	3.25	3450	4	3800	30	1	34
2400	3.25	3450	4	3800	50	1	34
3800	3.25	3450	4	3800	75	1	34
9000	3.25	3450	4	3800	175	1	34
18000	3.25	3450	4	3800	350	1	34
4500	15	3450	18	3800	340	6	27
9000	15	3750	19	4000	750	3	36
16000	15	3200	21	4000	1300	3	37.5
25000	15	3000	30	3800	2000 to 3400	3	45.5
40000	15	2500	30	3200	2900 to 5200	3	54

equal $\frac{p}{\rho}$ for water gas. Hence

$$\frac{11.44}{0.0764}=\frac{p}{0.05167}$$

or

$$p=\frac{11.44\times.05167}{0.764}=7.74 \text{ lbs. per sq. in.}$$

If the mean effective pressure for water gas is 7.74 lbs. per sq. in. the final or discharge pressure is (from Fig. 3) 9.3 lbs. per sq. in. Therefore a compressor which delivers 25000 cu. ft. of air against 15 lbs. per sq. in. pressure will deliver 25000 cu. ft. of water gas against 9.3 lbs. per sq. in. pressure.

The power required when compressing this water gas is, of course, less than that required to compress the air. The theoretical power required to compress 25000 cu. ft. of air to 15 lbs. per sq. in. pressure can be found from the curve in Fig. 4, or from equation 12*a*. From the curve we find it takes 5 h.p. to compress 100 cu. ft. of air per minute to 15 lbs. pressure, hence 250×5, or 1250 h.p. to compress 25000 cu. ft. of air per minute to this pressure. Using equation (12*a*), Q is $\frac{25000}{60}$ cu. ft. per min. and p (the mean effective pressure) is 11.44 lbs. per sq. in.,

Hence, $P=0.2620\times\frac{25000}{60}\times11.44=1249$ h.p.

If actually 2000 h.p. is required, then the efficiency of this compressor is $\frac{1249}{2000}$ or 62.5 per cent. The theoretical power necessary to compress 25000 cu. ft. water gas per minute against 9.3 lbs. per sq. in. pressure is also found from equation (12*a*). Q remains the same, $\frac{25000}{60}$ cu. ft. per sec.; while p (the mean effective pressure) for the water gas is 7.74 lbs. per sq. in.

Hence, $P=0.2620\times\frac{25000}{60}\times7.74=845$ h.p.

The compressor will have the same efficiency as before, and therefore the actual horse power required to compress 25000 cu. ft. of water gas per min. against a final pressure of 9.3 lbs. per sq. in. is $\frac{845}{0.625}=1351$ h.p.

The actual horse power required to compress the water gas could have been found in a much shorter way, but it might not perhaps have been as clear. We might have said, if it takes 2000 h.p. to compress the air to a mean effective pressure of 11.44 lbs. per sq. in., the power required to compress the same volume of water gas to a mean effective pressure of 7.74 lbs. per sq. in. is

$$2000\times\frac{7.74}{11.44}=1351 \text{ h.p.};$$

that is, in equation (12*a*) all terms are constant except the value of p. Hence the power (theoretical or actual) is directly proportional to the value of p.

For problems dealing with low pressures, as in single stage compressor work, the value of p can be taken as the actual pressure rise instead of the mean effective pressure. A reference to the curve in Fig. 3 shows that the correction for pressures of 3 lbs. per sq. in. and under is negligible.

Equivalent Rating at Other Speeds

A standard centrifugal compressor rated 4500 cu. ft. of air per minute against 15 lbs. per sq. in. pressure is to be speeded up from 3450 r.p.m. to 4000 r.p.m. What increase of pressure and increase of quantity results?

Equation 10, $\frac{p}{\rho}=\eta\frac{u_a^2}{g}$ can be used for this problem. As the initial density is constant and the efficiency η is constant, the mean effective pressures vary directly with the square of the wheel speed (u_a^2), or with the square of the number of revolutions.

From the curve in Fig. 3 for 15 lbs. per sq. in. discharge pressure, the mean effective pressure p is 11.44 lbs. per sq. in. Hence the mean effective pressure at the increased speed is

$$p=\frac{4000^2}{3450^2}\times11.44\times15.38 \text{ lbs. per sq in.}$$

The actual discharge pressure corresponding to 15.38 lbs. per sq. in. mean effective pressure is found from Fig. 3 to be 22.05 lbs. per sq. in.

Again when the pressures are low the final discharge pressures are directly proportional to the square of the speeds. The increase of volume delivered is directly proportional to the increase of speed, as was explained after equation 18. As the speed was increased from 3450 r.p.m. to 4000 r.p.m. and as $\frac{Q}{r.p.m.}$ is a constant, the increased quantity of air delivered in this case is

$$Q=\frac{4000}{3450}\times4500=5220 \text{ cu. ft. per min.}$$

General Problem

Enough examples have been given to illustrate the usual corrections necessary to obtain the rating of any standard centrifugal compressor when operating under conditions not quite standard. In conclusion we might recapitulate by taking a general problem, as follows:

What standard compressor can be used to exhaust 18500 cu. ft. of anthracite producer gas per minute against a suction of 7 lbs. per sq. in? The compressor is to be installed 2000 ft. above sea level. What h.p. is required?

Referring to the curve in Fig. 7, the barometric pressure at an altitude of 2000 ft. is 13.56 lbs. per sq. in. absolute. The compressor, in order to exhaust against a suction of 7 lbs. per sq. in., must draw the gas from 6.56 lbs. per sq. in. absolute and discharge it at 13.56 lbs. per sq. in. absolute. Changing this to sea level rating and to the equivalent discharge pressure (if compressor worked initially from atmosphere, 14.7 lbs. per sq. in.) by means of equation 17 (which says the ratio of the absolute final pressure to the absolute initial pressure is always constant if the speed of the compressor remains constant and if the initial temperature is constant), we have

$$\frac{p_2}{p_1}=\frac{13.56}{6.56}=\frac{x}{14.7}=\text{ constant},$$

in which x is the final pressure when the initial pressure of the compressor is atmosphere

Then

$$x=\frac{14.7\times 13.56}{6.56}=30.4 \text{ lbs. per sq. in. abs.}$$

That is, a compressor capable of exhausting gas from 6.56 lbs. per sq. in. absolute to 13.56 lbs. per sq. in. absolute can compress the same gas from 14.7 lbs. per sq. in. absolute to 30.4 lbs. per sq. in. absolute (or 15.7 lbs. per sq. in. gauge).

Referring to Table 1, the density of anthracite producer gas is 0.065 lbs. per cu. ft. Equation 10 can be used in changing the rating of this compressor from gas at 0.065 density to air at 0.764 density. (p remains constant if wheel speed remains constant.) The mean effective pressure for compressing gas to 15.7 lbs. per sq. in. pressure is (see Fig. 3) 11.9 lbs. per sq. in. Hence

$$\frac{p}{\rho}=\frac{11.9}{0.065}=\frac{x}{0.0764}=\text{constant},$$

in which x is the equivalent mean effective pressure for air at 0.0764 lbs. per cu. ft. density.

or

$$x=\frac{11.9\times 0.0764}{0.065}=14 \text{ lbs. per sq. in.}$$

Referring to Fig. 3, for 14 lbs. per sq. in. mean effective pressure, we find 19.4 lbs. per sq. in. discharge pressure. That is, a compressor compressing gas of 0.065 lbs. per cu. ft. density from atmosphere to 15.7 lbs. per sq. in. pressure will compress air at 0.0764 density from atmosphere to 19.4 lbs. per sq. in. pressure.

The nearest standard compressor is the 16000 cu. ft. per minute 15 lb. unit, speeded up. The normal speed of this unit is 3200 r.p.m. To obtain the speed with which this unit must run to deliver 19.4 lbs. per sq. in. pressure we again apply equation 10. The mean effective pressure for 19.4 lbs. per sq. in. is 14 lbs. per sq. in., and the mean effective pressure for the standard unit discharging at 15 lbs. per sq. in. is 11.44 lbs. per sq. in.

Hence

$$\frac{14}{11.44}=\frac{x^2}{3200^2}$$

in which x is the speed in revs. per min. necessary to furnish 14 lbs. per sq. in. mean effective pressure: or

$$x=\sqrt{\frac{3200^2\times 14}{11.44}}=3540 \text{ r.p.m.}$$

In speeding up the compressor the quantity also increases. The load coefficient, $\frac{Q}{r.p.m.}$ remains constant; therefore, if the compressor delivers 16000 cu. ft. of air when running at 3200 r.p.m., it will deliver x cu. ft. of air per min. when running at 3530 r.p.m.

$$\frac{Q}{r.p.m.}=\frac{16000}{3200}=\frac{x}{3540}=\text{constant},$$

or

$$x=\frac{16000\times 3540}{3200}=17700 \text{ cu. ft. per min.}$$

Therefore this standard compressor, when speeded up to 3540 r.p.m., will compress 17700 cu. ft. of air per minute from atmosphere to 19.4 lbs. per sq. in. pressure, which is equivalent to exhausting 17700 cu. ft. of anthracite producer gas per minute against a suction of 7 lbs. per sq. in. at 2000 ft. altitude.

If 18500 cu. ft. per minute must be handled, the unit can be speeded up somewhat, but the resulting suction will be a little over 7 lbs. per sq. in.; or if just 7 lbs. suction must be maintained, then only 17700 cu. ft. of gas can be exhausted.

In other words, a standard centrifugal compressor rated 16000 cu. ft. of air per minute against 15 lbs. per sq. in. running at

3200 r.p.m., will exhaust 17700 cu. ft. of anthracite producer gas per minute against a suction of 7 lbs. per sq. in. at 2000 ft. altitude if the unit is speeded up to 3540 r.p.m.

The horse power required can be derived from equation 12*a*, which, for the unit under standard conditions, is 1300. The theoretical power for standard conditions is (equation 12*a*):

$$P = 0.2620 \times \frac{16000}{60} \times 11.44 = 800 \text{ h.p.}$$

The efficiency therefore is

$$\eta = \frac{800}{1300} = 0.615$$

Assuming no change in efficiency at the increased speed the power required by the compressor when exhausting 17700 cu. ft. of gas against a suction of 7 lbs. per sq. in. at 2000 ft. altitude (equivalent to compressing this gas from atmosphere to 15.7 lbs. per sq. in. gauge) is

$$P = 0.2620 \times \frac{17700}{60} \times p \times \frac{1}{\eta}$$

The mean effective pressure for 15.7 lbs. per sq. in. is 11.9 lbs. per sq. in., and η equals 0.615; hence

$$P = 0.2620 \times \frac{17700}{60} \times 11.9 \times \frac{1}{0.615} = 1495 \text{ h.p.}$$

Hence 1495 h.p. is required to exhaust 17700 cu. ft. of anthracite producer gas against a suction of 7 lbs. per sq. in. at an altitude of 2000 ft.

REVIEW OF RECENT DEVELOPMENTS RELATED TO PROTECTIVE APPARATUS

Part II

By Prof. E. E. F. Creighton

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In this, the second half of his article, the author discusses the application of the direct current aluminum arrester to the protection of traction motors; first, when connected directly to the trolley, and second, when used with a series gap of the aluminum type. Changes in the magnetic type of blow-out arrester, necessitated by the increase in potential from 600 to 1200 volts, are enumerated and a few remarks included on the selection of arresters for various conditions of service. The results of some investigations on internal resonance of transformer coils are given, which show for a certainty that this phenomenon is responsible for many breakdowns that operating engineers have been prone to contribute to defects in material or design. The article is concluded with a description of a registering device which may be made to record in type practically every switching or other operation performed in the power station; or, which may be applied to the study of lightning phenomena along transmission lines and similar transients.—Editor.

Protection of Railway Circuits

In the protection of railway apparatus new problems have arisen due to the natural growth and progress in this line of activity. In railway practice direct current potentials were raised successively from 600 volts to 1200 volts, then to 1800 volts, and more recently to 2400 volts. In the matter of size and importance of the installation we have passed from the small power installation of a single car to the large power and more important service on electric locomotives. In many places the small single truck cars, and even the double truck cars, have received little consideration in regard to the protection against lightning. Armature failures are due to a number of different causes, and a fixed force for repairing motors simply adds on the extra duty from failures by lightning. There are, however, localities where lightning causes such great losses both in apparatus and service that it is found better from all standpoints to discontinue the power during storms and pull down the trolley poles. Such a condition exists in many places in Colorado. In order to try out the direct current aluminum arrester the place where the conditions were of the worst known was chosen. On the Denver City Tramway practically all types of lightning arresters have been tried without avail, and the practice of discontinuing service during the severe parts of the storms has been followed. In spite of these interruptions, however, more than a hundred armatures were lost during a season due to lightning. The direct current aluminum arrester was applied to these lines and has now passed through two successive summers with a record of only one armature lost by lightning each year. On one occasion a direct bolt of lightning struck within a half block of a car but the motors on the car were not damaged.

In making this installation every possible precaution was taken to avoid induction between bus wires and the controlling wires of the motor, and also to keep the length of the circuit through the lightning arrester as short as possible. So far as the protection is concerned, the lightning arresters have given perfect satisfaction, and up to the present their maintenance has not been high. This factor of maintenance is the only one that stands in the way of the direct current aluminum arrester, and where conditions are sufficiently severe to warrant the maintenance charge the arresters are fully applicable.

The cost of maintenance of the direct current aluminum arrester is not yet determined. It is understood that in the application of these arresters, so far no gap in series has been used. There is consequently a small but continuous wear on the plates, due to the 1/1000 ampere current which normally leaks through the cells. In the past, cells have operated continuously for one to three years without a renewal of the plates. During this time improvements have been made in the cells and there has not as yet been sufficient time to determine the life of an aluminum plate. In general, the plates do not wear out, but simply become clogged and cause the electrolyte to boil out. Sometimes they can be recovered by simply washing them; while in other cases it is necessary either to reform the films or to renew the plates.

In order to take advantage of the excellent protective qualities of this aluminum arrester a series gap of the vacuum type is being tried out, the spark potential of which is only a few volts above the trolley potential. In order to keep the films in good condition, an automatic charging device is placed in parallel with the gap. This device works on the principle of inertia and closes an auxiliary gap to the arrester each time the car starts and stops. This means that the arrester gets a charge about every block. From experience already obtained with the vacuum gaps it is believed that by their introduction the protective value will not be appreciably decreased. This auxiliary apparatus to the aluminum cell adds to its cost and becomes a factor in the choice of arresters.

Without a series gap the direct current aluminum arrester gives a great degree of protection against flash-overs on commutators. This has been proved by the application of the aluminum arrester to rotary converters. Systems where the converters have flashed over frequently have been enabled to suppress these troubles by the direct application of the direct current aluminum cells.

With the increase of potential from 600 volts to 1200 volts it was necessary to reconsider the elements of design in the magnetic blow-out type of arrester. This resulted in improvements of value. By substituting a permanent magnet for the electromagnet all possibility of shunting out the magnetism by a spark across the coil of the electromagnet has been avoided. By changing the form of the arc chute to one long and narrow, the dynamic arc is squeezed out into a flat form, and by being brought in contact with the cool porcelain walls is more easily extinguished. In addition to this, however, an arc grid consisting of insulated metal plates is laid across the top of the arc chute in such a way as to absorb all the flame of the arc, the gases emerging on the upper side in a non-conductive condition. This feature allows the active part of the arrester to be entirely enclosed. The resistance rod is placed externally in series and becomes the tell-tale factor for the inspector, showing the condition of the arrester. This construction is particularly adapted to use along trolley lines where the condition of the rod can be observed from a moving trolley car. The arrester is in operating condition or not according to whether the resistance rod is complete or not. This arrester extends the use of the magnetic blow-out type of arrester to the highest voltage in practice.

In the choice of arresters, account must be taken of the severity of lightning in the districts under consideration and the nature of the apparatus to be protected. Briefly put, the following factors are given to guide in the choice of arresters. For the protection of station apparatus, locomotives, and cars in districts where lightning is particularly severe, it takes very little engineering consideration to show that the cost of maintenance of the direct current aluminum arrester is fully warranted. In districts where storms are less severe, it will usually be found that the use of the aluminum arrester is still justified for stations and electric locomotives. It may, however, be a question whether the gap type of arrester will not give a sufficiently high degree of protection to warrant their use in protecting against occasional troubles. In every case, line arresters of the gap type are to be recommended, and never aluminum arresters. Where aluminum arresters are used on the car, an engineer is justified in using a less number of gap type arresters along the line. In localities where lightning is only occasional, the gap type of arrester will continue to be the one most adaptable.

As the matter stands at present the gap arrester seems to give satisfaction for the majority of lines. As service becomes more and more important, however, this problem of protection is going to need reconsideration.

For the protection of signals and meters on 600 volt direct current work the aluminum arrester has proved efficient, although again we come to frequent cases where the nature of the signals and the cost of repair against lightning is such that a gap type of arrester suffices. If the signals are of importance such that by their failure they jeopardize human life, then naturally the highest degree of protection, regardless of the maintenance, is justified.

The subject of protection of railway apparatus has been covered in more detail in a paper written by Messrs. F. R. Shavor, R. P. Clark, and the writer for the Schenectady meeting of the A.I.E.E., May, 1912.

Internal Resonance of Coils in Transformers and Other Apparatus

Cases in practice have occurred where lightning arresters have failed to give protection. No doubt in some cases in the past these failures to protect could be attributed to lack of discharge rate in the lightning arrester. However, there are many cases where it has been recognized that the lightning

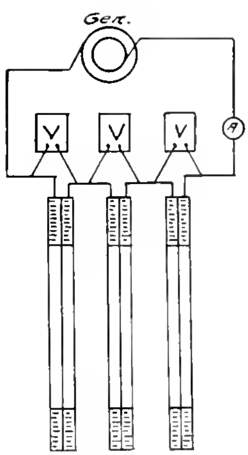


Fig. 11. Circuit Connections of High Frequency Generator as Used for Determining the Resonance of Transformer Coils

arrester was in no way to blame and had performed its full functions. These cases, although exceedingly rare when compared to the tremendous number of strokes effectively discharged by lightning arresters, are nevertheless of sufficient number to warrant careful investigations. The results of these investigations have shown without a doubt that occasional internal surges occur on transformers and generators which damage

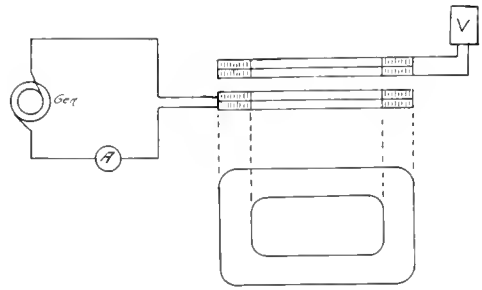
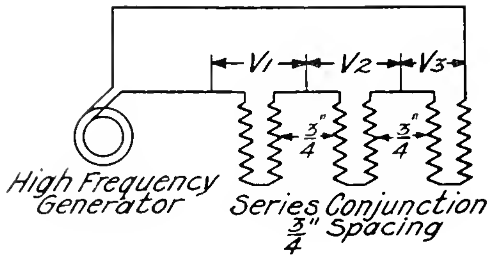


Fig 12. Two Coil Arrangement for Determining the Resonance of Transformer Coils

the insulation, unaccompanied by simultaneous dangerous rises in potential at the terminals of the apparatus. Such conditions occur most usually from an accidental arcing ground.

The dangers from internal resonance have been considered by many engineers as of only theoretical moment—that failures of insulation due really to inherent weakness are liable to be explained by erroneously attributing them to resonance. This is far from accurate. Although internal resonance in transformers and generators is comparatively rare on account of the small chance there is of the frequency of a surge in general being equal to the natural frequency of a coil in the apparatus, still, marked effects of this kind have been noted and reproduced in practice.

An extreme case of this kind occurred a few years ago on a bank of six transformers of over 2,000 kw. capacity, operating two in parallel on a three-phase circuit and transforming from 11,000 volts to 110 volts. Previous to the appearance of trouble three of the transformers had operated entirely satisfactorily for a year and it was only by the addition of a second bank of these transformers that the dangerous resonant condition was reached. These six transformers broke down nine times, almost as rapidly as they could be repaired. In the midst of this trouble a lightning arrester was placed on the 11,000 volt side and the gap setting from line to ground was set for about 11,000 volts, the delta potential of the circuit. A discharge recorder was placed in series so that every abnormal potential, even of harmless value, would cause a discharge of the lightning arrester. At certain times of day when switching took place on



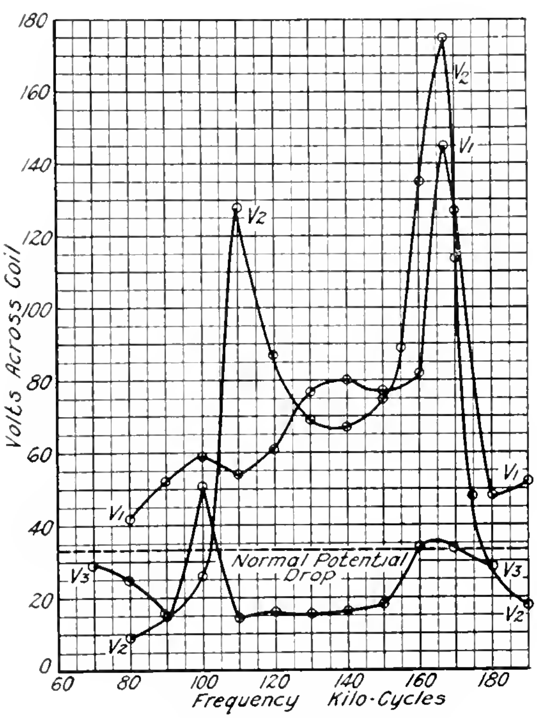


Fig. 13. Curve Showing the Two Peaks of Resonance at Different Frequencies

the system the arrester would discharge. This was an indication of the sensibility of the arrester and of the reliability of the record. When transformers broke down, however, there was not sufficient rise of potential on the primary circuit to cause the arrester to discharge. It simply happened that in this transformer the frequency which came from arcs on the 110 volt side was exactly equal to the natural frequency of the inductance and capacity of the coil. This produced resonance and abnormal potential in the coils, which finally destroyed the insulation. As a proof that the insulation was not weak, tests were made in the coil that had been damaged, and even after sustaining an internal arc such a coil would stand a test of 4000 volts on insulation that had impressed on it under normal conditions only 20 volts. This is in reality a factor of safety of 200. Surely no criticism of weakness can be made.

The foregoing illustration is one of the extremes that has been brought to attention. There are many others where resonance has, no doubt, taken place. In still other cases, other factors, such as come from lightning, have been present and there has been the possibility that these were the ones that caused the damage. Experimental proofs, however, are now abundant, and the contention that resonance is a serious factor and one to be counted with is well grounded.

With the completion of Mr. E. F. Alexananderson's high frequency generators, which give a maximum frequency of 200,000 cycles per second, a careful experimental study of the resonant conditions is made feasible. The results of numerous tests have been given in a paper prepared by Mr. S. Thomson and the writer for the 1912 annual meeting of the Institute. Some typical illustrations taken from this paper will be herewith reviewed.

Every transformer coil has its own natural frequency due to its distributed inductance and capacity. For example, a double backwound coil having a total of 100 turns has (when isolated from other coils) a natural frequency of about 50,000 cycles per second. When such a coil is connected to the high frequency generator directly, it responds to a frequency of about 200,000 cycles. This difference is due to the fact that the coil by itself oscillates as one-quarter wave, whereas a coil close circuited oscillates as a complete wave, the ratio between the two being one to four. Again, when coils are spaced at different distances apart they will respond to different frequencies. The thickness of insulation between turns is also an important factor in determining the natural frequency. If a double backwound coil has its halves gradually separated, little by little the natural frequency of the coil increases, providing the coil is isolated from all other coils. If such a coil, however, is sandwiched between two other coils and its halves are separated the natural frequency remains the same, but the potential of resonance varies. On the other hand, if two double coils are gradually separated, then the frequency of the isolated coil gradually decreases until, when it is entirely separated from its exciting coil, it oscillates at its own natural frequency. This matter will be made clearer by the typical tests herewith given.

Fig. 11 represents a typical circuit of a transformer. Three coils are placed side by side in series and connected to the high frequency generator. There is a hot wire ammeter in series with the generator and an electrostatic voltmeter shunting each coil. Keeping the generator potential constant at 100 volts (i.e. $33\frac{1}{3}$ volts per coil) and varying the frequency, it is found that the voltmeter shows increases and decreases in potential at certain frequencies. Under one condition of test at a frequency of 140,000 cycles, a coil shows a rise in potential to over 2000 volts, whereas the normal distribution of potential is but $33\frac{1}{3}$ volts.

Under a different spacing of the coils, the test shown in Fig. 13 was made. The potentials were not high in this case but the figure is a good illustration of two peaks of resonance which were found almost invariably in the circuits tested.

Fig. 12 represents another type of experimental circuit in which the total number of coils is two, one coil being connected to the generator and the other simply to a voltmeter. Again, the generator potential is kept constant at 100 volts and the frequency varies from 10,000 cycles to 200,000 cycles per second. With a spacing between coils of about 2 in. the voltage in the secondary coil and the current in the pr mary coil rise as the frequency approaches 150,000 cycles. Although the number of turns on the two coils is equal, that is, the ratio is one to one, and with very poor regulation between the coils due to lack of iron and distance between the coils, still, with a potential of 100 volts impressed on the primary, 6000 volts are produced on the secondary. This is clearly the effect of resonance. When the frequency is still further increased the potential and current both drop. When, however, the frequency approaches 170,000 cycles the current and potential again begin to rise. The maximum potential in this case is less than for the lower frequency. This double peak condition was puzzling at first, but seems now to be explained by the different frequencies of the two circuits.

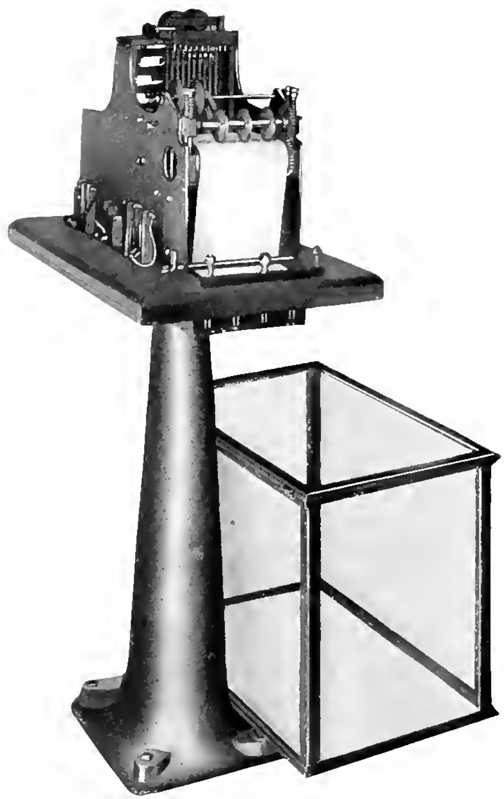


Fig. 14. The Multi-Recorder

4P	6	28	59	1G	2G	3G	4R	5R	6R	7R	8G	9R	10R	11R	12G
4P	6	28	57	1G	2R	3G	4R	5R	6R	7R	8G	9R	10R	11R	12G
4P	6	28	56	1G	2R	3G	4R	5R	6R	7R	8G	9R	10R	11R	12R
4P	6	28	55	1G	2R	3G	4R	5R	6R	7R	8G	9G	10R	11R	12R
4P	6	28	54	1G	2R	3G	4R	5R	6R	7R	8R	9G	10R	11R	12R
4P	6	28	54	1G	2R	3G	4R	5R	6R	7G	8R	9G	10R	11R	12R
4P	6	28	53	1G	2R	3G	4R	5R	6G	7G	8R	9G	10R	11R	12R

Fig. 15. A Record Taken from the Multi-Recorder

Several relations will be stated briefly. The two coils are identical. Each one, isolated from other coils, has a natural frequency of 44,000 cycles; still, when used as shown in Fig. 12, two frequencies of resonance are produced. The first frequency of resonance occurs in the secondary coil, and its reaction on the primary coil causes the current from the generator to rise. The higher peak of resonance is due to the primary coil. Its own inductance is greatly neutralized by its internal capacity, and as a result of this condition the current from the generator rises. This heavier current produces more flux, which threads the secondary coil and produces the rise on the voltmeter of the secondary coil, although there is no resonance in this coil. In the latter case it is purely a matter of increase in flux in the secondary coil.

In each of the cases so far the lowest frequencies of resonance of the circuits are described. Since there is distributed inductance and capacity, an electrical wave is formed which can be split up into multiple waves, and therefore as the frequency is still further increased above 200,000 cycles new resonant peaks will be found, all of which are multiples of the original peaks. In other words, this transformer coil may resonate at many different values of high frequency.

Multi-Recorder

The multi-recorder, Fig. 14, is a new device which contains type wheels moved by the beat of a pendulum clock and other type wheels or pencils which are operated by the opening or closing of any auxiliary circuit. There is a strip of paper which passes between the type wheels and a hammer. Normally, the paper is at rest, but whenever a circuit is closed which moves a type wheel or a pencil, a hammer is thrown up from underneath and prints the position of all the type wheels and the exact time to the second that the switch is operated. The paper is then pulled forward about ¼ of an inch to a new space and remains at rest until some new phenomenon is to be recorded. A typical record taken from this instrument is shown in Fig. 15. The time required at the left indicates the 4th day of the week, P.M. 6:00 o'clock, 28th minute and 59th second. The types recording the movement of an auxiliary switch are numbered consecutively from 1 to 12 inclusive. The letters G and R correspond to green and red, which are ordinarily used as signals on switchboards. Green indicates that the switch is open and red that the switch is closed. These recorders can be made with any convenient number of records on a single sheet. The highest number so far placed on one sheet is 30.

This device has several uses, some of which are described in an Institute paper by Messrs. H. E. Nichols, P. E. Hosegood, and the writer, written for the May, 1912, meeting of the A.I.E.E. Two of the principal uses are as follows:

First: To give to an engineer a reliable record of any interesting thing taking place in his power house, that can be made to open or close a circuit; specifically, the operation of every important switch on the switchboard. Where reliability is important it is essential that the engineer responsible for the proper operation of a system with multiple feeders should know when and how the switching is done. In cases of accidental damage to the insulation of the system it is of great importance to know where the trouble started. In order to record the operation of a switch a mechanical connection is made to some part of the switch mechanism, which opens and closes a small low voltage contact. The movement of this contact causes the multi-recorder to print the time to the second, and simultaneously the positions of all other switches. The device is sufficiently rapid to make four distinct records in one second. In so doing it prints the same number of the second, but the second is split in four parts by the successive movements of the paper.

Second: To assist in the study of lightning phenomena along transmission lines. Up to the present time there has been no adequate way of getting simultaneous records of discharges at different points of the line. The particular device used in engineering work that requires careful study is the overhead ground wire. At the present time all engineers are convinced that the overhead ground wire is a valuable feature, providing it is mechanically strong; but there is no engineer in a position to state how valuable it is, or whether it would not be many times more valuable if installed in a different way or with a greater number of wires. Other uses for this device will suggest themselves to anyone who has transitory operations to record.

SYNCHRONOUS CONDENSERS

By C. T. Mosman

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The rapid increase in the application of induction motors and the use of individual drives has made the question of the independent raising of the power-factor of a system one of great commercial importance. Much has been written on the subject; but the present paper, originally presented before the New England section of the N.E.L.A., adopts a treatment somewhat unique in its strictly practical bearing. The various respects in which low power-factor reacts harmfully on the economy of the system are enumerated. It is explained theoretically how synchronous motors may be used to control the power-factor by adding wattless current (leading or lagging) to the circuit. A table of sines, cosines and tangents is shown, and the author explains how to use it for resolving a current into its components and determining what condenser capacity is required to produce any desired correction. The same ground is covered diagrammatically, and the two methods applied to actual examples. The article concludes with a discussion of the factors affecting the feasibility and expediency of employing this method of power-factor correction.—Editor.

An alternating current flowing in a circuit such as a wire, or the windings of a transformer or of an induction motor, may be resolved into two components: one an energy component in phase with the electromotive force applied to the circuit, the other displaced ninety degrees of phase from that electromotive force and hence representing no consumption of energy and called wattless. This latter component is due to the induction of cables, transformers, induction motors, etc.

The product of the current component in amperes by the impressed electromotive force in volts gives respectively, volt-amperes energy and volt-amperes wattless; or, dividing by 1000, gives kilo-volt-amperes energy (=kilowatts) and kilo-volt-amperes wattless. The combination of both components gives the total kv-a. or apparent load. The ratio of energy component to the total $\left(\text{or } \frac{\text{kw.}}{\text{kv-a. (total)}}\right)$ is called the power-factor.

This may be illustrated diagrammatically by Fig. 1. The electromotive force E is taken as the basis of phase:

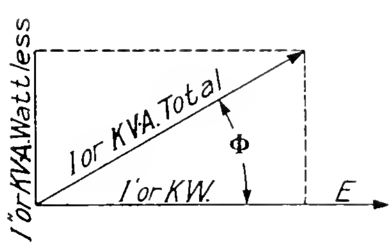

Fig. 1

I' is the energy component of the current;
I'' is the wattless component of the current;
I is the total current;
ϕ is the angle of lag or total current behind the electromotive force. Inspection will show that the cosine of this angle is $\frac{I'}{I}$; this is also the ratio called power-factor. The ratio $\frac{I''}{I}$ is the sine of the angle ϕ and may be called the wattless or inductive factor. In the diagram we may replace I' by kilowatts, I'' and I by kv-a. and cosine ϕ or power-factor $= \frac{\text{kw.}}{\text{kv-a. (total)}}$

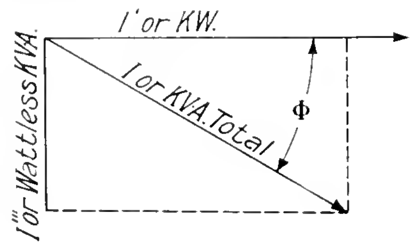

Fig. 2

The power-factor of the current taken by constant potential transformers is high—practically 100 per cent. under normal load conditions; but is very low at no load, as then the magnetizing or wattless component of the current input becomes a large percentage of the total, the energy component representing only the iron and copper losses. The power-factor of an induction motor is relatively low even under load conditions, due to the air-gap in the magnetic circuit which necessitates a large magnetizing current. At light loads the power-factor decreases considerably, being very low at no load. Constant current transformers for the operation of series lighting circuits, including the circuit, have a low power-factor when fully loaded and very low power-factors at light loads due to the method of regulation.

The wattless components so far considered have been lagging, or later in phase position than the electromotive force. Fig. 2 illustrates the case of a leading wattless component and total current, ϕ being now angle of lead instead of lag, and power-factor $= \cos. \phi = \frac{I'}{I}$ as before. If Figs. 1 and 2 are

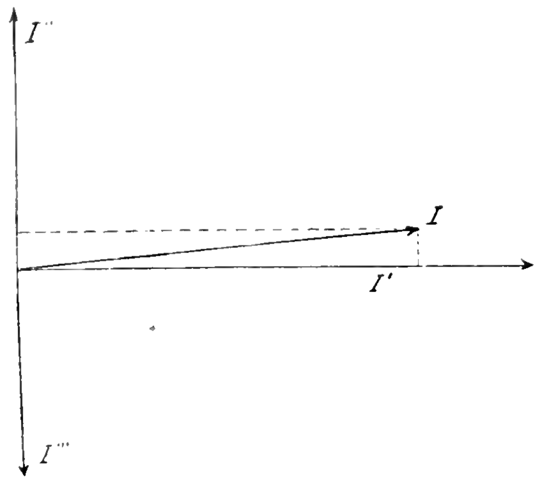

Fig. 3

combined we find that the wattless components leading and lagging are in opposition and tend to mutual elimination. (Fig. 3.) If $I'' = 100$, $I''' = 80$, and $I' = 100$, the resultant wattless component becomes 20 lagging, and the total current $\sqrt{100^2+20^2} = 102$, and the power-factor $\frac{100}{102} = 0.98$; whereas considering the lagging component only the total current would have been $\sqrt{100^2+100^2} = 141$. The power-factor would have been $\frac{100}{141} = 0.71$.

It is evident that adding to a circuit wattless current, which may be lagging or leading at will, results in control of the power-factor. The practical method of doing this is by means of the synchronous condenser. Before describing the synchronous condenser and its application, it is well to note the objectionable effects of lower power-factor on commercial circuits and plants.

The most important cause of low power-factor is the induction motor. The tendency of the times is toward individual drives and small motors, and hence lower power-factors. The tendency should also be toward a careful study of each installation and a proper fitting of each motor to the work to be done, and hence a raising of power-factor due to fewer underloaded motors.

An inspection of Figs. 1 and 2 shows that the low power-factor means large total currents; at 0.80 power-factor the total current for doing a certain work is 25 per cent. larger than would be the case with power-factor 1. The heating of lines, transformers, generators, etc., is related to the square of the total current. The necessary capacity of apparatus to supply a certain amount of energy is inversely proportional to the power-factor.

Lagging currents have an objectionable effect on the regulation of lines, transformers and generators, greatly increasing the drop of voltage with load. An alternating generator of 8 per cent. regulation on a load of power-factor 1.0 will have a regulation of approximately 25 per cent. at 0.75 power-factor lagging. A transformer having a regulation of 2 per cent. on a load of power-factor 1.0 may have a regulation of 4 per cent. to 5 per cent. on a load of power-factor 0.75 lagging. A three-phase line delivering 1000 kw. a distance of five miles over No. 0 wire at a delivery voltage of 6000, will show the following voltage drops at various power-factors:

Power-factor 0.70: drop in per cent. of delivered voltage 16.

Power-factor 0.80: drop in per cent. of delivered voltage 14.

Power-factor 0.90: drop in per cent. of delivered voltage 11.

Power-factor 1.00: drop in per cent. of delivered voltage 7.

Thus the regulation at 0.7 power-factor is 45 per cent. greater or poorer than at power-factor 0.9, and 130 per cent. worse than at power-factor 1.00.

A generator to deliver 1000 kw. at 0.7 power-factor must deliver 1430 kv-a., and hence be nominally of 1430 kw. capacity. This generator will require from 30 per cent. to 50 per cent. more current and 70 per cent. to 120 per cent. more kilowatts excitation (depending on the type of generator), to maintain the bus voltage with 100 kw. load at 0.7 power-factor (i.e., 1430 kv-a.), than for 1430 kv-a. at 1.0 power-factor. This heavy excitation means increased heating in the generator fields; and it is frequently found that this heating, or the limitations of the exciting system, impose a limit on the generator output. The prime-mover driving this generator need be equivalent to only 1000 kw. energy output instead of to 1430 kw. energy output. If the generating units in a station supplying the above load are of 500 kw. capacity at 1.0 power-factor, and the prime movers are sufficiently large to drive the generators at full-rating energy load and overloads, then it will be necessary to operate three units to carry 1430 kv-a., whereas there is only sufficient load for two prime movers, i.e., 1000 kw. If the units are each of 1000 kw. capacity, 1.0 power-factor, then two must operate on energy load sufficient for the economical operation of but one.

It will thus be seen that low power-factor results in: Increased losses in lines and apparatus; poorer regulation in lines and apparatus; wasted capacity in lines and apparatus; wasted capacity in exciting system; a discrepancy between the capacity of generator and its prime mover. It is evident that a reasonable investment solely for the purpose of raising the power-factor of a system is justifiable; and that the nearer the load or source of low power-factor, and hence the farther from the generating station the improvement in power-factor is made, the better, as thereby the greatest gain in regulation and the greatest saving in lines and apparatus are made, since distribution lines, transformers, transmission lines and generators will all be benefited.

Power-factor and efficiency are closely related in the design of an induction motor, and one may be improved at the expense of the other. The power consumer is generally much more interested in high efficiency than high power-factor. The central station may appear to be more interested in power-factor than in efficiency; but as satisfied customers are necessary to success, this is actually not the case, and a wise station management will decide to face the situation by independently raising the power-factor of the system to an economical point.

By varying the excitation of any synchronous machine, generator or motor, which is connected to the same system with another synchronous machine, the phase relation of the terminal voltage and the current taken by the machine may be varied, and consequently the amount of current taken also varied. An under-excited generator or motor will receive excitation from the system by alternating currents, and an over-excited motor or generator will deliver excitation to the system in like manner. In the case of two generators the alternating excitation current which is wattless is leading in the generator receiving it, and lagging in the generator delivering it. If the power-factor of the load is 1.00, the current flowing in each generator is increased by the alternating exciting current. If the power-factor of the load is less than 1.00, the current of one generator may be increased and the other decreased thereby, the desirable condition being when the power-factor of the output of each generator is the same as that of its load. A synchronous motor under-excited receives alternating excitation from the system by means of a wattless current which is lagging with reference to the system; if over-excited, it delivers excitation to the system by means of a wattless leading current. The tendency is always toward an equalization of excitation among synchronous machines by means of wattless alternating currents. The total current input to a synchronous motor will be

TABLE I

Cosine or Power-Factor or Energy Component	Sine or Inductive Factor or Wattless Component	Tangent or Ratio of Wattless to Energy	Approx. Angle	
			Deg.	Min.
1	0	0	0	0
0.99	0.1391	0.1405	8	0
0.98	0.1965	0.2004	11	20
0.97	0.2419	0.2493	14	0
0.96	0.2784	0.2899	16	10
0.95	0.3117	0.3281	18	10
0.94	0.3392	0.3606	19	50
0.93	0.3665	0.3939	21	30
0.92	0.3907	0.4244	23	0
0.91	0.4146	0.4557	24	30
0.90	0.4357	0.4841	25	50
0.89	0.4565	0.5132	27	10
0.88	0.4746	0.5392	28	20
0.87	0.4924	0.5657	29	30
0.86	0.5100	0.5929	30	40
0.85	0.5274	0.6208	31	50
0.84	0.5422	0.6452	32	50
0.83	0.5567	0.6702	33	50
0.82	0.5711	0.6958	34	50
0.81	0.5854	0.7221	35	50
0.80	0.5994	0.7490	36	50
0.79	0.6133	0.7766	37	50
0.78	0.6247	0.8002	38	40
0.77	0.6383	0.8292	39	40
0.76	0.6494	0.8540	40	30
0.75	0.6604	0.8795	41	20
0.74	0.6734	0.9109	42	20
0.73	0.6841	0.9379	43	10
0.72	0.6946	0.9656	44	0
0.71	0.7050	0.9942	44	50
0.70	0.7132	1.0176	45	30
0.69	0.7233	1.0476	46	20
0.68	0.7333	1.0786	47	10
0.67	0.7431	1.1106	48	0
0.66	0.7508	1.1369	48	40
0.65	0.7604	1.1708	49	30
0.64	0.7679	1.1988	50	10
0.63	0.7771	1.2349	51	0
0.62	0.7844	1.2647	51	40
0.61	0.7915	1.2954	52	20
0.60	0.8003	1.3351	53	10

the resultant of an energy component representing the work the motor is doing, plus the losses of the motor and a wattless component which may be leading, lagging or zero, depending upon the excitation. If the synchronous motor does no work but simply furnishes wattless leading currents, the machine becomes a synchronous condenser.

Table 1 shows that a load of power-factor 0.75 has an energy component 75 per cent., and a wattless component 66 per cent. of the total. If it is desired to raise the power factor to 0.9 and keep the total kv-a. the same, the table of sines shows that the wattless component must be reduced to 43.6 per cent.; or, in other words, we must furnish a wattless leading current equal to 66−43.6=22.4 per cent. of the total kv-a. If it is desired to keep the energy component of the load constant and reduce the total kv-a. by raising the power-factor, which is the usual case, the table of tangents shows that the wattless component must be reduced from 88 per cent. to 48.4 per cent., or by 39.6 per cent. of the energy component. If in the above examples the total kv-a. is 1000, the energy component or kilowatts will be 750 and the lagging wattless component 660 kv-a. Hence to raise the power-factor to 0.9 and keep constant kv-a., we must use a condenser of 224 kv-a. capacity, and to keep constant kw., one of 0.396×750=297 kv-a.

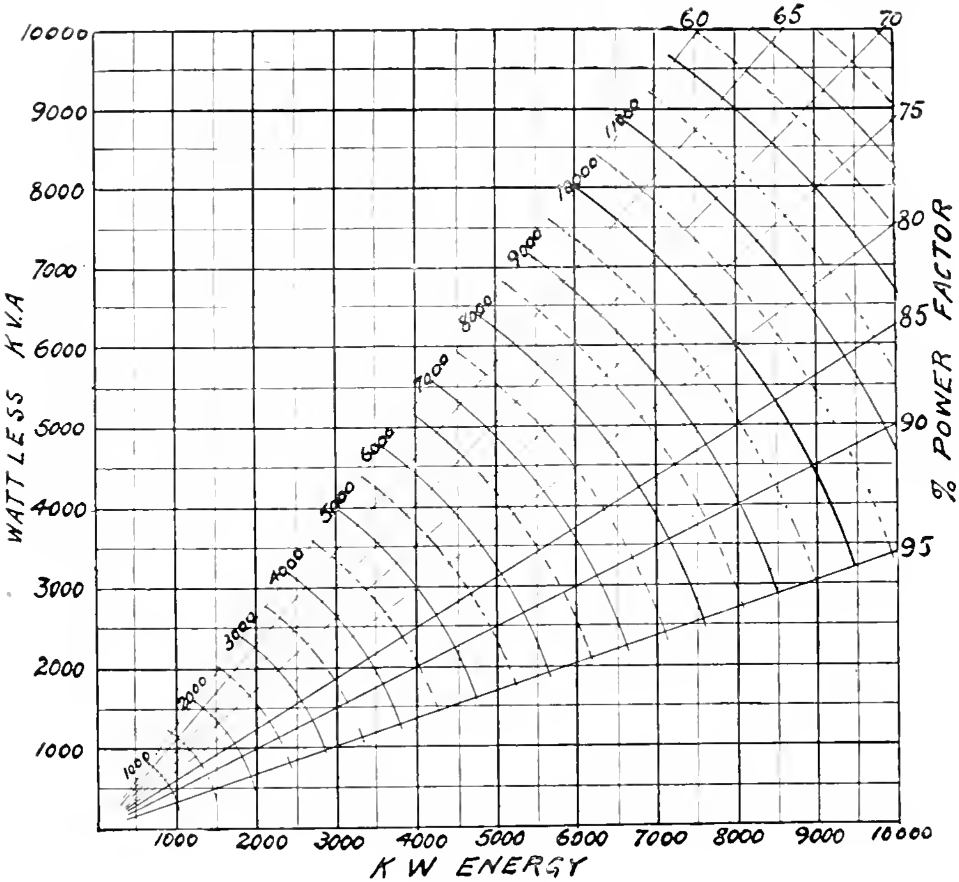

Fig. 4

A table of natural sines, cosines and tangents of angles gives a ready means of resolving a current into its components and determining the condenser capacity necessary to produce desired results. The cosine of an angle is equal to the power-factor of a load having that angle of phase displacement of current from voltage; it is also numerically equal to the ratio of the energy component to the total of that current. The sine of the angle likewise represents the inductive factor and the wattless component. The tangent of the angle of phase is numerically equal to the ratio of wattless component, divided by the energy component.

Neither of these examples takes account of the losses in the condenser itself. These losses will have little effect in determining the size of the condenser. A 300 kv-a. synchronous condenser will have about 18 kw. losses, of which excitation will be about 4 kw. If the condenser is at the far end of the line, its total losses must be added to the energy component of the line; if it is in the generating station its excitation may or may not add to the energy load on the generators. Applying the former case to the above illustration for constant energy component of the load, the total energy load at 0.9 power-factor will be 750+18=768 kw.; the total kv-a. 768÷.9 =854; and the wattless component 854 × 0.436 = 372 kv-a., and thus the condenser input, 660−372=288 kv-a.

This same ground may be covered diagrammatically by reference to Fig. 4. This diagram consists of a number of superimposed triangles, one for each power-factor, thus giving the energy component, wattless component and total kv-a. for any power-factor and load. By dividing or multiplying the kv-a. and kw. scales of this diagram by the same number, its range may be so increased that it may be applied to any problem. Fig. 5 gives a still more convenient form of diagram for quick work where the load in kw. is to be held constant. This diagram is plotted from the table of tangents and is based on an energy load of 1000 kw.; for other loads, the values of wattless kv-a. should be proportionally increased or decreased. To illustrate the use of this diagram, take the example previously given, *viz.*, 750 kw. at 0.75 power-factor, to raise to power-factor 0.9. Follow the 0.75 curve from the bottom of the diagram up until it just intersects the vertical line passing through 0.9; from the point of intersection follow the horizontal line to the right and read from the scale 395.

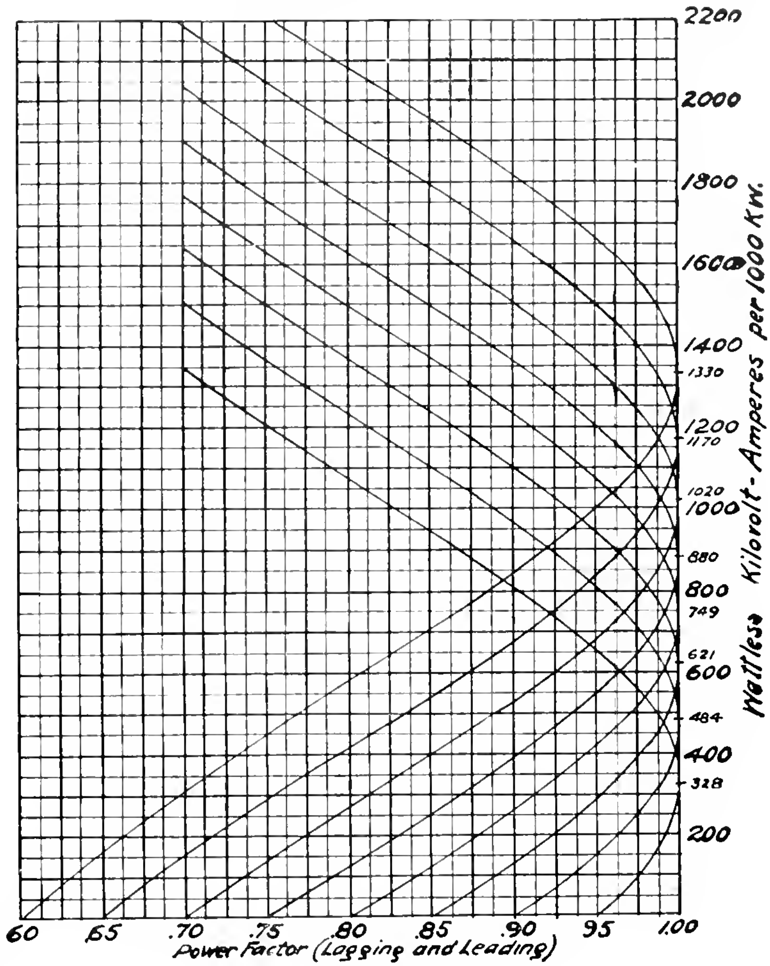

Fig. 5

$395 \times \frac{750}{1000} = 296$ kv-a., which is the size of condenser necessary. If it is desired to raise the power-factor to 1.00, follow the curve until it is tangent to the vertical line from 1.00, and read 880, which, multiplied by 0.75, gives 660 kv-a. capacity of condenser. If it is desired to raise the power-factor to 0.90 leading, follow the curve until it intersects the vertical line from 0.9 the second time, and read at the right 1365, which, multiplied by 0.75, gives 1024 kv-a. as the size of condenser.

An inspection of Table 1 shows that the nearer the power-factor is to 1.0 the greater is the condenser capacity required to raise it a certain number of points. For example, if a generator is fully loaded at 0.75 power-factor and the prime mover is capable of operating it at full load, 1.0 power-factor, and it is desired to increase the output of the unit by

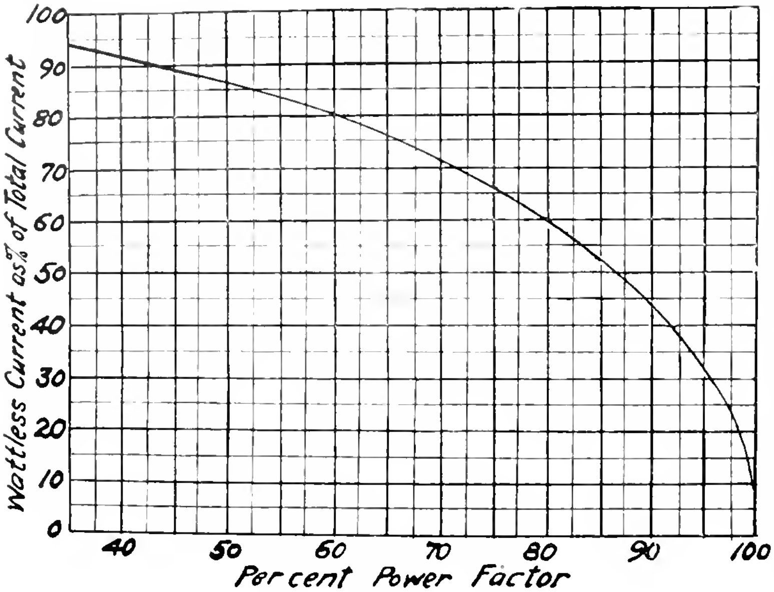

Fig. 6

raising the power-factor of its load, then from the table we get the results shown.

This table is illustrated diagrammatically by Fig. 6 which shows the wattless component as a per cent. of the total kv-a., or current at various power-factors; showing that to raise the power-factor from 0.95 to 1.0 requires the elimination of 31.2 per cent. wattless current; while to raise the power-factor from 0.75 to 0.80 requires the elimination of 66 — 60, or 6 per cent. wattless current.

The planning of a power station and distributing system may or may not properly include synchronous condensers. If there be opportunity to install synchronous motors on feeders carrying low power-factor important loads, the opportunity should not be missed; and the capacity of the motor be made sufficient to furnish the desired mechanical power and also the desired wattless leading current.

TABLE 2

Increase of Power-Factor	Condenser Capacity Required in Per Cent. of Generator Rating	Increase in Generator Energy Output in Per Cent. of Generator Rating
0.75—0.80	6.0	5
0.80—0.85	7.3	5
0.85—0.90	9.1	5
0.90—0.95	12.4	5
0.95—0.98	11.2	3
0.98—0.99	6.0	1
0.99—1.00	14.0	1

Operating such a motor at 0.71 power-factor leading gives a very efficient use of material, the wattless component then being also 0.71 and the total kv-a. capacity of the motor 1.00; i.e., a 500 kv-a. motor could take 355 kw. energy and 355 kv-a. wattless leading from the line by means of the synchronous motor, resulting in considerable saving in step-up and step-down transformers (if any), lines and generators. If there are no possible opportunities for large synchronous motors, it may pay to install purely synchronous condensers out on the feeders, making the same saving as above and securing the same improvements in regulation, but at greater outlay, as no work will be done by the condenser and no direct revenue be received from it. If there be no opportunity to install synchronous motors or synchronous condensers on the feeders, it may be advisable to install generators sufficiently larger than their prime movers to be adapted to commercial power-factors and with fields designed consistently, rather than to install in the generating station synchronous condensers to raise the power-factor. Where an existing plant finds that its prime movers are running underloaded with generators loaded, or that the raising of the power-factor by a reasonable amount will allow shutting down a generating unit, or that its generator fields are overheating, or that its exciting system is not able to deliver sufficient voltage to maintain the generator voltage, or that its wires and cables are overloaded on some feeder due to the low power-factor, then should that plant consider installing synchronous motors or synchronous condensers on its feeders, or failing that, a synchronous condenser in the generating station.

A synchronous motor or synchronous condenser at the end of a transmission line may have its excitation controlled by a generator potential regulator so as to maintain a constant voltage at that point on the transmission line; the size of condenser, and the ratio of the potential at that point to the potential at the generating station, depending upon the characteristics of the load and of the transmission line.

Within reasonable limits of energy load variations, a synchronous motor with fixed excitation may be used also to deliver leading current to a feeder. The usual motor may be used to run at 71 per cent. of its capacity energy load and 71 per cent. wattless leading, and this leading component will not vary greatly in value while the energy component is varying from zero to the 71 per cent. value or even higher, while the excitation of the motor is fixed. If, however, the total load on the feeder is quite variable the synchronous condenser or the synchronous motor should be equipped with a voltage regulator, set for a constant voltage and provided with a stop so that the condenser or motor may not be too heavily overloaded by wattless current.

TABLE 3

SYNCHRONOUS CONDENSERS—THREE-PHASE, 60 CYCLES, 2300 VOLTS

Poles	Kv-a. Capacity	Speed	Volts	Provide Exciter Kilowatts 125 Volts	Approx. Kw. Loss at Full Kv-a. Input
8	200	900	2300	5	14
8	300	900	2300	6.5	18
8	500	900	2300	8.5	27
10	750	720	2300	12	34
10	1000	720	2300	15	45
10	1500	720	2300	16	60
14	2500	514	2300	27	100
24	5000	300	2300	60	200

Table 3 shows a standard list of synchronous condensers designed especially for the purpose. These may be used to carry mechanical load by direct connection but not by belting.

Standard generators may be used as synchronous motors or condensers by making proper changes in the field poles and windings to render them self-starting, and safely insulated against voltages induced in the field when starting.

METHODS OF OPERATING MIXED PRESSURE TURBINES WITH ENGINES DRIVING MECHANICAL LOADS

By R. C. Muir

Power and Mining Engineering Dept. General Electric Company

It is difficult to lay down hard-and-fast rules and recommendations with regard to the application of mixed-pressure turbines to reciprocating engines driving mechanical loads, for the reason that each case requires special investigation and no general data can be given that apply to all cases. The following article, however, points out a few of the features of the subject which may prove of assistance to engineers in understanding propositions of this character. The article describes two methods of regulating or load balancing between the turbine and the engine, which may be employed in cases where high economy is of importance, i.e., where it is necessary to ensure that no exhaust steam is wasted and live steam used in the turbine only on overloads.—Editor.

When a mixed pressure turbine generator is used in connection with an engine which has a mechanical load entirely independent of the turbine electrical load, it is evident that the amount of exhaust steam from the engine will either be excessive or deficient for the turbine; in one case exhaust steam is wasted to the atmosphere and in the other case live steam is taken from the boilers. Many turbines are operated in this manner at present, but they are usually in connection with engines having very intermittent and variable loads, such as rolling mill engines in steel mills.

In cases where the engine load is moderately uniform, such as textile and paper mill loads, and where high economy is of utmost importance, some method of regulation or load balancing between the turbine and engine should be employed, so that no exhaust steam is wasted and live steam is used only on overloads. Two methods are used to accomplish this purpose. A load balancing synchronous motor connected electrically to the turbine and mechanically to the line shaft of the engine may be employed as shown in Fig. 1, or a pressure regulating governor as shown in Fig. 2.

The operation with the first method is as follows: When the amount of exhaust steam supplied by the engine is in excess of that required by the turbine for the electrical load, the motor will transmit any excess load developed by the turbine to the line-shaft driven by the engine. This diminishes the load on the engine—which in turn furnishes less steam to the turbine, and consequently a balance is reached. On the other hand if the engine does not furnish enough exhaust steam to the turbine for the electrical load, the motor will be driven as a generator, thereby assisting the turbine generator. With this arrangement therefore the motor acts as a load-balancer between the electrical and mechanical elements of the power system, no exhaust steam is wasted, and the combined electrical and mechanical loads are carried most economically.

To select the proper size of motor requires simply a knowledge of the mechanical and

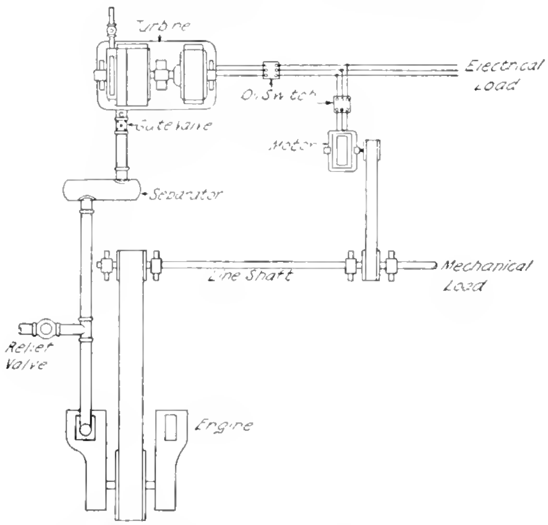

Fig. 1. Load Balancing Synchronous Motor Connected Electrically to Turbine and Mechanically to Line Shaft

electrical loads. The normal capacity of the load balancer must be equal to, or larger than, the maximum average difference of the mechanical and engine loads when operating as a generator, and the maximum average difference of the turbine and electrical loads when operating as a motor, over a period of time long enough to cause constant temperatures. The maximum capacity should be equal to the maximum possible difference between the turbine and electrical loads, or the mechanical and engine loads. The maximum capacity, which should usually be considered as short-period overload capacity only, is easily obtained by assuming the electrical load zero; in which case the turbine will transmit all of its load through the motor to the engine line-shaft. This load would equal approximately one-half the rating of the turbine, and the motor should therefore have an overload rating corresponding. If this condition is liable to exist over a period of time long enough to cause practically constant temperatures, the continuous rating of the motor should be equal to approximately one-half the turbine rating.

In order to obtain the average difference in mechanical and engine loads and turbine and electrical loads, when the electrical and mechanical load curves are known, it is necessary to know what proportion of the combined load each unit will carry. Since the steam consumption of the engine and turbine is usually known, this is probably most easily accomplished by plotting the steam-flow load curve for the engine and the corresponding curve for the turbine, allowing for moisture in the exhaust steam. The proportion of the load carried by each unit can then easily be obtained. For convenience it is desirable to reduce the output of both units to brake horse power. Fig. 3 shows such a curve.

Suppose in this case the average electrical load was 1000 h.p., and the average mechanical load was 2000 h.p., or a combined load of 3000 h.p. The turbine would develop 1400 h.p. and the engine 1600 h.p. The difference in turbine and electrical load would be 400 h.p. which would have to be taken care of by the motor. If, however, the electrical load should accidentally go off entirely the mechanical load of 2000 h.p. would still remain. The turbine would develop approximately 900 h.p.; and the motor must have a capacity sufficient to transmit this turbine load to the engine line-shaft. A 400 h.p. motor could not take care of this load, and therefore, the maximum requirement would determine the size. If 2000 h.p. were the maximum possible mechanical load, a motor having a maximum capacity for short periods of 900 h.p. would be sufficient. This would correspond to at least a normally-rated 600 h.p. motor having 50 per cent. overload capacity, or 900 h.p. for short periods. Since the momentary overload capacity would be approximately 100 per cent., or 1200 h.p., a motor of this rating should be entirely safe for the case considered.

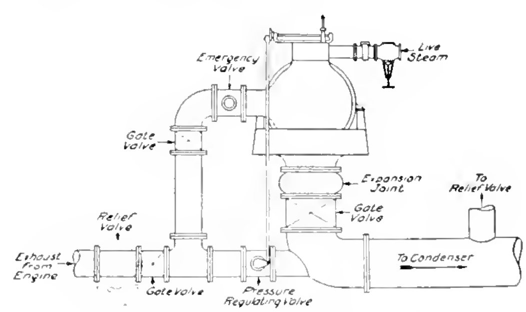

Fig. 2. Pressure Regulator Governor

In making recommendations for the proper motor for this service, the following suggestions are given:

1. Be sure the motor is large enough. The maximum short period overload should be equal to at least one-half the rating of the turbine. 2. Synchronous motors are to be preferred to induction motors, due to the better speed regulation and power-factor obtained. 3. The motor should be equipped with a heavy low-resistance squirrel cage winding to prevent hunting.

A study of the governing and speed regulation of the engine and turbine when operating under these conditions is interesting. Referring to Fig. 4, A-B represents the speed regulation of the turbine operating independently on exhaust steam only; D-E shows the regulation when operating on live steam only. The speed for part high-pressure and part exhaust steam will be somewhere between the lines A-B and D-E. A-C shows the assumed regulation of the engine, which is usually greater than the turbine regulation.

When operating with the synchronous load balancer the relative speed of the turbine and engine must be the same. Although the turbine, when running independently would operate at a slightly higher speed, in the case under consideration this is impossible. The turbine governor, and consequently the valve governing the inlet of exhaust steam, takes a position corresponding to the speed of the engine; and, disregarding this position, the turbine develops a load corresponding to the supply of the exhaust steam furnished it by the engine. Therefore, theoretically, up to the point where high-pressure steam is admitted, the turbine governor might as well be omitted. In case the load balancer, however, should become

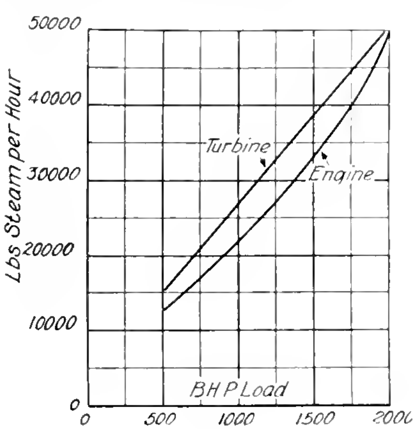

Fig. 3

disconnected, for any reason such as oil-switch tripping or belt breaking, the turbine governor would immediately come into action and control the speed.

Again referring to Fig. 4, it will be noted that the engine regulation is shown by the line A-C as a straight line; although, as a matter of fact, the speed usually drops very rapidly at overloads. With the mixed-pressure turbine this is largely prevented; because, as soon as the speed drops to the point where high-pressure steam is admitted, the turbine governor comes into action and helps the engine out by admitting live steam to the turbine, thereby maintaining a more uniform speed.

The operation with the second method of balancing the load between the engine and turbine may now be considered: Fig. 2 shows

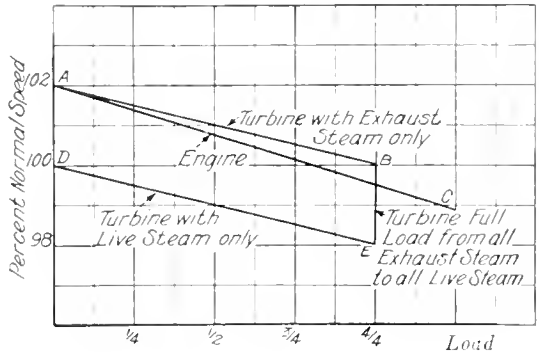

Fig. 4

the piping connections; and it will be noted that valves are included so that either the engine or turbine can be operated alone, in case one or the other is down for any reason. The pressure regulating valve is operated by the turbine governor and its function is to maintain an initial pressure on the turbine (the exhaust pressure on the engine), which will be just sufficient to carry the required turbine load. This means that for turbine loads less than normal, the initial pressure will be less than atmospheric pressure and the engine will benefit thereby. The excess exhaust steam passes through the regulating valve to the condenser. It is evident that this arrangement is of value only when the relation between the mechanical and electrical loads is such that the engine furnishes exhaust steam in excess of that required by the turbine to carry the electrical load. When the supply of exhaust steam is insufficient the regulating valve is entirely closed, and the turbine governor automatically admits live steam to make up the deficiency.

Theoretically this scheme of operation could be accomplished more economically by automatically adjusting the nozzle areas of the turbine, allowing all exhaust steam to pass through the turbine. This would complicate the design of the turbine, however, and affect the economy under certain conditions to such an extent as to render the scheme impractical. The advantages of the pressure regulating governor method as compared to the motor load-balancer method are: simplicity, lower first cost, and the possibility of applying the method in cases where it is not practical to use a motor. The disadvantages are that it is less efficient, greater precaution must be taken to maintain the vacuum, and there is no means whereby the turbine can assist the engine in carrying heavy mechanical loads other than by reducing the exhaust pressure on the engine.

MIXED-PRESSURE TURBINE INSTALLATION OF THE TENNESSEE COAL, IRON & R. R. CO.

By E. J. Best

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The power plant described in this article is notable as embracing the largest installation of mixed-pressure turbo-generators and equipment concentrated in one house for the utilization of exhaust steam from rolling-mill engines. The article gives particulars regarding the original generator equipment, driven by reciprocating engines which now furnish steam to the turbines. The new power house is then described, attention being given to piping arrangements (steam sources, exhaust, and ventilating ducts); cooling towers and water pumps; steam regenerator equipment; steam receivers and by-pass equalizing line; construction of the station; switchboard control equipment, bus-bar arrangement, high tension and distribution wiring; and storage battery system for operating the control switches.—Editor.

The Ensley Plant of the Tennessee Coal, Iron & R. R. Co., Ensley, Ala., has been equipped electrically as far as the operations would permit, except in certain cases where hydraulic power was considered preferable, and in the driving of the mill rolls where steam engines are used.

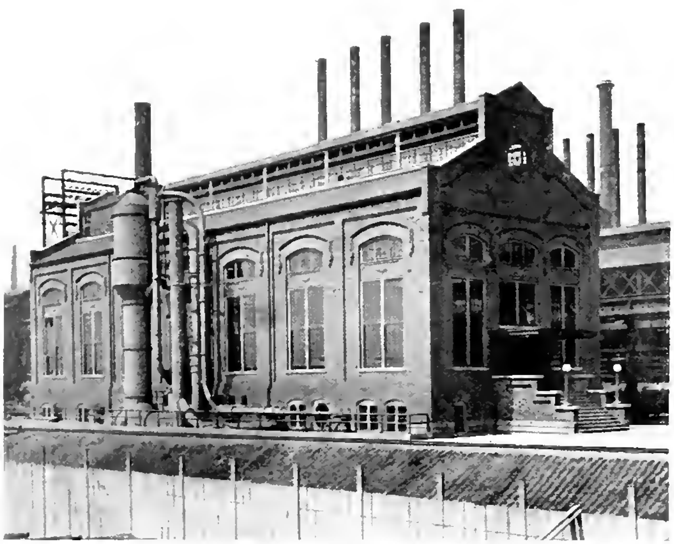


Fig. 1. Turbo-Generator Station. Front and Side Elevation Showing Condenser

The initial equipment of the original station that furnishes power for this plant consists of one 2200 kw. 6600 volt Crocker-Wheeler 25 cycle generator, direct-connected to a cross-compound Cooper-Corliss engine, and three 600 kw. 2300 volt (now transformed to 6600 volts) Westinghouse 25-cycle generators, direct-connected to cross-compound Wisconsin Corliss engines. Power requirements grew amazingly due to the decision of the American Steel and Wire Co. and the Tennessee C. I. and R. R. Co. to erect and operate at Corey, Ala., modern rod and wire mills and a by-product coke-oven plant. To obtain electrical power for these outside plants and additional power for the Ensley steel works, a mixed-pressure turbo-generator equipment was decided upon, comprising four units direct-connected to three-phase, 6600-volt, generators of the revolving field type. The turbines are of the General Electric Company manufacture, and are of the Curtis horizontal type. They are rated to develop 3000 kw. at 70 per cent. power-factor with not more than 26½ in. of vacuum in the exhaust chambers of the turbine, and with a pressure of 16 lb. absolute, or 125 pounds gauge, at the throttle. They operate in parallel with either the Cooper-Crocker-Wheeler unit, or with one or all of the three Westinghouse units. These engines have a regulation of approximately 2 per cent., the regular variation being within 2½ electrical degrees. The regulation of the Crocker-Wheeler generator is 6 per cent. at 2200 kw., 100 per cent. power-factor, and 16 per cent. at 2200 kw., 80 per cent. power-factor; while the regulation of the Westinghouse generators is 6 per cent. at 600 kw., 100 per cent. power-factor, and 16 per cent., at 500 kw., 80 per cent. power-factor.

The ventilation of the turbines is of interest in that the supply of air is admitted through screened openings in the wall below the main turbine floor and drawn through a duct fastened to the foundation. Openings in the foundation allow the air to be carried up through the laminations of the stator, and then down and out again through outlet ducts in the foundation, also beneath the floor. These ducts carry the air to the outside of the building, eliminating all possibility of the heated air discharging in the main operating room. It may also be noted here that all steam-pipe headers are carried in the basement below the station floor. The connections to the various machines come up through the floor, leaving the main operating room clear of all over-head piping. In planning the station, one unit was placed in the existing power house and received low-pressure steam from the 2200 kw. Cooper-Corliss engine, including make-up exhaust steam from the blowing engines.

A new station (Figs. 1, 2 and 3) was erected exclusively for housing the other three units, the third being considered a spare unit. These turbines are supplied from three sources: first, from exhaust steam of mill engines and auxiliaries (at an average absolute pressure of 16 lb.); second, from live steam now blown off during shut-downs; and third, from live steam generated by additional firing. The exhaust from the turbines is handled by what is probably the largest barometric condenser ever built, a 130 in. Helander; together with two 36 in. by 36 in. Corliss dry-air pumps built by the Mesta Machine Company. These air pumps are located on the turbine room floor without any foundation, one being considered a spare. The exhaust connections permit the turbines to be handled either individually or by grouping either pair. They are located outside the building midway between the three turbo-generator sets, the condenser having a large base lateral with three inlets, allowing easy steam connections from the turbines. The maximum steam consumption of each turbine is not over 120,000 pounds of exhaust steam per hour.

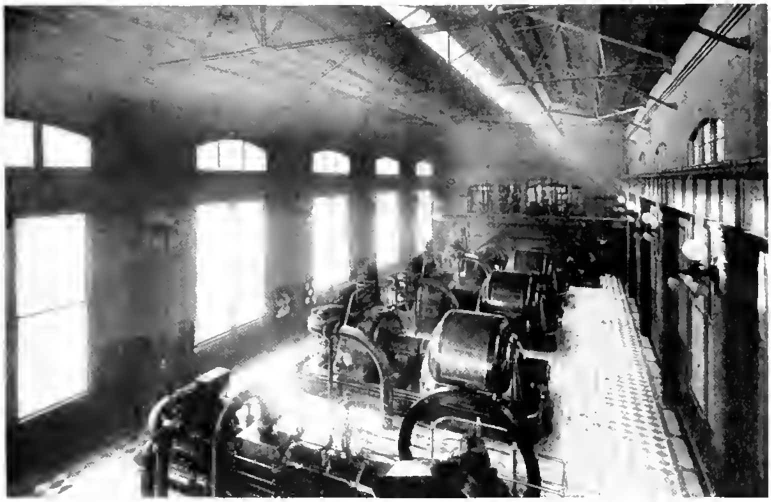


Fig. 3. Inside View of Station

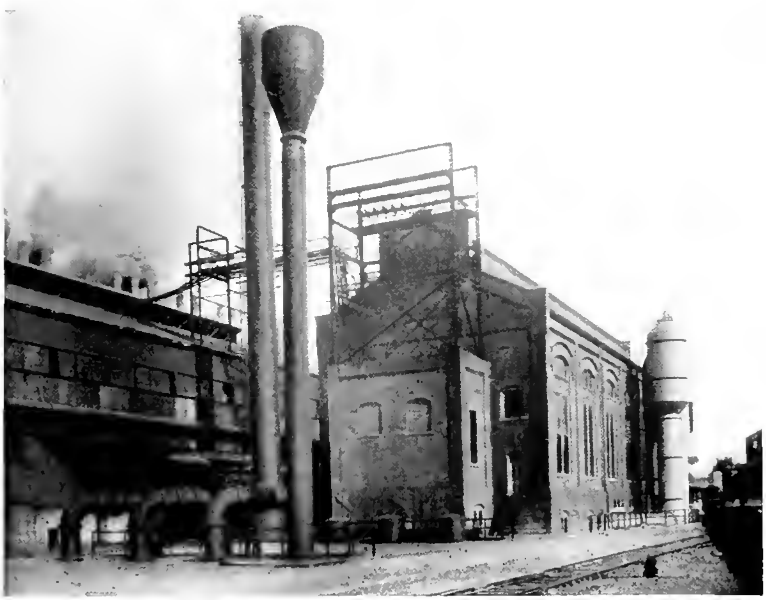


Fig. 2. Turbo-Generator Station. Rear Elevation, Showing Regenerators in the Foreground, Exit Tower Including Battery and Lightning Arrester Room

The cooling towers (Fig. 4) are of the natural draft type, the frame of which is of structural steel supporting the creosoted lumber. The cooling capacity of the six bays is about 22,000 gallons of water per minute, through a range of 28 deg. F. The towers are 90 feet high and 35 feet wide at the base; and in summer weather there is no difficulty in securing from $26\frac{1}{2}$ to $27\frac{1}{2}$ inches of vacuum. De Laval high-pressure steam turbine-driven centrifugal pumps supply the water requirements. A 450 b.h.p. 900 r.p.m. steam turbine is direct-connected to two De Laval horizontal

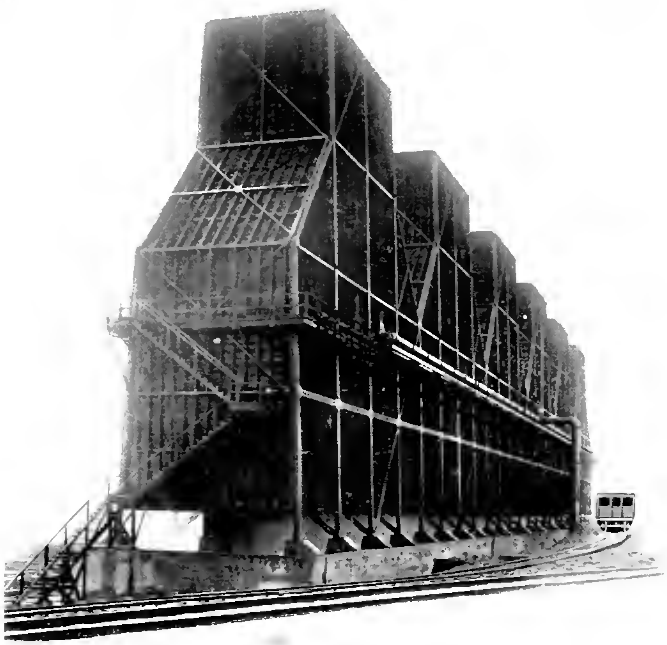


Fig. 4. Cooling Towers

single-stage double-suction pumps which deliver the water from the hot well to the cooling tower against a head of 67 ft.; while a 225 b.h.p. turbine is direct-connected to 18 in. horizontal single-stage double-suction centrifugal pumps for delivering water from the cold well to the condenser against a total head of 35 feet. As a spare for this service one of the larger units is connected and installed capable of operating either pump. The water from the cooling tower flows to the condenser cold well by gravity. These pumps are located in the basement directly under the air pumps.

The steam regenerator equipment, part of which can be seen in Fig. 2, receives exhaust steam from the mill engines and auxiliaries and is divided into two groups. One group consists of two regenerators 8 ft. by 50 ft. and receives steam from a 55 in. by 66 in. blooming mill reversing engine, pressure pumps and air-compressors. This equipment is capable of passing 250,000 pounds of steam per hour to the turbines, with a supply from the engines fluctuating between 40,000 pounds per hour and 400,000 pounds per hour. It is capable of delivering 2200 pounds of steam per minute for a period of one minute, with pressure varying from 19 pounds absolute to 15 pounds absolute, requiring not more than one minute to attain a temperature of 225 deg. F., over the entire body of water, when supplied with sufficient steam in excess of the turbine requirements. The other group consists of three regenerators of the same size, receiving steam from the roughing rail mill engine 55 in. by 66 in., the Allis 52 in. by 72 in., a simple Corliss and a Duplex pump. This equipment is capable of passing 220,000 pounds of steam per hour from a fluctuating supply varying from a rate of 1500 pounds per hour to a rate of 350,000 pounds per hour. It is capable of delivering 1500 pounds of steam per minute for a period of two minutes, not requiring more than two minutes to attain a temperature of 225 deg. F. The pressure drop in either case from inlet to outlet of the regenerators does not exceed 1.1 and 1.3 pounds per square inch for an average flow of 175,000 to 200,000 pounds per hour. The equipment is furnished by the Rateau Regenerator Company.

Large receivers are placed at the engines to reduce the momentary fluctuations in steam delivery therefrom. An 18 in. equalizing line between the regenerators, or between the two exhaust systems, has been installed for the safety of operation as well as for economy in the use of exhaust steam. This by-pass line accomplished at a small cost what could otherwise have been done only by grouping all of the regenerators at one point; since steam in excess of the capacity for absorption of the two regenerators at the blooming mill (which would otherwise be blown out by the blooming mill relief valve) can by this pipe be utilized or absorbed in the rail mill regenerators, thereby allowing all regenerators to be kept at a more even rating.

The station proper possesses plain and attractive architectural and decorative features. The structure is entirely fire-proof, and is of brick and steel resting upon a heavy concrete sub-base trimmed like concrete blocks. The floors are of steel-reinforced concrete, the main turbine floor is surfaced with white and black marble tiles laid diagonally, and the roof is of slate. The interiors of the main rooms are wainscoted in panels between the columns of the steel frames, with two different shades of brown pressed brick, finished above with a light buff brick. Other interior faces, such as the crane runway, steel trusses and roof sheeting and the 20-ton overhead traveling crane (spanning the turbine room floor and running the entire length of the building) are all painted of the same color as the buff brick, giving a fine diffusion of light throughout the building. The basement constitutes the transformer and storage battery room at one end and the pump floor at the other end, while the turbine foundations occupy the space between them. These foundations have been built entirely free from the floor above in order to avoid any vibration through the floor to the building. The building is located centrally between the rail and blooming mill engines and adjacent to these mills. The entire electrical equipment has been supplied by the General Electric Company.

In the wiring scheme all connections between the busbars and the units are made through motor-operated oil switches, all arranged for remote control from a bench-board placed in the electrical operating gallery overlooking the generator room (Fig. 5) which gives the operator an unobstructed view of the main units. The low voltage is transmitted through busbars and carried by cables between floors; while the high tension wiring between generators and control switches is made up of three-conductor lead cables, also concealed between floors. The busbars and their switches are installed in concrete barriers or cells for the prevention of arcing between phases, and all busbar equipment is in duplicate.

The local distribution is arranged and equipped as follows: The generating units are excited from a 150 kw. General Electric induction motor-generator set, together with a 35 kw. turbine exciter as an auxiliary for starting either generator from rest. The current for the steel works end of the plant is also furnished from this station from an equipment consisting of three synchronous motor-generator sets, each of 500 kw.

Fig. 5. Turbo-Generator Station. Switchboard Room

capacity (originally furnished by the Crocker-Wheeler Company and transferred to this station). These units supply the direct current. Five 200 kv-a. Westinghouse transformers are used to step the current down from 6600 volts to 240 volts for low tension motor work in the mills, and are controlled by a switch-board equipment on the same gallery as the high tension bench-board control.

In addition to the above equipment a storage battery system is provided in the basement for taking care of the operation of all the control switches and emergency lighting in case of a complete shut-down of the plant, and is automatic in its operation. Directly above the storage batteries, in the compartment at the base of the exit tower, static and electrolytic lightning arresters are located to take care of the tie-in line and transmission lines to Corey through a junction or exit tower. This is equipped with motor-controlled operating switches through double sets of hook switches at the summit of the tower, and can be seen in Fig. 2.

Power for the Corey plant is carried to a substation at Corey 2½ miles away, the wires being carried on steel towers along a right of way owned by the company. These towers are spaced from 204 to 1550 ft. apart and are from 43 ft. to 87 ft. high. The power is transmitted over six circuits of bare stranded copper cable of 300,000 c.m. capacity. An overhead steel cable is carried on the steel towers for lightning protection.

The new station is connected with the original power house by means of a tie-in line composed of three circuits of 300,000 c.m. bare stranded copper conductors, making it possible to concentrate the power of both plants as one. Additional switch control was installed at the old station to take care of the new turbine unit.

A MIXED-PRESSURE TURBINE INSTALLATION ON TRACTION SERVICE

By E. G. Morgan

Turbine Construction Dept., Chicago Office, General Electric Company

This article puts the case for the mixed-pressure turbine very thoroughly by citing an actual example, typical of many others, where a great increase in station capacity has been obtained without any increase in boiler equipment. Most of the load was traction and a steady elevation of the peak demanded additional generators. Several alternatives were considered, such as a modern high-pressure turbine and a 5000 kw. low-pressure machine with additional boilers. A 2500 kw. turbine without boiler addition was decided upon; and the published load diagrams with accompanying text show how successful this scheme has proved.—Editor.

The Batavia power plant of the Aurora, Elgin and Chicago Railway is situated about forty miles southwest of Chicago at Batavia, Illinois, and furnishes power to the Aurora, Elgin and Chicago Railroad—a high-speed third rail interurban railway, connecting Chicago with Wheaton, Elgin, Geneva, Batavia and Aurora; a 40-mile trolley interurban line extending from Yorkville, 12 miles south of Aurora, through Aurora and Elgin, to Carpentersville, 6 miles north of Elgin, and the city lines in Aurora and Elgin; to the Elgin and Belvidere Railway, an interurban line connecting Elgin with Belvidere, Rockford, Freeport and Madison; to the Aurora and DeKalb Railway, an interurban line running out of Aurora southwest through a number of small towns and to the Joliet and Southern Railway; a 22-mile interurban between Aurora and Joliet; and in addition furnishes power for lighting the cities of Elgin, Wheaton, West Chicago and Lombard, and a number of smaller towns.

The details of this power plant are very interesting on account of the increased efficiency and increased maximum capacity, with the same boiler equipment, which were achieved by the addition, in October, 1910, of one 2500 kw. mixed-pressure turbine, designed to operate on the exhaust steam from existing reciprocating units. The power station is located on the Batavia branch of the interurban railroad, and is on the Fox River whence a good supply of cooling water for condensing purposes is obtained. It has at present a boiler equipment of fourteen 500 h.p. Edgemore boilers operating at 175 lb. pressure, with just enough superheat coils to give dry steam at the engine. Ten boilers are provided with fuel economizers of 2700

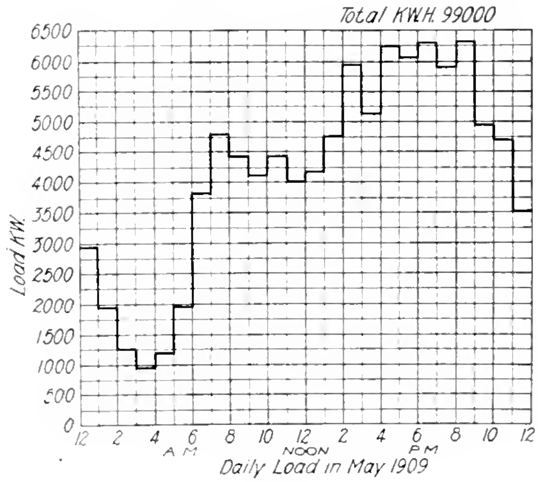


Fig. 1

sq. ft. heating surface, located between the boiler and the main flue. Four of the boilers have no economizers and were added to the station in the winter of 1910-11. Illinois and Indiana screenings are used for fuel.

All boilers are equipped with automatic stokers of the chain grate type.

The engine room equipment includes four Cooper-Corliss horizontal cross-compound engines. Three have 32 in. high-pressure cylinders, 64 in. low-pressure cylinders, 60 in. stroke and run at 75 r.p.m. The fourth has the same cylinder dimensions, but has a stroke of 48 in. and a speed of 94 r.p.m. Each engine is direct-connected to a 1500 kw., 2300 volt, 3-phase generator. The engine room also contains the necessary exciters and auxiliary equipment. The engines, before the installation of the turbine and the last four boilers, were run condensing into barometric condensers, with a vacuum ranging about 25 in. of mercury (referred to a 30″ barometer); and, operating under these conditions, the maximum capacity of the plant was 7500 kw. with all ten boilers working to maximum capacity. It was only possible to carry this load for one hour.

As the demand for power increased, the station's daily peak and daily output increased, and it was necessary to consider additional equipment. Fig. 1 shows the load for a day in May, 1909. The peak load on this day (6300 kw.) required all the ten boilers to operate at a very high overload, or the use of nine boilers at their ultimate capacity. If for any reason two boilers were down for repairs, it would not have been possible to pull the peak load. The curve in Fig. 1 represented about the ultimate capacity of the plant, considering the best load factor for the different hours of the day in relation to the peak load for the busy hours.

The economy of the plant as operating was considered, and means for bettering that economy by adding a modern high-pressure turbine were carefully gone into. It was estimated that a 10 per cent. increase in overall efficiency could be obtained in this way; but it was realized that more boiler equipment would be necessary, which would increase the fixed charges and slightly reduce the above saving. The alternative of using low-pressure turbines with modern condensing apparatus employing the exhaust steam from the engines was also considered. It became evident that an installation of this kind would give the best results, and that it would reduce the cost per kw-hr. developed by about 20 per cent., if all the exhaust from the reciprocating units were used in connection with low-pressure turbines. It appeared that the rated capacity of the plant could be increased by 5000 kw. (or 83 per cent.) with the addition of only 36 per cent. more boiler capacity due to the increased over-all efficiency; while it was also found that a 2500 kw. low-pressure turbine could be operated with the existing units with the

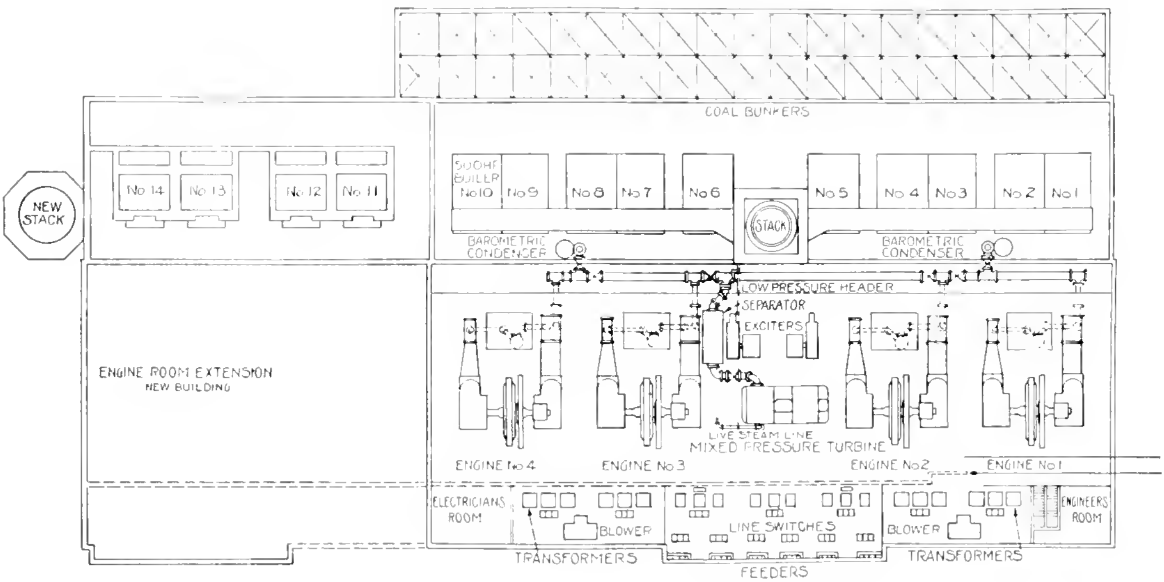


Fig. 2

same boiler installation. It was decided to install a 2500 kw. low-pressure turbine immediately, in order to realize at least part of the 20 per cent. saving.

As a consequence, there was installed, in October, 1910, a 2500 kw. Curtis mixed-

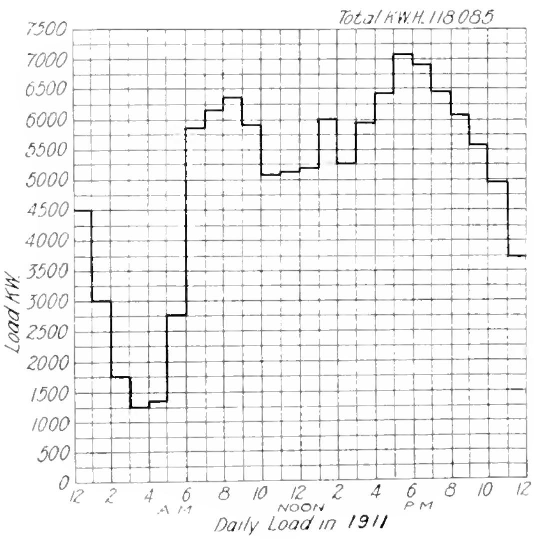


Fig. 3

pressure turbine, direct-connected to a 2500 kw., 25-cycle, 2300 volt generator. The unit occupies the center of the engine room between two of the reciprocating engines; and the exhaust piping is arranged so that the turbine can take steam from any one or all of the engines (as indicated in Fig. 2) depending upon the most efficient operation as determined by the load. The barometric condensers are connected to the exhaust header as formerly, but the piping is arranged with valves so that any condenser or engine can be cut out and the exhaust from any engine turned into a common 22 in. exhaust header to feed the turbine. The turbine is equipped with a set of high-pressure steam valves under control of the main governor, so that the set may be operated with high-pressure steam in the event of no low-pressure steam being available, or to make up a deficiency of low-pressure steam. A surface condenser is installed to take the exhaust from the turbine. This condenser has 12,000 ft. of cooling surface, and is designed to give a vacuum of 28 in. (referred to a 30 in. barometer).

With this turbine installed, the results obtained were very gratifying, from the operating, as well as from the economical, standpoint. Fig. 3 shows the load for an average day in 1911 after the turbine was installed, and this load was carried without any of the over-crowding of the boilers which was necessary before. The average daily summer output of the station has been increased from about 99,000 to 118,000 kw-hrs., or approximately 19 per cent.; and the additional peak load is carried with the same boilers without any difficulty. The station economy has been bettered by about 16 per cent. The operation of the combination is extremely simple, as the generator is tied in on the common bus with the engine generator. The turbine generator operating with the engine generators gives better voltage regulation than that previously obtained with the engine generators alone, due to the fly-wheel effect and the constant drive on the turbine generator. The curves in Fig. 4 show the turbine taking the exhaust

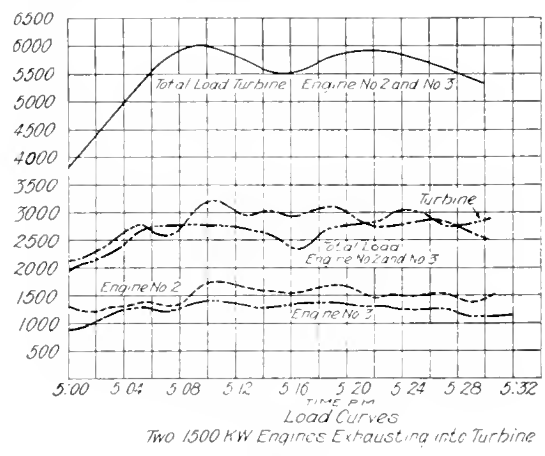


Fig. 4

from two 1500 kw. engines—units which, when operating at rated load, supply sufficient low-pressure steam to develop rated load on the low-pressure machine. The curve indicates good regulation and equal division of the load.

A MIXED-PRESSURE TURBINE INSTALLATION AT A STEEL WORKS

By B. E. Semple

Power and Mining Department, Chicago Office, General Electric Company

This article describes a 7000 kw. mixed-pressure Curtis turbine, the largest of its type built to date, installed at the plant of a large steel manufacturing corporation. It will operate on 140 lbs. high-pressure steam or 16 lbs. low-pressure (vacuum $28\frac{1}{2}$ inches) or both; and under the latter conditions may receive its supply either from three reciprocating engines driving electric generators in the existing power house or from four of the blast furnace engines. Reference is made to some of the general principles of the control and operation of turbines of this type, and the article concludes with a statement as to the operating economies which have been effected by the unit in this instance. Considering only reduction in steam consumption per kilowatt-hour, there is a net saving probably in the neighborhood of $85,000 annually.—Editor.

Those who are only slightly familiar with the operation of a reciprocating steam engine are not in the least surprised to see a massive unit driving an electric generator that supplies power for the operation of an electric railway or an industrial plant, as they are aware of the fact that the engine is receiving steam at a pressure considerably higher than is necessary for the heating of an ordinary apartment building. They would be extremely startled if they were to visit a power station and see a ten thousand horse-power engine of the turbine type operating on a steam pressure but one and one-half pounds above that of the atmosphere; and they would doubtless be still more confused if they learned that the same steam that was doing this work had previously existed in a high-pressure form, and had passed through reciprocating steam engines and caused them to perform equally as much work.

Such situations, however, are in existence at the present day. Although they came into existence without arousing even the slightest interest amongst people outside the engineering profession, yet they actually represent a development which is of the greatest importance to the inhabitants of any civilized country, since they maintain the true principles of conservation and make for economy in countless manufacturing operations.

Here the question may be asked, "How is all this accomplished?" The answer is found in the fact that, if one pound of steam at atmospheric pressure is expanded to a 28 in. vacuum, it produces an available energy of approximately 130,000 foot-pounds (with a proper allowance for moisture); and thus a condition is established to which a turbine is particularly adapted. A reciprocating steam engine is not adapted to such a condition, as its highest efficiency is obtained when it utilizes the available energy of steam from a boiler-gauge pressure of, say, 150 pounds to atmospheric pressure. During the last few years the possibilities of the steam turbine, for utilizing the low-pressure steam from reciprocating engines which have originally taken it at high pressures from the boilers, have been recognized; and one could cite countless instances where this principle is being successfully applied for all classes of electrical service. It is the purpose of the present article to describe an equipment which was supplied in 1909 to a large steel manufacturing corporation for installation in one of its existing power stations.

The turbine is of the mixed pressure Curtis vertical shaft type and drives a 25-cycle three-phase 2200 volt generator at a speed of 750 r.p.m., rated to develop 7777 kv-a. (normal) and 9722 kv-a. (maximum). The unit is designed for operation on both high-pressure steam at 140 pounds absolute and low-pressure steam at 16 pounds absolute and a vacuum of $28\frac{1}{2}$ in.; and is capable of carrying its rated load with steam supplied at either pressure or at both pressures in proper proportions. It is the largest unit of its kind built to date in this country. Low pressure steam is admitted to the turbine through an inlet pipe equipped with a butterfly throttling valve. This valve acts as a governing device when the turbine is supplied with sufficient low-pressure steam for the load on the generator. The high-pressure steam is admitted through, and controlled by, a number of independent valves which govern groups of nozzles connected to the high pressure steam chest. The butterfly valve in the low-pressure inlet pipe is controlled by the same governing mechanism which controls the high-pressure inlet valves; and by this arrangement the speed of the turbine is automatically governed, regardless of the amount of low-pressure steam available.

Fig. 1 represents a simple diagram of the steam and electrical connections in the station containing the turbine. Reference to this diagram will indicate that the turbine receives its low-pressure steam from two sources, one being from the reciprocating steam engines driving alternating current generators, and the other from the reciprocating steam blowing engines which supply air to the blast furnaces. The high-pressure steam is supplied by the same boilers that supply the engines just mentioned. Two of these reciprocating electric units are of the Allis type, twin tandem compound, each having two high-pressure cylinders 24 in. by 48 in. and two low-pressure cylinders 48 by 48 in. The third is a Westinghouse machine with a single high-pressure cylinder 38 by 54 in. and a single low-pressure cylinder 72 by 54 in. Four blast furnace blowing engines of the Mesta type are arranged in such a way that their exhaust can be used in the turbine. They each have a single high-pressure cylinder 44 by 66 in. and a single low-pressure cylinder 84 by 66 in. In ordinary operation the three reciprocating electric units will supply enough low-pressure steam for full load conditions on the turbine; but at times, for convenience, one or more of the reciprocating electric units may not be in use, at which time one or more of the four blast furnace blowing engines exhausts into the turbine. Suitable condensing facilities are provided so that any of the reciprocating electric units or the blast furnace blowing units can be operated condensing, when not used with the turbine as a source of steam supply to the latter unit.

The high-pressure connection to the turbine comes into action at times, when a portion or all of the low-pressure supply is being used from the blowing engines, since at intervals blast furnace operation requires that the air supply be cut off instantly. At such times the turbine governor automatically admits high-pressure steam directly into the turbine, thus allowing it to continue to carry its load without interruption to the electrical system. It will also be of interest to note that the generator of the turbine operates on the same bus and in parallel with the generators driven by the reciprocating steam engines which supply a portion of the low-pressure steam for the turbine, and also in parallel with the gas engine-driven generators. The entire station also operates in parallel with another station located several hundred feet distant containing two 1000 kw. high-pressure turbines, and with a gas engine plant some twenty miles distant.

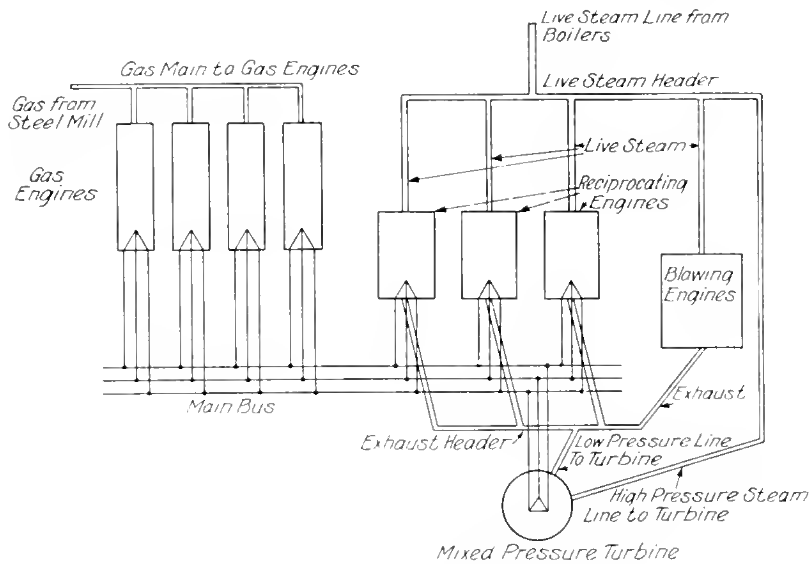


Fig. 1. Steam and Electrical Connections in Turbine Station

Fig. 2 gives a general view of the mixed-pressure turbine unit. It will be noted that its overall dimensions are quite small, particularly as regards shaft length, since this type requires less revolving wheels than the high-pressure type. The machine has but three stages, each stage being equipped with a wheel carrying two rows of revolving buckets. This turbine is not in any way different in design from the standard Curtis machine as installed elsewhere. The high-pressure steam is made use of on the same revolving buckets as is the low-pressure steam, and there are no idle buckets or wheels in either operation. The pressure distribution in all stages is worked out so carefully in the design of the machine as to give almost equal stage pressures at either high- or low-pressure operation. The Curtis mixed-pressure turbine differs from other types, in that it does not require the use of reducing valves for reducing steam from boiler pressure to the lower values made use of in low-pressure operation, since it is equipped with high-pressure valves similar to those used on strictly high-pressure machines. The losses incident to the use of reducing valves are in this manner entirely avoided.

In operation this turbine makes use of all of the low-pressure steam available to it; and if, after the low-pressure steam inlet has been opened to its maximum the generator is called upon for more output, the governor automatically begins to open the high-pressure valves, thus admitting high-pressure steam to take care of the additional load. The turbine is also equipped with a suitable number of hand-operated valves located in the first stage, allowing the number of low-pressure admission nozzles to be varied at will, in order to bring about the most economical operation of turbine and engine at different loads.

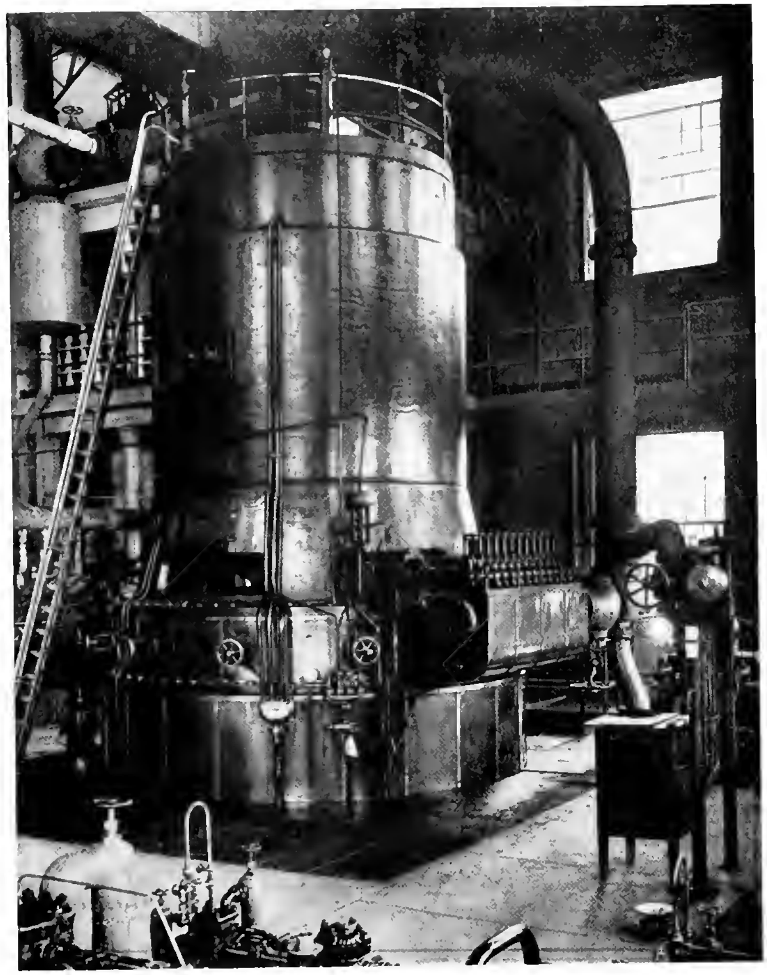


Fig. 2. 9722 Kv-a. Mixed-Pressure Curtis Turbine

In making a statement as to what economies have been accomplished at this plant through the installation of the turbine, it can be better understood if only the three reciprocating electric units and the turbine are considered. The steam consumption of the reciprocating electric units when operating condensing, without the turbine, is 26 pounds per kilowatt-hour based on an output of 6000 kw. When operating with the turbine the steam consumption is but 17 pounds per kilowatt-hour based on an output of 13,000 kw., or a saving of 9 pounds of steam per kilowatt-hour. Let it be assumed that one pound of steam per kilowatt-hour is used for the auxiliaries, leaving a net saving of 8 pounds per kilowatt-hour. Let it also be assumed that one pound of coal at $1.50 a ton (2000 lb.) will evaporate seven pounds of water, making the cost of a pound of steam $0.000107. In a year of 320 days there will thus be a saving of $85,463.04 based on an output of 13,000 kilowatt-hours. If the amount saved annually were capitalized at the rate of 5 per cent. for interest and 10 per cent. for depreciation and upkeep, this would mean that $569,753.60 could reasonably be spent in bringing about this saving in steam by the installation of the turbine and would be an excellent investment. The load conditions at this plant are such that the turbine operates 24 hours a day at about full load, and is shut down for cleaning and inspection every other Sunday. The turbine was put into operation in May, 1910, and has been operating successfully with a negligible amount of repairs since that time.

The condenser is of the surface type and is located directly beneath the turbine. It is equipped with tubes having an outside diameter of one inch, sufficient in number to give an effective cooling surface of 25,000 square feet. An excellent supply of cooling water for the condenser is obtained from Lake Michigan which is close at hand, and it is not an uncommon occurrence in winter to observe a vacuum of $29\frac{1}{4}$ in.

The condenser base was furnished by the makers of the turbine as a part of the machine, while the remainder of the condenser equipment was furnished and installed by the Wheeler Condensing and Engineering Company.

CONFIRMATION OF THE ADVANTAGES OF ELECTRICITY TO THE CEMENT MANUFACTURERS

By J. Benton Porter

Philadelphia Office, General Electric Company

The fact that, of the last twenty cement plants put down in this country, seventeen are using electric drive throughout, is sufficient proof that the claims which have been made regarding the use of electricity in this industrial field are fully borne out by practice. This article, which was originally presented by Mr. Porter before the American Society of Mechanical Engineers, discusses the advantages which are to be obtained. —Editor.

The advantages of electricity in cement manufacture are enumerated in this paper in accordance with information obtained from cement manufacturers.

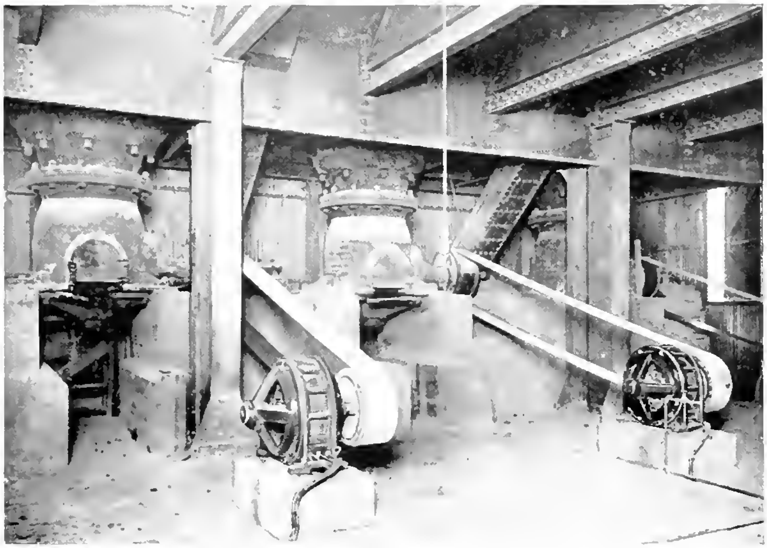
The process of manufacturing cement has advanced in a comparatively short time, from the confines of cement rock to any locality where the necessary ingredients can be found in satisfactory compounds for the raw material. The kilns have grown from the stationary Saylor kiln to the enormous rotary kiln capable of producing over 2000 bbl. in 24 hours. Grinding and crushing machinery has kept pace with this growth until plants having a capacity of less than 2000 bbl. per day are the exception. Electricity has played an important part in this development. Before 1900 the use of the electric drive to any great extent was practically unknown in cement mills; but in the last ten years it has been introduced so extensively, both in old and new plants, that there are now comparatively few that do not use electric motors on at least part of their equipment. In the last three or four years in the neighborhood of twenty new cement plants, representing over 60,000 electric horse power, have been built. All but a very small proportion have used motor drive throughout; while the remainder have used motors for their kilns, crushers and auxiliaries, with engine and line-shaft drive on their main grinding departments.

It is very difficult to make comparisons of the cost of operation of different plants as affected by the method of drive, because it seems to be impossible to find two which are operating under exactly the same conditions. The tube mill, which is supposed to give the steadier output and to require practically the same power continuously, has shown considerable variation. Records have been made of the power consumed on these mills, operating under daily commercial conditions and located in the same plant, where the power varied from 112 to 160 h.p., due

75 H.P., 720 R.P.M., 60 Cycle, 440 Volt, Slip Ring Induction Motors Driving Rotary Kilns. Knickerbocker Portland Cement Company, Hudson, N. Y.

to the height of the pebbles in the mill. By means of electricity this trouble was immediately corrected. Similar differences have been found in practically every other type of grinding machine located in cement mills. The difference in power consumption, or cost of power per barrel, depends so much more on the type of grinding mills, the fineness of the finished product, and the character of the raw material, than on the method of drive, that any conclusions regarding the latter, drawn from concrete figures on different plants, are apt to be misleading. This is true of comparisons between two electrically-driven plants and even more so in the case of mechanical drive, on account of the difficulty of getting accurate load tests on the latter.

The effect of the physical properties of the raw material is well illustrated in the experience of a plant located in the middle west. Here it was found that an additional hammer mill had to be installed to break the material up finer than usual in order to dry it, as it was impossible to expel all of the moisture from the rock when reduced only to the size customary in other plants. The power required for crushing and raw grinding will also vary considerably, depending on the hardness of the rock used.



25 H.P., 600 R.P.M., 60 Cycle, 440 Volt, Induction Motors Driving No. 5 Gyratory Crushers. Knickerbocker Portland Cement Company, Hudson, N. Y.

75 H.P., 400 R.P.M, 60 Cycle, Vertical Induction Motors Driving Giant Griffin Mills Knickerbocker Portland Cement Company, Hudson, N. Y.

The few recently installed plants which were mentioned as having put in a mechanical drive for their main grinding departments, with motors only on the auxiliaries representing about one-third the total power in these plants, have done so because they believed that this reduced their power consumption per barrel output. The theory is that, since the use of electric drive interposes, between the prime mover and the mills, the generator, transmission lines, and motors with their attendant losses—which in the mechanical system are replaced simply by the main belt and line shaft—the economy of the latter should be higher. This may be true with a good mechanical transmission, i.e., one with a minimum of shafting and belts; but there are a number of compensating advantages possessed by the electrical system which tend to raise its ultimate steam economy as compared with the engine drive.

150/375 H.P. Vertical Induction Motor

The most important of these is the fact that *no plant operates at a constant load*, so that the transmission losses, which may be only a small percentage in the mechanical system at full load, are really a considerably greater proportion of the actual average power produced; while with the electrical system the losses are reduced much more nearly in proportion to the reduction in load. There are several reasons why the load on plants is not constant, such as individual mills being shut down for repairs, re-pebbling in the case of tube mills, accidents to elevators or conveyors, and the desire to restrict production.

Readings which have been obtained from a number of different plants indicate that the average load factor, or ratio between the average power used and that required to operate all of the machinery at its full capacity, is only about 80 per cent. This is on the complete plant. On the grinding departments it is somewhat higher, but even there it does not seem to run over about 85 per cent. A typical load curve on an entire plant is shown in Fig. 1, while a similar curve covering the load on the raw grinding department for one day is shown in Fig. 2. A load curve taken on the raw grinding department of this plant, covering its operation over a period of several months, is shown in Fig. 3. Another typical plant when operating under normal conditions averaged only about 80 per cent. of its raw grinding mills in operation, and about 85 per cent. of its finishing mills. These variations cannot but reduce the theoretical efficiency of a mechanical drive, and are still more noticeable in times of restricted production.

The electric drive suffers practically no deterioration in efficiency after it is installed, while a mechanical transmission does. It was found in one cement plant that the friction load, i.e., the power required to drive the transmission belts and shafting, on a group of Griffin mills, was increased from about 7 per cent. to over 15 per cent. on account of wear in the line-shafting bearings. This was of course an abnormal condition, but one which is liable to occur in any mechanically-driven plant. Another respect in which economy can be obtained by the use of the electric drive is that steam turbines may be employed as prime movers. Turbines can show a higher economy at all loads than reciprocating engines, and require less attendance and supplies. A test was made in two central power stations to find wherein the turbine improved the economies. The turbine station, operating under the same conditions of load, coal supply, etc., as the engine plant, reduced the cost of coal 9.9 per cent., while the expense of the operating force, oil, waste, water and sundries, was reduced over 42.9 per cent. From this test is shown the fact that not only coal economy may be accomplished by the turbine installation.

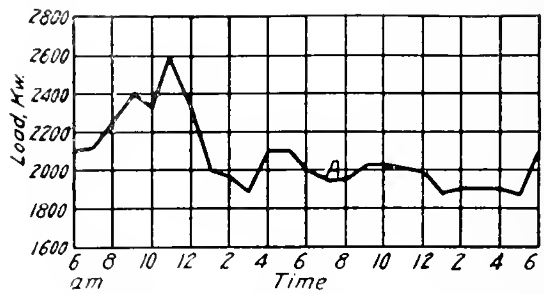


Fig. 1. Load Curve of 3000 Barrel Plant. Hourly Indicating Wattmeter Readings

One of the greatest advantages of the electric over the mechanical drive is flexibility. This applies both to the operation of the power plant and the mill itself. The generating station may contain either two or three units of a total capacity somewhat greater than the maximum demand of the plant. Some cement engineers recommend the use of three units, each of about 40 per cent. of the total capacity required. This permits the operating engineer to keep the load on each unit very near the point of maximum efficiency, even though the plant is operating at a fraction of its rated output. The three units allow adjustments and repairs to be made on any machine without crippling the plant, and the various departments are then more independent of their prime movers. In a mechanically-driven plant extended repairs on an engine can be made only at the expense of shutting down the entire mill or some particular department. This point of flexibility is demanded by the cement engineer in the arrangement of his kilns. No plant with a rated output of 2000 bbl. would consider for an instant the use of a single kiln having an equal capacity.

The flexibility in the operation of the various machines is something that cannot be stated in figures, but which is recognized by all cement men. One superintendent operating a plant driven by large motors on groups consisting of two or more grinding mills, stated that his experience would lead him—in the case of another plant—to subdivide the apparatus still further, putting an individual motor on each mill, in order to make the machines absolutely independent of each other. In another plant where each of the grinding departments was originally driven by an engine, motors have been installed driving the mills in groups. Each department was divided into two groups, so that four motors took the place of two engines. Even with this small amount of subdivision, the production was increased with the same force of men, largely because accidents to mills, conveyors, or belts ceased to shut down the entire department in which

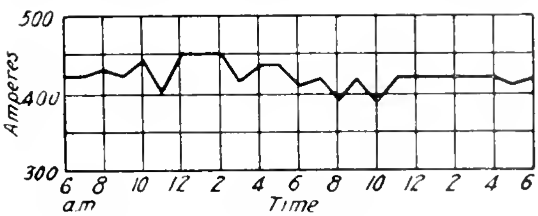


Fig. 2. Load Curve on Raw Mill of 2000 Barrel Plant Hourly Ammeter Reading

they occurred. It is worthy of note, also, that the company which owns this plant is installing individual motors almost entirely in new plants.

The wide latitude which the use of the individual motor drive gives in the operation of a mill is well illustrated in starting new plants. Parts of the apparatus can be put

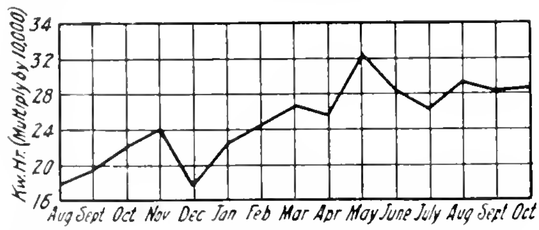


Fig. 3. Curve Showing Variation of Power Used in Raw Grinding Department in 2000 Barrel Plant, by Months

into operation long before the construction is completed on the entire plant. Several months often elapse after starting the first kiln before the plant is in full operation. In the meantime, with the motor drive, the completed portions of the plant are operated under practically normal conditions so far as power per barrel is concerned. This point is not so important in itself, as, of course, a plant only starts once; but it illustrates the ease with which an electrically-operated mill can be run at reduced capacity, a matter which the fluctuations of the cement market force the engineer to consider. The flexibility in the construction of a plant allowed by the use of the electric drive is a point which may affect the future cost of operation considerably. The location of the power station can be governed by such consideration as water supply for boiler feed and condensing, ease of coal-handling and ash-disposal. At least one plant erected in recent years found these considerations important enough, in view of local conditions, to warrant locating the power house nearly a mile from the mill, the saving in cost of operation more than compensating for the energy lost in transmission. The results obtained in this installation have been most satisfactory. It is of interest to note that their cost of repairs on the entire electrical equipment, including about 3000 h.p., in motors and over 2000 kw. in steam turbines, has been less than 1/1000 of a cent. per kw-hr. in the $2\frac{1}{2}$ years of their operation. This is evidence of the reliability of the modern turbine and induction motor operating under the severe conditions of cement plant service.

The electrical apparatus best suited to meet the conditions of the cement industry consists of steam turbine-driven generators and induction motors arranged for the individual motor drive. The induction motor is better fitted to deliver constant speed to the mills than any other form of drive, since it is not affected by heating or fluctuations in voltage. The design of any machinery is made to give its most satisfactory results at a predetermined speed, and if operated continuously at that speed should give its greatest economy. Elaborate tests made on textile mills showed that the mechanical drive gave a speed variation of over 10 per cent. under ordinary operating conditions, but during damp weather the percentage was greatly increased. The installation of induction motors practically maintained a constant speed, increasing the production of these mills in proportion to it, and the cloth was very materially improved by uniform weave. Variation in speed may be due to belt slippage, but in this case it can easily be adjusted with the individual motor drive. The extensive development of vertical belted motors for driving Griffin and Fuller mills has eliminated the necessity for idlers and quarter-turn belts with this type of mill. This is regarded as a decided improvement.

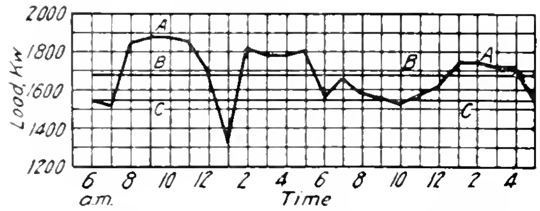


Fig. 4. Load Curve on 2000 Barrel Plant. A, Hourly Readings on Indicating Wattmeter; B, Average of A; C, Average Power Based on Watthour Meter Readings

Without the individual drive it is necessary to equip mills with friction clutches—always a source of trouble and annoyance. One of the advantages of electricity lies in the equipment of compensators with an automatic overload release, often of inestimable value because it can be tripped so as to shut down the motor by a push button, located in any convenient place near the machine. Another advantage is the convenience of testing a mill to see if repairs are needed.

The ease and accuracy with which the power used can be metered and apportioned between the different departments with the electrical system is an advantage of which the cement engineer makes frequent use in locating trouble and reducing cost. Data obtained by the use of indicators with mechanically-driven plants are liable to be inaccurate and to lead to erroneous conclusions, because of the difficulty of taking cards often enough, and over periods long enough, to show the true load curve. This point is illustrated by Fig. 4. Curve *A* shows the apparent load curve obtained on a plant by taking hourly readings of the indicating wattmeter. The average of these readings, *B*, is 1675 kw., which is the apparent power required to operate the mill. The actual average power, however, required on the day of the test, as determined from the recording wattmeter *C*, was only 1554 kw., or 7 per cent. less than would be concluded from the hourly readings alone. It is practically impossible with engine-driven plants to obtain more accurate data than those represented by curve *A*, and it is evident that conclusions as to the actual cost per horse power, or the power used in a certain operation, might be very misleading if based on such readings. Curve drawing and integrating meters, however, give the engineer of an electrically-driven plant an absolute check on both operation and cost.

If curve *B*, shown in Fig. 4, was taken as the basis of average power consumed in a mill, it can be readily seen from Fig. 3, giving the actual power consumed by months, that the average would not be nearly correct. Fig. 3 was used particularly to show the variation in power required on batteries of tube, ball, Kent, Griffin, and similar mills. These types operated in batteries are supposed to require a constant power, and it is claimed, therefore, to be more economical to drive them with an engine. The explanation of these power variations, shown in Fig. 3, may be due to complete shutdowns of this department, or the output may have been cut down by running fewer machines; however, the peak load in May shows the maximum power required and the installation has to be equipped with sufficient power to meet this maximum demand. The mechanical drive provides no means for the improvement of this condition, except to cut out this department when not operating all machines full. The electric drive gives greater flexibility even in this department, as the power consumption is a variable quantity.

The advantages of electricity in the manufacture of cement are confirmed by the engineer. The last 20 plants constructed, with three exceptions, have installed the electric drive complete, and these three have used the mechanical drive only in two departments, and yet the kilns are driven with individual electric motors. It is considered imperative to equip a cement mill with more than one kiln in order to have the flexibility of independent units. The kilns are the arteries and the power plant the heart of the cement industry, and must be equipped with the most dependable power in order to keep it in continuous operation.

CASTING PURE COPPER BY THE USE OF BORON SUBOXIDE

By R. D. Thomson

Supply Department, General Electric Company

A satisfactory process for making sound, pure copper castings long resisted all efforts at its discovery, although an immense amount of research work was done in this direction. As the result of the work of Dr. E. Weintraub, it is now possible to obtain pure copper castings of complicated form by adding boron suboxide in proper proportions to the molten copper. Castings poured from this metal show high conductivity and a homogeneity of structure equal to that of forged copper. Pieces of intricate shapes, formerly built up from rolled copper, are now cast from this deoxidized copper at a great saving in cost.—Editor.

Along with the development of electrical machinery and apparatus there has been a great demand for mechanically sound, high conductivity cast copper. A vast amount of effort has been expended in the search for some process by which castings could be made, which would compare favorably with forged copper. Many compounds have been on the market and many foundrymen claim to have secret processes for accomplishing the desired result, but in no case has the result, if satisfactory, been commercially practicable. Some eight years ago it was found that sound castings could be made in metal moulds, using "poled" copper of tough pitch, such as is used in wire making; but the method was not practicable because of the cost of the moulds, and because the casting had to be done in a refinery and not in a foundry.

For years progress had been away from the use of cast copper, and this in itself added an obstacle to the production of this copper.

Fig. 1. Structure of Cast Copper Just Beyond Original End of Bar

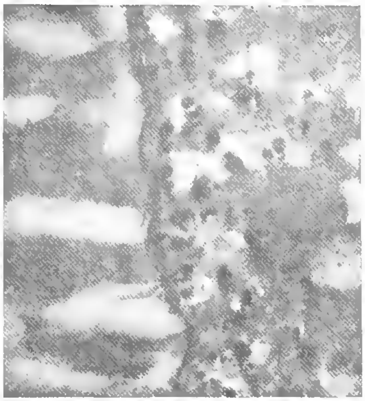


Fig. 2. Line Between Bar and Casting

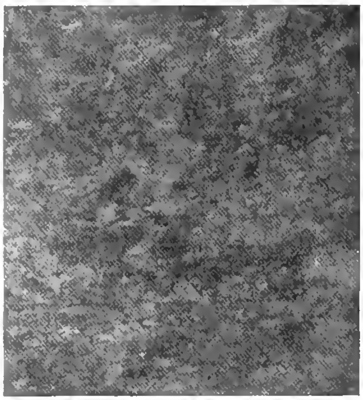


Fig. 3. Structure of Drawn Bar Copper

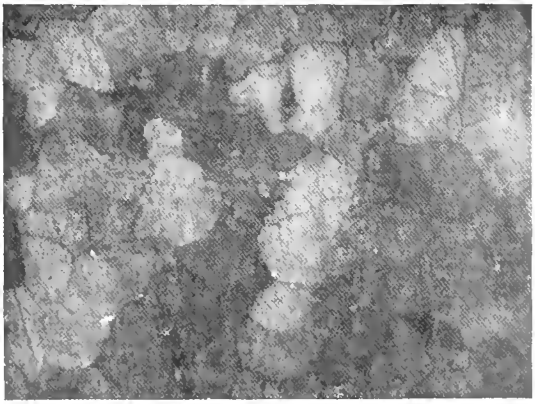


Fig. 4. Tough Pitch Copper Cast in Iron Mould. Transverse Section Near End of Bar

Fig. 5. Cast Copper Deoxidized with Boron Suboxide. Section Near Gate End

In spite of the failures and discouraging results of others, Dr. E. Weintraub, of Lynn, Mass., finally succeeded in producing the long-sought-for substance by the addition of boron suboxide to molten copper. It is now a simple matter to cast sound, high conductivity copper in either sand or metal moulds. Already, in the short space of two years, the tendency to discontinue the use of cast copper has been overcome and the process come into extensive use in the foundries of electrical manufacturers and elsewhere.

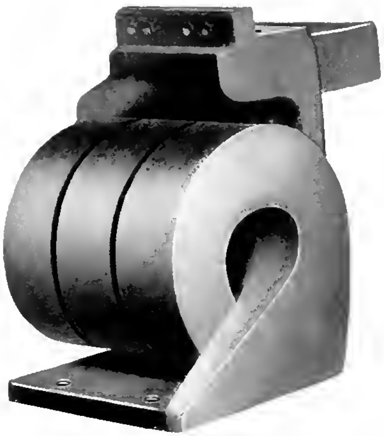


Fig. 6. Blow-out Coil Cast in One Piece by the Use of Boron Suboxide. Turns Squeezed Together After Casting

In order to get high conductivity when using boron suboxide, it is essential to start with pure copper, as the compound is not a purifier but simply a deoxidizer. If impure copper is used the casting will be sound, but the conductivity will be reduced in proportion to the amount and kind of impurity present.

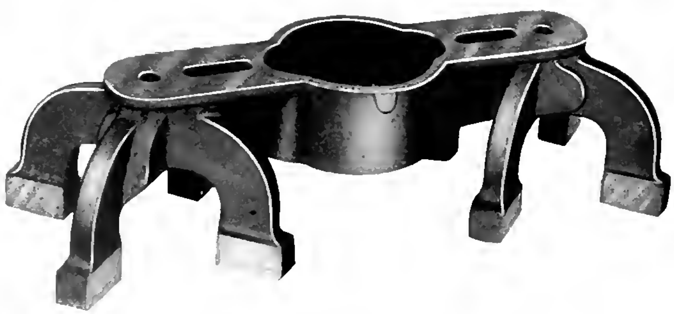


Fig. 7. Crosshead for 3000 Ampere Oil Switch Cast from Pure Deoxidized Copper

The copper is heated to a temperature approaching 1350 deg. F. and the suboxide added, the reaction taking place immediately. At lower temperatures the reaction takes place slowly and there is danger that the copper will cool down too much to cast before the reaction is completed. Best results are obtained by the use of one per cent. by weight of the compound added to the copper; that is, one pound for every one hundred pounds of metal melted, although the amount may be somewhat diminished or increased without perceptibly changing the action. This gives us a process, therefore, which can be handled by any foundryman and which will always give the desired result.

Fig. 8. Series Coil of Pure Copper, Cast in One Piece by the Use of Boron Suboxide

Castings made in this way are mechanically sound throughout, being entirely free from blow holes, and can be readily machined. Electrical conductivity as high as 97 per cent. has been obtained, while in general practice it is found to be 88–90 per cent. Many shapes and sizes are being made at present with no more difficulty than in the case of brass, while some other castings are being made which cannot be made in brass, because of the difficulty in getting homogeneity. Among the simple parts are to be found conductors, terminals, collector rings, contact blades, etc., etc. In many cases a saving is being effected through the reduction in bulk made possible by the increase in conductivity, especially where high mechanical strength is not essential. Fig. 7 shows a successful, pure copper casting, complicated in form.

It is also interesting to note here the remarkable results obtained by casting this copper to drawn bar copper. For instance, Figs. 1 and 3 show the structure of the two metals each side of a weld, while Fig. 2 shows the union itself. The weld is perfect and absolutely free from the blow holes which have characterized this sort of work. Undoubtedly there is an extensive field opened in this direction for the use of this new compound. Figs. 4 and 5 show respectively the structure of tough pitch copper cast in an iron mould and copper cast in a sand mould after being deoxidized with boron suboxide. Note the density of the deoxidized copper.

The advantages gained by the use of pure cast copper are not limited to the qualities of high electrical conductivity and mechanical soundness. In addition to these important

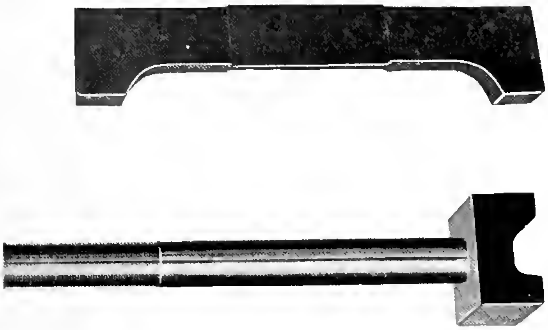


Fig. 9. 15,000 Ampere Contact Stud and Switch Blade, Cast of Pure Deoxidixed Copper

characteristics it has been found that the copper is capable of taking very complicated moulds, making it possible to use castings where formerly the pieces were built up, requiring the machining of surfaces and the introduction of joints into the construction. Take for example, the blowout coil shown in Fig. 6. This coil was formerly built up from bar copper wound to form, the terminal pieces being riveted and soldered in place, as it was impossible to cast this by ordinary methods. The very first attempt in a sand mould, using the deoxidized copper, resulted in a perfectly sound, one-piece casting, and now this process is used entirely in the manufacture of these coils, replacing those built of several parts, with considerable saving of time and cost.

Castings made from this pure copper compare very favorably with forged copper, and there are, therefore, innumerable places where castings may be used with great saving. Undoubtedly the placing of this compound on the market will see a return to the use of cast copper. Figs. 7, 8 and 9 show a few of the many interesting castings now being made commercially.

The latest reports show that the Schenectady Works of the General Electric Company alone have cast more than 35,000 pounds of this copper in the last year, while the Lynn and Pittsfield Works have cast 18,121 and 9533 pounds, respectively, in the last six months. There can be little doubt that the casting of mechanically sound, high conductivity copper has passed the experimental stage and is an important development in the electrical, as well as in the metal industry.

THE DIFFERENT METHODS OF CONNECTING THREE-PHASE ARMATURE WINDINGS FOR SINGLE-PHASE SERVICE

By W. J. Foster

Alternating Current Engineering Department, General Electric Company

The most common type of polyphase generator is so wound that it may readily have its circuits connected for six-phase service. Figs. 1, 2 and 3 show six circuits, in which the e.m.f's are generated at 60 deg. time intervals. Each circuit at normal magnetization generates 1000 volts and, hence, two adjacent circuits in series generate 1732 volts. Fig. 1 shows the delta and Fig. 3 the star connections of three-phase windings, in which terminals 1, 3 and 5 are for three-phase service. 1 and 3 may be used as single-phase terminals. Fig. 2 shows the delta connections with terminals 1, 3 and 5 for three-phase and the diametrical terminals 1 and 4 for single-phase. Hence, in this case only one terminal is common to both single-phase and three-phase. For convenience, we will discuss single-phase output of 519.6 kv-a.

By far the most common method of connecting armature windings for single-phase service is shown in Fig. 3. One of the three phases carries no current whatever when the generator is used exclusively single-phase. When operating exclusively three-phase with balanced load and same current, 173.2 amperes in every circuit, the output becomes 900 kv-a.

The relative I^2R in armature windings at output of 519.6 kv-a., single-phase, is for the different connections as follows:

	Fig. 1	Fig. 2	Fig. 3
I^2R in heaviest loaded circuit .	400	169	300
I^2R in all six circuits . .	1200	1014	1200

It thus appears that the I^2R total is the same for delta or star connections, Figs. 1 and 3, but is less for the diametrical connection Fig. 2; but the I^2R in certain sections is much greater in the delta connected (Fig. 1) than in either of the others. This makes it impossible to obtain as large output single-phase for delta connections in the case of high potential generators, where the limit of the rating lies in the heating of the individual armature coils. A consideration of the case of a high potential three-phase generator with coils designed to carry 173.2 amperes, results in single-phase ratings as follows:

Fig. 1

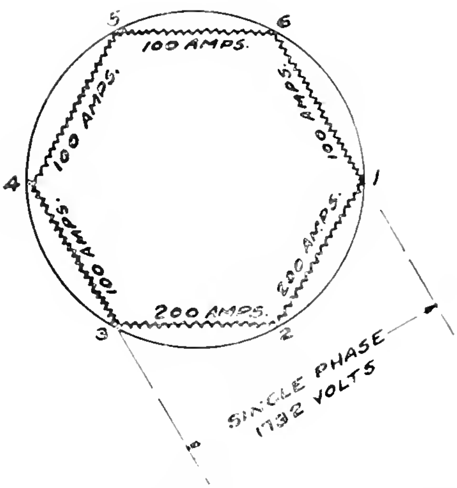


Fig. 2

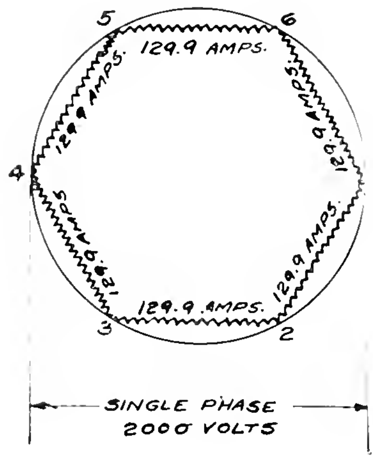


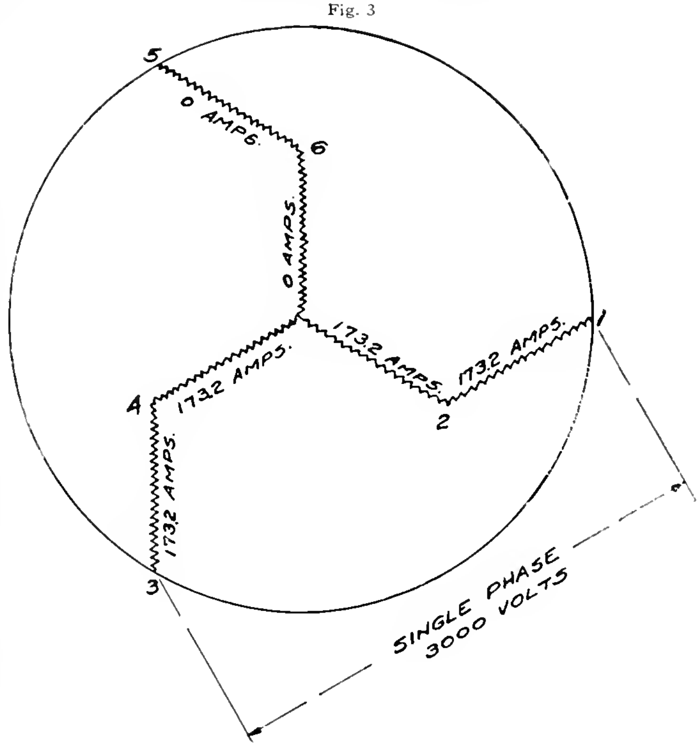
	Fig. 1	Fig. 2	Fig. 3
Kv-a. single-phase	450.0	692.8	519.6
Per cent. of three-phase 900 kv-a.	50	77	58

The armature reaction is the same for any given kv-a. load for the three different methods of connecting. The single-phase load with armature reaction and, consequently, excitation the same as for 900 kv-a. three-phase, is approximately 600 kv-a., or $66\frac{2}{3}$ per cent. of the three-phase rating. It thus appears that the diametrical connection (Fig. 2) is necessary in the case of a closely designed high potential generator, to allow the single-phase rating to be as high as 70 or 75 per cent. of the three-phase rating.

The pulsating magnetic flux, peculiar to single-phase alternators, is the same for all three connections, since it is dependent upon the armature reaction. The double frequency hysteresis losses, due to this pulsating flux, always cause greater heating of the iron parts, especially the pole faces, than exists in the generator operating three-phase. Hence, in the case of the diametrical connections, the losses incidental to the double-frequency effects must be reckoned with, as well as the field winding, in determining the possible single-phase rating.

The potential wave at the single-phase terminals of commercial generators is not the same for any two of the three methods of connecting. The star connected (Fig. 3) is the safer in that the third harmonic is cancelled out. The closest approximation to

Fig. 3



Diagrams for Connecting Three-Phase Generator to Single-Phase (519.6 Kv-a.)

a sine wave, as a rule, is obtained by the diametrical (Fig. 2). It is often possible by proper selection of pole chamfer, pitch of winding, etc., to eliminate the third harmonic. Such precaution should be taken whenever either the plain delta or diametrical connection is contemplated.

It remains to discuss the unbalancing of potential at the three-phase terminals. This unbalancing varies with the single-phase load. With generators as ordinarily designed for 25 per cent. overload, the current on short-circuit with excitation for full non-inductive load is approximately $2\frac{1}{2}$ times the rated full load current. Such generators, operating at full load single-phase and no load three-phase have unbalanced voltages expressed in percentages about as follows:

	Figs. 1 and 3	Fig. 2
Volts across 1–4	. . .	100
Volts across 1–3	100	95
Volts across 3–5	115	95
Volts across 5–1	101	82

It thus appears that the unbalancing is the same in Figs. 1 and 3, or in the ordinary delta and star connections; and furthermore, that there is no gain in the matter of balancing of volts on three-phase terminals by connecting as per Fig. 2. This has two high and one low, while the others have one high and two low, but this diametrical connection has the disadvantage that the single-phase potential is several per cent. higher than the three-phase.

The conclusion to be drawn is that it is highly desirable to design armature windings for the diametrical connection in all cases where a generator is to be used exclusively single-phase. There may also be many cases where it should be used when some three-phase load is to be carried. Such a generator is just as adaptable at any time to either three-phase or six-phase service exclusively as any other except, that its potential three-phase is only 87 per cent. of the single-phase, and may require special transformers.

An ingenious method of taking single-phase current from a polyphase armature by means of a transformer is shown in Fig. 4. This method was suggested by Mr. H. M. Hobart as a possible means of reducing the unbalancing at the three-phase terminals. It is evident that the e.m.f's. 1-2, 6-3 and 5-4 are absolutely in phase on open-circuit, and

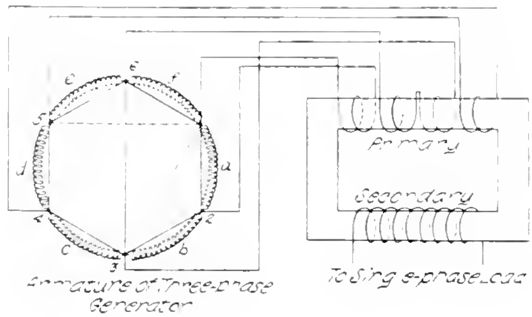


Fig. 4

that 1-2 and 5-4 are of same magnitude, while 6-3 is just double. The transformer has four identical coils in the primary, one of which is connected to terminals 1 and 2, another to 5 and 4; the remaining two coils placed in series are connected to 6 and 3. As soon as the transformer is thrown on, the e.m.f's. become slightly out of phase with one another and also change in magnitude. Mutual inductance in the transformer coils assists the single-phase armature reaction in the alternator in causing unequal currents in the several circuits. A great variety of results may be obtained by changing the details of connections, such as placing the two outer coils of the transformer primary, (instead of the two middle) on terminals 6 and 3. Reactive coils may also be used between armature and transformer. Undoubtedly better conditions can be obtained in the matter of balanced voltages on the three-phase terminals 1, 3 and 5 by the use of the transformer than by any of the three methods of direct connection to load shown in Figs. 1, 2 and 3. The division of work in the armature winding, however, approximates the poorest of the direct connections, viz., that of Fig. 1, unless by the use of reactive coils more than one-half of the load is thrown on terminals 6 and 3, in which case the primary coils of the transformer are unequally loaded. This method of obtaining single-phase current may be found desirable in certain cases.

NOTES ON THE OPERATION OF THE WASHINGTON, BALTIMORE & ANNAPOLIS RAILROAD AS A 1200-VOLT SYSTEM

By John R. Hewett

Railway and Traction Engineering Department, General Electric Company

In the November, 1910, Review we published an article by Mr. Hewett describing the conversion of the Washington, Baltimore and Annapolis Railroad from 6600 volts alternating current to 1200 volts direct current, in which general particulars of the system were given and a detailed description of the d-c. equipment included. Railway men have been watching for the results with considerable interest, and we are glad to be able to publish a further article from Mr. Hewett this month showing the economies which have been effected, the satisfactory behavior and endurance of the apparatus, and how the expectations of the management of the road have been more than realized.—Editor.

Some of the ruling factors which led to changing the Washington, Baltimore & Annapolis Electric Railroad from 6600-volt alternating current to 1200-volt direct current operation should be cited before showing the economies secured by the change.

Many of the operating conditions were peculiar to the system. The run from the White House depot, on the outskirts of Washington, to the center of the city is over an underground conduit system, which, owing to its limited strength prohibited the use of cars weighing more than 40 tons. This was lighter than single-phase cars, capable of performing the service, could be built. Formerly, with alternating current operation, it was necessary for the passengers to change cars at the White House interurban depot, while now the 1200-volt interurban cars run right to the center of the city. Another reason for the change was that the curves in Baltimore, around which it was desired to operate in trains, demanded a shorter car than those used for the single-phase operation. The third reason was the high operating expenses, particularly the car-barn expenses. When the change was made the weight of cars was reduced from 59 to 39 tons, and the seating capacity per car from 66 to 54 passengers.

From the following statements it will be noted that the change from alternating current to direct current operation has secured a saving of approximately 40 per cent. in the railway company's power bill. This wonderful showing is partly accounted for by the good inherent characteristics of the 1200-volt apparatus, and partly by the peculiar conditions which existed before the change. With single-phase operation short stretches of track at Baltimore and at Annapolis were operated by 600-volt direct current, which was furnished by single-phase motor-generator sets taking power from the single-phase trolley. When the change was made to 1200-volt direct current operation these sections were tied directly to the interurban trolley.

To maintain the same time table with 1200 volts direct current as was formerly maintained by 6600 volts alternating current, a reduction in the maximum speed was found possible as the rate of acceleration was increased; this factor accounts for a saving in power, as losses in the brake shoes are reduced.

It is interesting to note that the final substitution of 1200-volt apparatus for alternating current apparatus was made in a single night, and that not one trip of the regular time table was missed on the first day of change.

The reduction of car-barn expenses since the change-over is perhaps one of the most significant advantages which have been derived. The following figures speak for themselves:

	1909 A-C. Operation	1911 D-C. Operation
Number of cars	23	44
Car-barn employees	63	27
Car-barn expenses per car mile	3.72 cts.	1.37 cts.

A complete analysis of these expenses for direct-current operation is as follows:

	Operating Expenses	Cents per Car Mile
32	Passenger and combination cars	$0.37
33-a	Freight cars	.05
33-b	Express cars	.00
33-c	Mail cars	.00
34	Locomotives	.00
35	Service cars	.04
36	Electric equipment of cars	.21
37	Electric equipment of locomotives	.00
38	Shop machines and tools	.02
39	Shop expenses	.18
66	Car house employees	.50
67	Car house expenses	.00
	Total	$1.37

The above figures refer to a period of nine months ending December 31, 1911. The original carbon brushes furnished with the motors have now run over 130,000 miles and show less than 1/8 in. wear; not one brush has been renewed. The brushes on the dynamotors have run over 130,000 miles; not one has been renewed. The brushes on the compressors have run over 130,000 miles; not one has been renewed. The wear on all of the above brushes is so small that after over 130,000 miles of service there is not sufficient wear to enable any prediction as to their ultimate life. All of the original armature bearings are still in service after having run over 130,000 miles. The axle bearings average 40,000 miles, and the journal bearings 85,000 miles, before being re-babbitted. The average wheel mileage per turning is 45,000 miles. Owing to the thorough methods of inspection which are in vogue on the road, which call for an inspection after every 1500 miles of service and a general overhauling after every 45,000 miles of service, the above figures do not represent the life of bearings, etc., used up to their ultimate wearing life; but, rather, show what the management consider a good policy as regards re-babbitting.

It is of special interest to note that the original car-control-contact burning tips furnished with the equipment are still in service, and that not one burning tip has been renewed. No arc-chutes have been replaced.

As a point of general interest it may be mentioned that the average cost per 1000 wheel-miles for brake shoes is $0.0875, and that the wheel mileage per brake shoe amounts to 8838 miles; also, that the trolley wheels cost per 1000 car miles $0.2246, and that the average car-miles per wheel is 3693.18.

The record for the small double-truck city car used in Annapolis, which has been in continuous service for seventeen months, is of special interest as there have been no expenses of any kind for replacements on this equipment, with the exception of the renewal of fifteen resistance grids which were burnt out by coming into contact with very heavy snow. This happened in January, 1911, and no replacements of any kind have been made on this car since that date.

Troubles on Car Equipment Caused by Lightning

During the year 1911 there was an unusual amount of damage done by lightning throughout the State of Maryland and District of Columbia; but the entire damage done to car equipments on the Washington, Baltimore & Annapolis Electric Railroad amounted to but $71.10. In each case the damage was quickly and cheaply repaired.

Notes on Substation Operation

Since the 1200-volt equipment has been installed, no new brushes have been put in on the direct current side of the synchronous converters (the converter equipment of the whole road consists of fifteen units); there have been no flashovers; no commutators have been turned down; there has been no trouble with direct current circuit breakers; no trouble with or repairs to switchboards since the road was started up; while the cost of substation maintenance has been practically nil.

Lightning

The alternating current side is protected by aluminum cell arresters on the 33,000 volt line and on the direct current side. No trouble of any kind has been experienced from lightning in any substation since these arresters have been installed, which was considerably over a year ago. As stated above, the change from 6600-volt operation to 1200-volt direct current operation was made on the night of February 14-15, 1910; and therefore the power record for the month of February is an excellent means of comparing the relative power consumption of the two systems.

POWER REPORT FOR FEBRUARY, 1910

	Feb. 1–14 A-C. Operation	Feb. 14–28 D-C. Operation
Kw-hr. consumption	374,880	231,895
Car-miles (interurban)	57,287	58,809
Kw-hr. per car mile	6.54	3.94
Peak load (average)	1491	1101
Cost per car mile	0.0617	0.0391

The most significant point in the above statement is that the kw-hr. consumption per car mile is just about one-half for the direct current operation, as compared with alternating current operation; and accordingly the cost for power per car-mile has been cut almost in half.

The following notes are from the Power Report for the entire year of 1910 and for nine months (April-December) 1911. The figures are in all cases the average per month.

	Average per Month 1910 D-C. Operation	Average per Month 1911 D-C. Operation
Kw-hr. consumption	555,000	512,500
Car miles (interurban)	138,300	144,000
Kw-hr. per car mile	4.015	3.561
Peak load	1182	1195
Cost per car mile	0.0386	0.0352

The following detailed analysis of the operating expenses and the general statistical data show a most satisfactory condition of operation and should prove of use to all interested in interurban railway operation.

DETAILED OPERATING EXPENSES FOR 9 MONTHS 1910 AND 1911

	Operating Expenses		9 Mos. to Dec. 31 Cents per C.M. 1911	1910
	I. WAY AND STRUCTURES			
1	Superintendence of way and structures	*	0.55	0.60
2	Ballast	*	0.04	...
3	Ties	*	0.09	0.28
4	Rails	*	0.01	...
5	Rail fastenings and joints	*	0.01	0.04
6	Special work	*	0.03	0.02
7	Underground construction	*	...	...
8	Roadway and track labor	*	1.02	1.29
9	Paving	*	0.12	0.10
10	Miscellaneous roadway and track expenses	*	0.03	0.06
11	Cleaning and sanding tracks	*	0.08	0.07
12	Removal of snow, ice and sand	*	...	0.04
13	Tunnels	*	...	...
14	Elevated structures and foundations	*	...	...
15	Bridges, trestles, and culverts	*	0.04	0.25
16	Crossings, fences, cattle guards and signs	*	0.02	0.02
17	Signal and interlocking systems	*	0.06	0.04
18	Telephone and telegraph systems	†	0.04	0.06
19	Other miscellaneous way expenses	*	...	0.01
20	Poles and fixtures	*	0.05	0.06
21	Underground conduits	*	...	...
22	Transmission system	†	0.05	0.03
23	Distribution system	*	0.25	0.39
24	Miscellaneous electric line express	*	...	...
25	Buildings and structures	*	0.21	0.11
26	Depreciation of way and structures	*	...	...
27	Other operations—Dr.	*	...	...
28	Other operations—Cr.	*	...	...
	TOTAL WAY AND STRUCTURES		2.70	3.47
	II. EQUIPMENT			
29	Superintendence of equipment	†	0.13	0.22
30	Power plant equipment	*	...	...
31	Substation equipment	†	...	0.01
32	Passenger and combination cars	†	0.37	0.29
33a	Freight cars	*	0.05	0.05
33b	Express cars	†	...	...
33c	Mail cars	†	...	...
34	Locomotives	†	...	...
35	Service cars	*	0.04	0.04
36	Electric equipment of cars	†	0.21	0.19
37	Electric equipment of locomotives	†	...	...
38	Shop machinery and tools	†	0.02	0.01
39	Shop expenses	†	0.18	0.10
40	Horses and vehicles	*	0.02	0.04
41	Other miscellaneous equipment expenses	†	...	0.01
42	Depreciation of equipment	†	...	...
43	Other operations—Dr.	*	...	...
44	Other operations—Cr.	*	...	...
	TOTAL EQUIPMENT		1.02	0.96
	III. TRAFFIC			
45	Superintendence and solicitation	†	0.31	0.40
46	Advertising	†	0.44	0.56
47	Miscellaneous traffic expenses	†	0.01	0.03
	TOTAL TRAFFIC		0.76	0.99

* Interurban. † Entire system.

DETAILED OPERATING EXPENSES FOR 9 MONTHS 1910 AND 1911—Continued

	Operating Expenses		9 Mos. to Dec. 31 Cents per C.M. 1911	1910
	IV. CONDUCTING TRANSPORTATION			
48	Superintendence of transportation	†	0.40	0.40
49	Power plant employees	*	...	...
50	Substation employees	†	0.34	0.32
51	Fuel for power	*	...	...
52	Water for power	*	...	...
53	Lubricants for power	*	...	...
54	Miscellaneous power plant supplies and expenses	*	...	...
55	Substation supplies and expenses	†	0.02	0.01
56	Power purchased	*	3.66	3.73
57	Power exchanged—balance	*	...	...
58	Other operations—Dr.	*	...	...
59	Other operations—Cr.	*	...	...
60a	Passenger conductors	†	1.50	1.37
60b	Passenger motormen	†	1.50	1.42
60c	Other passenger trainmen	†	0.01	0.01
61a	Freight and express conductors	†	0.14	0.11
61b	Freight and express motormen	†	0.14	0.12
61c	Other freight and express trainmen	†	0.20	0.20
62	Miscellaneous car service employees	†	0.18	0.14
63	Miscellaneous car service expenses	†	0.23	0.45
64	Station employees	†	0.90	0.86
65	Station expenses	†	0.33	0.34
66	Car house employees	†	0.50	0.50
67	Car house expenses	†	...	0.01
68	Operation of signals and interlocks	*	0.07	0.10
69	Operation of telephone and telegraph	†	0.04	0.03
70	Express and freight collections and deliveries	†	...	0.07
71	Loss and damage	†	0.01	0.02
72	Other transportation expenses	†	0.02	0.02
	TOTAL CONDUCTING TRANSPORTATION		10.19	10.23
	Items 73–88:			
	Total, general and miscellaneous		3.32	3.04
	TOTAL OPERATING EXPENSES		17.99	18.69

* Interurban † Entire system.

MONTH OF DECEMBER AND 9 MONTHS TO DECEMBER 31ST

		Month of Dec. 1911	1910	9 Mos. to Dec. 31 1911	1910
	1. TRAINS AND CARS OPERATED				
a	Number of trains operated	4139	4146	35954	37977
b	Number of cars operated	4754	4466	42415	42494
	2. CAR MILES				
a	Passenger cars, on W. B. & A. tracks	138114	.....	1245813	....
b	Special cars, on W. B. & A. tracks	134	.....	9292	......
c	Total passenger and spec., on W. B. & A. tracks	138248	133722	1255105	1231583
d	Freight cars, on W. B. & A. tracks	5384	6124	52358	48014
e	Total passenger spl. and freight, on W. B. & A. tracks	143632	139846	1307463	1279597
f	Service cars, on W. B. & A. tracks	2969	1194	16785	19496
g	Total car miles, on W. B. & A. tracks	146601	141040	1324248	1299093
h	Passenger cars, on W. Ry. & E. tracks	22561	21525	203572	203583
i	Freight cars, on W. Ry. & E. tracks	256	244	2521	2461
j	Total car miles, on W. Ry. & E. tracks	22817	21769	206093	206044
k	Total car miles, on all tracks	169418	162809	1530341	1505137
l	Items c and h, on all tracks	160809	155247	1458677	1435166
m	Items d and i, on all tracks	5640	6368	54879	50475

ESSAYS ON VOLTAGE REGULATION

Part I

By F. W. Shackelford

Supply Department, General Electric Company

Where lighting and power are supplied from the same mains, the fluctuations in the voltage are so large and frequent that efficient control by hand is practically impossible. Even where the two classes of service are supplied from independent mains and generators, the IR drop has to be contended with on the lighting circuits, and demands the almost constant attention of the switchboard attendant. The installation of a generator automatic voltage regulator, preferably when constructing the station, will obviate the necessity of carrying the lighting and power loads on separate mains, and should thus result in considerable economy for the central station. For larger systems, possessing many feeders, it is further necessary to regulate each feeder independently; several methods for accomplishing this regulation being outlined in the article. The author also offers some suggestions, with diagrams, for laying out a new system of distribution or for reconstructing an old one.—Editor.

In great or small undertakings for the generation, transmission and distribution of electric energy for public service, there enters the element of voltage regulation. Is it better to plan, build and operate an electric property before investigating the voltage regulation of the system, or is it better to plan the equipment initially and take into consideration this problem of regulation? These are questions which no doubt have as many supporters on the one hand as opposers on the other, and each faction can give apparently good reasons for its opinions. In taking up this subject, therefore, we will first endeavor to deal with the more general problems of voltage regulation and then consider a few special or unusual cases to see if it is a practicable and economical plan to prepare for conditions that we calculate will exist.

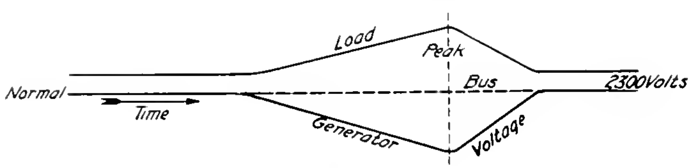


Fig. 1

In these days our central stations are after load factor, and to get this in a country where, on an average, daylight exists for the better part of the twenty-four hours, means that electrical energy must be adapted to the driving of power machinery, thus furnishing an application for this energy during the hours of the day.

Now it is not necessary in the majority of cases to regulate the voltage delivered to motors, but the fact that we have motors on the line from which we are trying to deliver lighting, brings in the element of variation of potential, caused not only by the IR drop of the line, but possibly by the power-factor and the cycle of service required in case of intermittent motor loads.

With stations, therefore, which have both power and lighting to supply, there is always the certainty that this power load will overlap the lighting; the length of this overlap depending on the weather and season. In the northern section of the States, the overlap during December and early in January is greater, and the lighting peak may be on before the power load has decreased to any extent. It is apparent, therefore, that in the case of combined power and lighting we have two conditions to deal with; one the gradually increasing IR drop as the lighting load increases, and the other the sudden and decided decreases and increases in this potential, caused by throwing large motors on and off the service lines.

For instance, if we have a purely lighting load and set the generator rheostat for 2300 volts at normal load, leaving it in that position, we will find that the voltage gradually drops as the load on the bus increases, until the peak is reached; then as the load decreases, the voltage will increase until it again attains normal value, corresponding to the load for which the voltage setting was originally made (Fig. 1).

In the case of Fig. 2, which also represents a lighting load, the resistance in the generator rheostat is cut out at such a rate as to maintain constant voltage on the bus as the load increases. If then, after the load has reached a maximum, the generator rheostat is not disturbed, the rise in voltage from peak load to normal load will be proportional to the average drop in the system at peak load. The change in voltage resulting from a gradual change in load of this kind can be taken care of by the operator, but his personal equation is sometimes likely to cause an increase or decrease in generator voltage disproportionate to the requirements of the load.

It is practically impossible for the operator to take care of such a load change as that indicated in Fig. 3, which represents a power load, by adjusting the generator field rheostat, and therefore the necessity of having some means of automatically controlling the generator voltage so that its voltage will be proportional to the load is evident.

Many of the stations do not combine the lighting and power loads, some using separate busses fed from different generators, others feeding a common bus from generators and carrying separate power and lighting lines to the respective loads. In the first case the lighting voltage is independent of power voltage, but we still have the drop; and in the second case, while the lighting is separated from the power, the power fluctuations are reflected on the lighting circuit, and we have both the drop and the resultant bus fluctuations. With means of automatically controlling the generator voltage, there should be an advantage in carrying both lighting and power on the same feeder. The question of the relative merits of the different systems of distribution has no bearing on the subject of voltage regulation, except as to the degree to which each is susceptible of such regulation. It will, therefore, be well to investigate first the regulation of the generator station, and later to show how regulation of the several systems of distribution may be effected.

In Figs. 1 and 2 we have considered characteristic drops on lighting circuits, while Fig. 3 gives an example of power load fluctuations; but in addition to these effects, we may have other causes of voltage disturbances, resulting from poor regulation of prime movers.

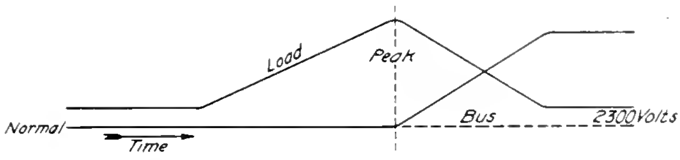


Fig. 2

With the slow speed type of prime movers generally in use until a few years ago, the speed regulation was effected by the use of heavy flywheels and some form of mechanical governor. When at full speed, however, the heavy revolving elements were sluggish in response to the controlling mechanisms, with the result that the speed was very irregular, first racing above and then falling below normal, unless all adjustments were practically perfect. With the modern high speed turbines and waterwheels it is possible to obtain

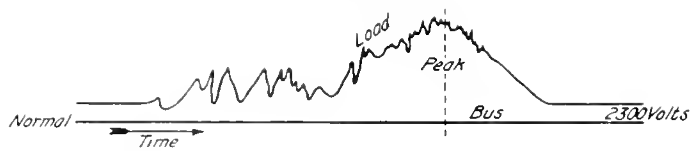


Fig. 3

a good degree of regulation, but even so, under certain conditions of load, etc., the effect of speed regulation is clearly evidenced in the voltage variations.

Now in order to secure good automatic regulation of the generator voltage, the controlling device should act instantly, or actually before any degree of speed change, and not only handle variations in voltage due to speed change, but compensate for the inherent regulation of the generators and the variations due to load changes. An automatic device of this kind would then force the generating units to deliver energy in proportion to the load demand.

The most successful instrument of this kind is the automatic generator voltage regulator, the construction of which is doubtless familiar and needs no explanation here. This automatic generator voltage regulator is now used in more than 75 per cent. of the central stations in the United States, and there are only a few cases—very exceptional—where it cannot be applied to advantage. One example is found in generators that have sluggish field circuits, and another in exciters that will not deliver sufficient magnetizing current at maximum load demand; in both of which cases quick response to excitation changes is impossible. One regulator can take care of all the machines in the station, and if the generators and exciters are responsive to the regulator control, the voltage can be held strictly at normal.

There is no practicable advantage in waiting until a station is put in operation before installing this device; *it should always form part of the initial generator equipment.*

DISTRIBUTING NETWORKS

In small plants where only one feeder is operated the regulation of the generator can be made to conform to the regulation required by the feeder; but when we deal with larger systems, and with many feeders, the regulation is a problem which has to be worked out with respect to both economically minimizing the number and predetermining the capacities of the feeders and to designing a symmetrical system of network.

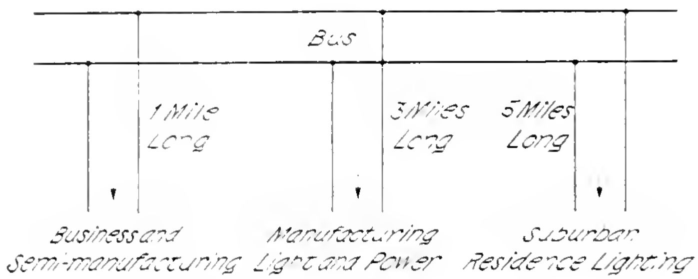


Fig. 4

The feeding system can be made very simple and economical if care is exercised at the time the initial layout is made, and it would no doubt be a good investment for many existing plants to thoroughly investigate their feeding systems with a view to making them more symmetrical and of uniform regulation.

In laying out a new system or reconstructing an old one, it is an excellent plan to divide the area to be lighted into districts and determine the maximum kilovolt-ampere capacity to be handled in each district, bearing in mind the advantages of having, in so far as possible, the feeders as nearly equal in capacity as practicable. This insures symmetrical switchboards and feeder equipments, and simplicity of maintenance. It is usual when selecting or subdividing the total area to be lighted to take into consideration the actual anticipated loads in each subdivision, so that the laying out of feeders is by no means a mere stringing-up of copper wherever a light is needed. Forethought in this respect often saves considerable expense in the future growth of the system. For example: one district may be 90 per cent. loaded, while another may be only 50 per cent. loaded. The latter, however, we will say, is of such a character as to lead the lighting company to believe that there are prospects of a load equally as great as in the former. If the latter feeder is a duplicate of the first, it would, of course, have much less drop; but in the end if care has been exercised the extra cost and fixed charges of copper necessary to handle the anticipated load is cheaper than if only sufficient copper were installed to take care of the actual load and a smaller percentage of anticipated load. A diversified load fed from a common bus is illustrated in Fig. 4 and it can readily be seen that the load periods of the three feeders will differ considerably.

The feeding system may be single-phase, quarter-phase, three-wire or four-wire, or three-phase, three-wire or four-wire; but in any event we would determine the center of distribution of each section in the same manner.

Fig. 5 represents a section to be fed. The load center of each block is obtained by taking the individual loads and determining their center of load by proportionate distances in the ratio of their capacity. Thus, referring to Fig. 5, the loads in blocks "A" and "B" equal 65 kv-a. The load center of "A" and "B" is 50/65 of the distance between "A" and "B," and is at a point marked "a." Likewise, the center of "a" and block "C" is at "b." By continuing this process we find that the total load would be concentrated at "Z." "Z" would be the logical point at which to feed the network, but

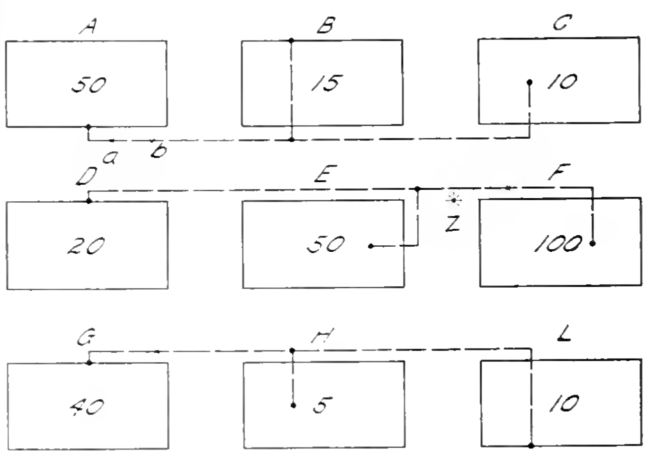


Fig. 5

the actual feed may be located as conveniently near the center as possible; or for safety two feed points may be taken, so that the network would be less liable to disturbance. The load centers for each block, such as "A," "B," "C," "D," etc., in Fig. 5, would be suitable points for the location of the transformers; but it would be necessary with the tying-in of mains, as in Fig. 4, to provide cutouts, etc., so as to facilitate the location of trouble.

Referring to Fig. 6, the primary and secondary mains should be laid out with a maximum drop to extremes of, say, 2 per cent. from the feed point. It is sometimes necessary to use copper much larger than is required by the load on account of the necessary mechanical strength demanded. In laying out the feeder and the mains, that cross section of copper should be used which is most economical. The value of feeder regulation at this point enters into the problem, for without feeder regulation the most economical amount of copper could not be used, provided the drop at maximum load was to be maintained within a reasonable percentage. By employing feeder regulators, however, it is a question of utilizing the most economical copper, plus the cost of the regulator, as against the cost of copper of much greater section.

A system of lighting or power, or a combination of these, uniformly laid out along the lines indicated above, easily permits the calculation of feeder losses and an accurate account of the revenue represented by such loss. It does not follow, however, that the loads in the different sections will be at peak within the same period of time, for the character of the load may vary widely. It is practically impossible, therefore, to raise or lower the station bus so that the voltage at each load center is proportionate to the demand at that center. It is necessary to employ some means of adjusting the voltages on the feeders so that the voltage is maintained within that predetermined and selected for each section.

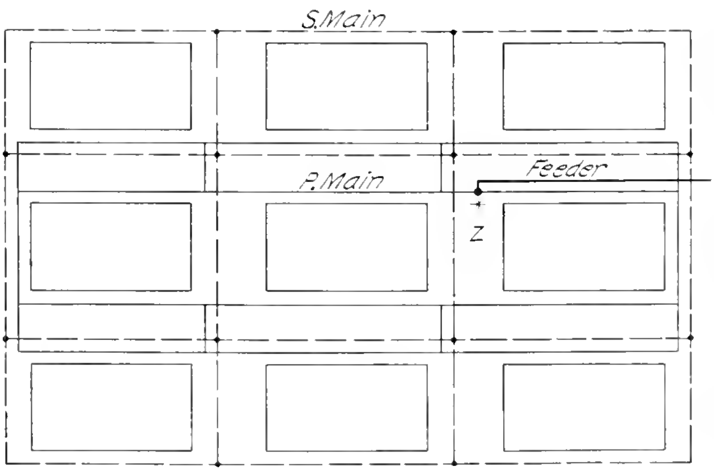


Fig. 6

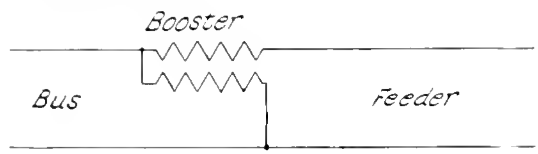


Fig. 7

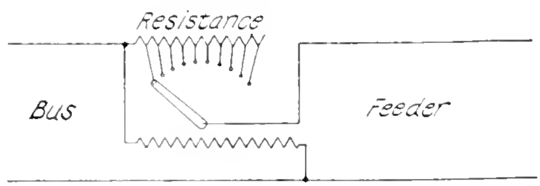


Fig. 8

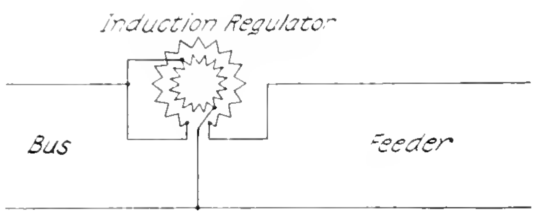


Fig. 9

In the old direct current networks of large systems the various feeders differed greatly in length and were unequally loaded, the latter condition constantly changing so that it became necessary to individually control each feeder. In this respect the alternating current systems will not differ except as to the method employed for obtaining the necessary regulation. Several methods were employed in the old Edison systems; first, such as connecting and disconnecting feeders at various points on the mains; second, feeder regulating rheostats; third, auxiliary busses; and fourth, boosters. In alternating current work no method is as satisfactory as the booster method. This is actually the equipment of a system composed of several auxiliary busses supplied with different potentials. The objection to the regulation by the resistance method is that there is an actual loss of energy represented by the percentage by which the supply voltage is lowered. Other methods employed in alternating current work make use of reactance and capacity. There are objections to both of these methods. The most successful is that of the variable ratio transformer booster. The simple booster method is represented in Fig. 7, showing the permanent booster with its secondary in series, and its primary in shunt with the feeder. The variable ratio feature is illustrated in Fig. 8, whereby an actual range of voltage can be obtained to meet the requirements of the feeder load. The regulation illustrated in Fig. 8, however, is that of step-by-step, and a more satisfactory method is that shown in Fig. 9, which represents an induction or regenerative booster, in which the steps are almost infinitely small.

ADVANCED COURSE IN ELECTRICAL ENGINEERING

Part III

By Ernst J. Berg

Professor of Electrical Engineering, University of Illinois

Harmonic e.m.f. Impressed on a Circuit of Resistance and Inductance in Series

The exponential term in equation 42, while of importance during the first second or so, ceases to affect the result very shortly after the switch is closed.

Thus the equation for the current after the system is stable is

$$i=\frac{E}{Z}\,sin\,(\theta-\beta) \qquad (43)$$

The current lags behind the e.m.f., $E\,sin\,\theta$, by an angle β, whose tangent is $\frac{x}{r}$

The effective value of the e.m.f. is

$$E_{eff}=\frac{E}{\sqrt{2}}$$

and of the current

$$I_{eff}=\frac{E}{\sqrt{2}Z}$$

It is of interest to note that the transient term is a maximum when $sin\,(\theta_1-\beta)=1$, that is $\theta_1-\beta=90$, or $\theta_1=90+\beta$.

This value of θ_1 also gives the maximum value of the permanent current.

The exponential term is zero, that is, there is no transient effect if $\theta_1-\beta=\theta$ or $\theta_1=\beta$ or, in other words, if the circuit is closed at such a time as would give zero value of the permanent current.

Fig. 11 shows a series of such transient currents. Each curve corresponds to the closing of the switch at a particular value θ_1 of the phase of the e.m.f.

Thus, for instance, curve D shows the starting current when the e.m.f. wave has a phase angle of $+60°$, that is, when $\theta_1=60°$. These curves are calculated with the following constants

$$e=E\,sin\,\phi \quad E=1 \quad r=0.196 \quad x=0.98$$

Problem No. 6

Check some curve in Fig. 11.

It is of interest to study the rate at which energy is being supplied at any instant. This is equal to the product of the e.m.f. and the current:

$$P=ei=E\,sin\,\theta\times\frac{E}{Z}\left[sin\,(\theta-\beta)-\epsilon^{-\frac{r}{x}(\theta-\theta_1)}\,sin\,(\theta_1-\beta)\right] \qquad (44)$$

By simple transformations the equation becomes

$$P=\frac{E^2}{Z}\left[\frac{cos\,\beta-cos\,(2\theta-\beta)}{Z}-\epsilon^{-\frac{r}{x}(\theta-\theta_1)}\,sin\,(\theta_1-\beta)\,sin\,\theta\right] \qquad (45)$$

The first term in equation 45 must represent the power at any instant after the conditions have become stable. This power is expressed by

$$P_1=\frac{E^2}{2Z}\left[cos\,\beta-cos\,(2\theta-\beta)\right] \qquad (46)$$

It again consists of two terms, one a constant term $\frac{E^2}{2Z}cos\,\beta$, the other a term which changes with double frequency; but the net result affecting the delivery of power over a complete period is obviously zero, since the positive values are as large as the negative. Thus while the instantaneous values of the power vary from instant to instant and may alternate from positive to negative values there is a definite average power delivered, which is

$$P=\frac{E^2}{2Z}\cos\beta$$

The exponential part of the power,

$$P_2=-\epsilon^{-\frac{r}{x}(\theta-\theta_1)}\sin(\theta_1-\beta)\sin\theta \qquad (47)$$

is gradually decreasing in magnitude as well as oscillating at normal frequency.

In Fig. 12 are given three curves; the first, *A*, being the wave of the impressed e.m.f.; the second, *B*, the power input; and the third, *C*, the power curve after conditions are stable. These curves are figured for the constants given in problem 6 and are well worth reproducing by calculation.

The curves show that during the transient period the instant of maximum power is practically the same as that for permanent condition. They also show that the first rush of power is greater than that which corresponds to permanent condition, the reason being that the change of flux during the first part of the cycle is greater than during the corresponding time under stable condition.

Problems Involving Mutual Inductance

Up to this point the problems considered have dealt with circuits of inductance and resistance only. However, in many circuits of commercial interest there are secondary circuits which are more or less closely connected with the primary, and which influence the former materially. As instances of such circuits may be given the secondary winding of a transformer, the eddy currents in pole pieces of generators and motors, induced currents in telephone lines running parallel to transmission lines, etc.

Sometimes the secondary circuits carry currents by virtue of impressed e.m.f.'s, but frequently the currents are the result of the action of the primary currents. With a change of primary current there is obviously a change of flux produced by the current and if this flux interlinks with the second circuit, e.m.f.'s are induced therein, the values of which become higher as the interlinkage becomes more nearly perfect. While it is impossible to arrange two circuits so that all flux interlinking one will also interlink the other, the condition can be approached reasonably close under the most favorable conditions.

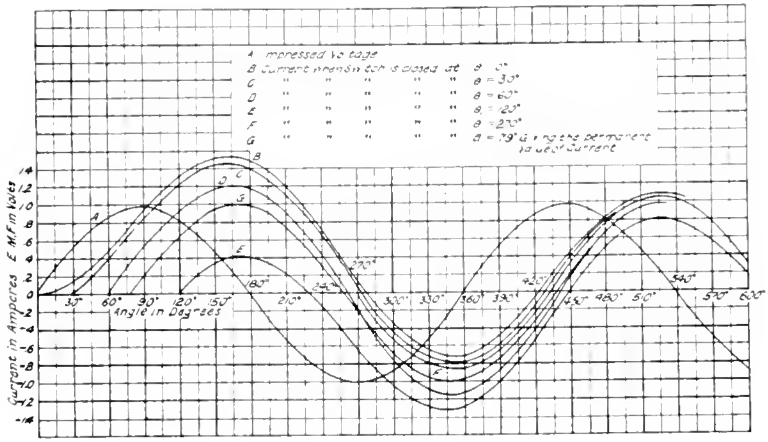


Fig. 11

The limiting case is, of course, perfect mutual induction, which condition will therefore be considered briefly.

Two Coils of Perfect Mutual Inductance

Assume then that it is possible to place two coils so close together that there is no leakage flux between them, that is, all flux that surrounds one coil also surrounds the other. Let the first coil, the primary coil, have N_1 turns and r_1 ohms resistance, and the secondary coil N_2 turns and r_2 ohms resistance. Determine the open circuit voltage of the second winding. When the first is connected to a source of constant potential E,

$$E=i_1r_1+\frac{N_1}{10^8}\frac{d\phi}{dt}.$$

The rate of change of flux is thus

$$\frac{d\phi}{dt}=\frac{E-i_1r_1}{N_1 10^{-8}} \qquad (48)$$

Therefore the voltage of the second coil e_2 is

$$-\frac{N_2}{10^8}\frac{d\phi}{dt}=-\frac{N_2}{N_1}(E-i_1r_1)$$

At the instant of starting, when i_1 is zero, the secondary voltage is $e_2 = -\frac{N_2}{N_1}E$, that is, it is proportional to the ratio of turns.

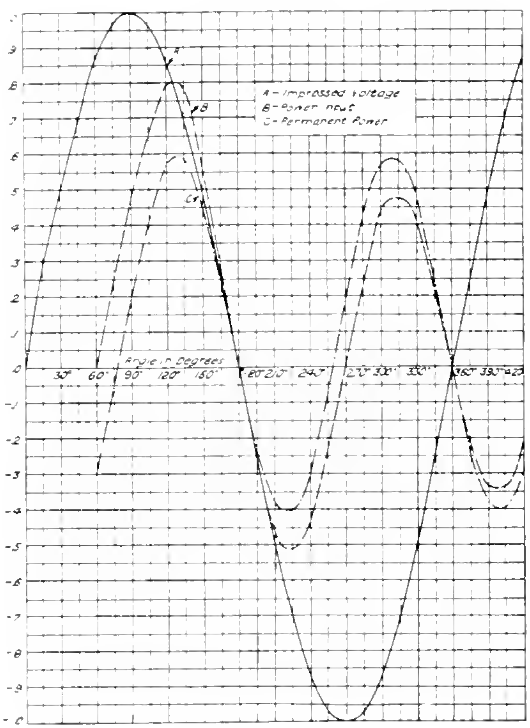


Fig. 12

When the primary current reaches its constant value $I_0 = \frac{E}{r}$ the secondary voltage e_2 is zero. If the secondary winding has more turns than the primary, then at first the secondary voltage is higher than the impressed voltage. It decreases rapidly, however, and soon becomes zero.

Prove that the two voltages are equal numerically when

$$i_1 = \frac{E}{r_1 N_2}(N_2 - N_1)$$

Assume that two coils, which, when considered alone, have resistances and inductances of r_1, r_2 and L_1, L_2, respectively, are placed so close together that there is perfect mutual inductance between them (which of course is in reality impossible). Find the open circuit voltage of the second coil if the first coil is connected to a source of constant potential.

The first step is to prove that the ratio of turns must be

$$\frac{N_2}{N_1} = \sqrt{\frac{L_2}{L_1}}$$

$$E = i_1 r_1 + L_1 \frac{di_1}{dt}.$$

The counter e.m.f. of self induction of the primary coil is $-L_1 \frac{di_1}{dt}$, and thus the voltage of the second coil is

$$e_2 = -\frac{N_2}{N_1} L_1 \frac{di_1}{dt} = -\sqrt{\frac{L_2}{L_1}} L_1 \frac{di_1}{dt}$$

$$= -\sqrt{\frac{L_2}{L_1}}(E - i_1 r_1).$$

Check the values of the primary current and secondary voltage as given in full lines of Fig. 13, for

$E = 10$	$r_1 = 0.10$	$L_1 = 2.5$	$N_1 = 10$
	$r_2 = 0.50$	$L_2 = 10$	$N_2 = 20$

In the case referred to above the primary current will rise from zero to a final value of 100 amp., while the secondary voltage decreases from -20 volts to zero.

If when the primary current has reached its final value the coil is suddenly short circuited, what will the primary current and secondary voltage be?

The primary current will decrease according to equation:

$$i_1 = I\epsilon^{-\frac{r_1 t}{L_1}} = \frac{E}{r_1}\epsilon^{-\frac{r_1 t}{L_1}}$$

$$e_2 = -\frac{N_2}{N_1}(E - i_1 r_1) = -\frac{EN_2}{N_1}(I - \epsilon^{-\frac{r_1 t}{L_1}}).$$

Check numerically the two dotted curves in Fig. 13.

During the discharge of the primary the number of coulombs are

$$\int_0^\infty i_1 dt = \int_0^\infty I_1 \epsilon^{-\frac{r_1 t}{L_1}} dt = 100\frac{L_1}{r_1}$$

$$= 2500 \text{ coulombs.}$$

Obviously, when connecting the primary to the source of supply, the number of coulombs required up to the time when the current becomes stationary is infinite, since it takes infinite time for the current to reach this value.

Two coils of resistances and inductances of r_1, r and L_1 L are connected in series and placed so close together that it is assumed that they have perfect mutual inductance. What will be the resultant resistance and inductance (a), if the coils are wound in the same direction; (b), if the coils are wound in opposite directions?

The inductance of an air coil is subject to rigid mathematical determination, but the complete solution is very cumbersome. However, one of the best approximations, that of Brooks and Turner, published as an Engineering Experiment Station Bulletin by the University of Illinois, is:

$$L = \frac{Cm^2}{10^9(b+c+R)} \times \frac{10b+12c+2R}{10b+10c+1.4R} \times 0.5 \log_{10}\left(100+\frac{14R}{2b+3c}\right) \quad (50)$$

For coils which are not extremely thin or extremely long, this equation becomes approximately:

$$L = \frac{Cm^2}{(b+c+.9R)10^9} \quad (51)$$

Where L is expressed in henrys

Cm = centimeter length of wire

b and c are the height and thickness respectively of the coil and R the *outside* radius, all in *cm*.

It is seen that the inductance is proportional to the square of the total length of wire, which is, of course, proportional to the turns. Thus the inductance is proportional to the square of the number of turns, or

$L = KN^2$.

(a) Coils in the same direction.

Let N be the number of turns in the first coil, or,

$$N = \sqrt{\frac{L}{K}};$$

and N_1 the number of the turns in the second coil, or,

$$N_1 = \sqrt{\frac{L_1}{K}}.$$

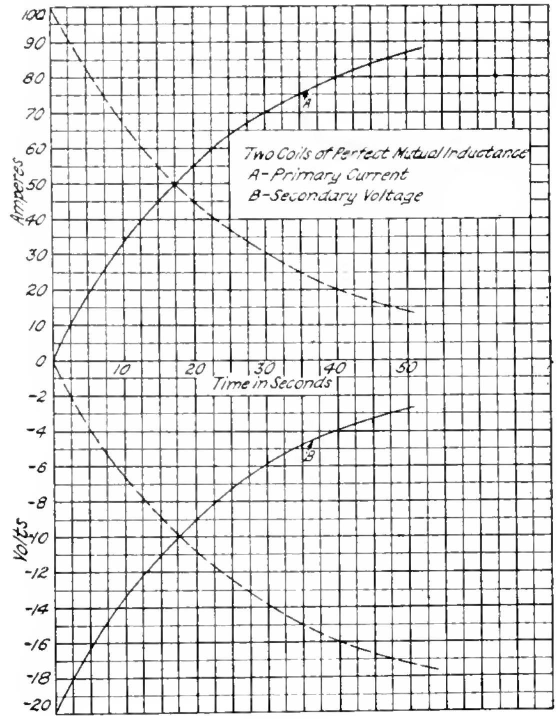


Fig. 13

The total number of turns in the two coils when considered as one coil (which is permissible when perfect mutual inductance is assumed) is

$$N_0 = N + N_1 = \frac{\sqrt{L}+\sqrt{L_1}}{\sqrt{K}} \therefore L_0,$$

the combined inductance, is

$$L_0 = KN_0^2 = (\sqrt{L}+\sqrt{L_1})^2 = L+L_1+2\sqrt{LL_1}$$

The resistance is obviously $r_0 = r + r_1$.

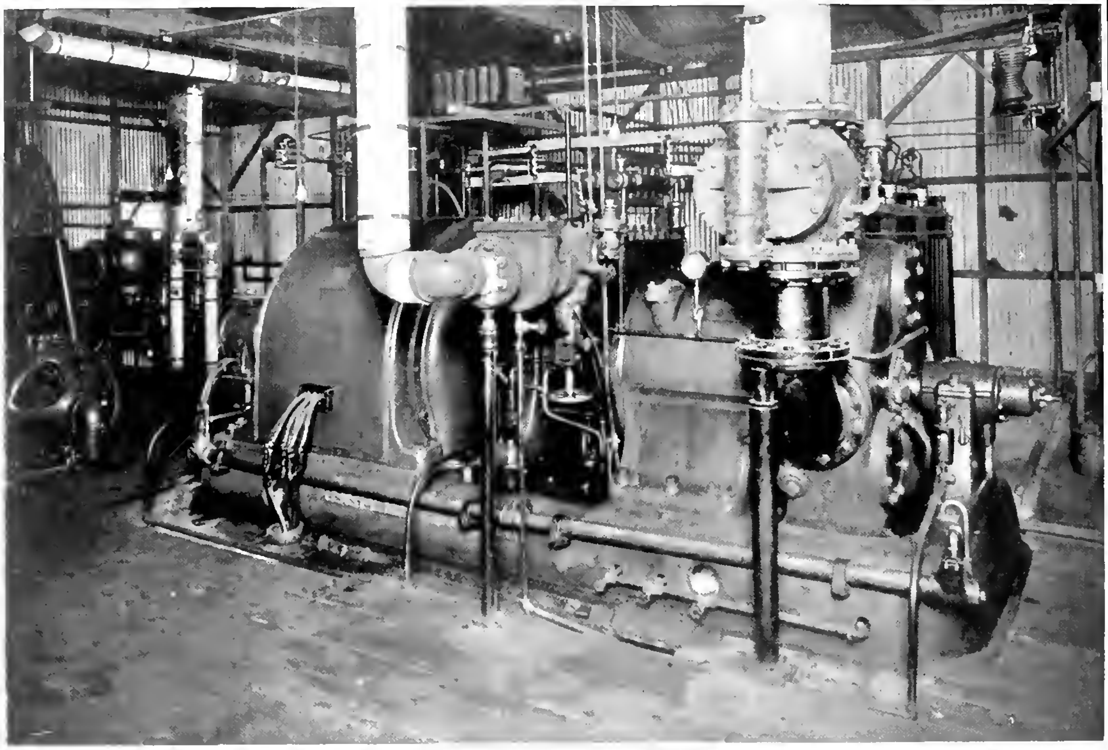
(b) By similar reasoning it is found that if the turns are in opposite directions

$L_0 = L + L_1 - 2\sqrt{LL_1}$ and $r_0 = r + r_1$

From the above it is evident that the equation for the starting current, for instance, is:

$$i = \frac{E}{r_0}\left[1 - \epsilon^{-\frac{r_0 t}{L_0}}\right]$$

(To be Continued)



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W. L. R. Emmet

Mr. Emmet is the engineer of the Lighting Department of the General Electric Company, and for many years has devoted a great deal of time and energy to a study of electric ship propulsion. Of the American engineers who have studied this question, no one has addressed the matter with the energy and breadth of judgment which have been displayed by Mr. Emmet. An article written for the REVIEW by his assistant, Mr. Eskil Berg, describing the electrical equipment designed by Mr. Emmet for the propulsion of the U.S. collier Jupiter, appears on page 490 of this issue.

GENERAL ELECTRIC REVIEW

THE ARGUMENTS FOR THE ELECTRIC PROPULSION OF SHIPS

Mr. H. M. Hobart, in the introduction to his treatise on "The Electric Propulsion of Ships" remarks: "It is impossible to generalize to the extent of stating unqualifiedly that it is not commercially advantageous to incorporate electrical apparatus in the machinery employed for propelling ships. But I consider that it can be definitely stated that for certain ships and services it is commercially advantageous to introduce electrical apparatus as a component part of the propulsive machinery, and that for other types of ship or other services it would be commercially disadvantageous."

The main plank in the platform is simply this. Steam is usually the medium by which energy is developed in the engines of the vessel. The most efficient steam engine is the turbine. The most efficient turbine is the high-speed turbine. The most efficient propeller is the low-speed propeller. The high-speed turbine and the low-speed propeller must be employed in order to obtain maximum efficiency; and any compromise between the ideal speeds for these two elements involves sacrifice in the efficiency. To preserve these ideal speeds recourse must be made to gearing. Shall this be mechanical or electrical? Cannot the most highly developed forms of helical gearing satisfactorily fulfill the function for which the electrical apparatus is intended? "The only just answer to this is that the practicability of electric propulsion on any scale and with any ratio of speed reduction is an unquestionable certainty, while the proved limits of gear application are still very narrow."* Furthermore, mechanical gearing permits of providing but one definite speed ratio, while by electrical gearing an adjustable speed ratio is provided. The circumstance must also be kept in mind that, while double helical speed reduction gearing does not eliminate the necessity for astern turbines, the latter are not required with the electrical system, since it is an important characteristic of the electric motor that it can be promptly reversed and can at once develop strong torque in the reverse direction. The total loss involved in electric transmission on board ship at any load will not exceed 8 per cent. in large vessels. The losses of gearing will presumably amount to 2 per cent. at full load and more at light load. This advantage of some 6 per cent. is more than lost by the sacrifices which have to be made in the matter of employing the relatively higher propeller speeds, and the relatively lower turbine speeds, corresponding to the much smaller ratios of speed reduction permissible with mechanical gearing, as compared with the high ratios which are entirely practicable with electrical gearing. As a matter of fact the manufacture of such gears as would now be required in the greatest sea-going liners and battleships, to realize the most efficient high turbine-speed on the one hand and the most efficient low propeller-speed on the other, is quite beyond the bounds of possibility, at least at the present time.

During the past ten years many engineers of standing—some in this country, some abroad—have been working out the possibilities of electric propulsion very closely. Of the European engineers probably chief credit belongs to Mr. Henry A. Mavor, of Glasgow, who has for many years, with comparatively little financial backing, performed real pioneer work in demonstrating to the full all the possibilities of which the electrical system is capable. Amongst American engineers, no one has addressed the matter with the skill, thoroughness and breadth of judgment which have been shown by Mr. W. L. R. Emmet. Although Mr. Emmet must have worked out scores of hypothetical designs which have been destined to fulfil no other purpose than to raise a

*W. L. R. Emmet, in discussion of electric ship propulsion before the Northeast Coast Institution of Engineers and Shipbuilders, Newcastle-on-Tyne, April, 1912.

temporary interest in the subject, he can at least claim as his own, practically in its entirety, all that has been actually achieved in the equipping of vessels which have demonstrated the feasibility of the theorists' arguments. He, better than anyone else, should know the ground on which to stand the case; and we therefore quote in full, from his Newcastle argument, already referred to in a footnote, his seven reasons:—

First, turbines, where applicable, afford the best means of producing power from steam, because they give simple rotation and admit the possibility of large ranges of expansion; second, high-speed turbines are far cheaper, simpler, lighter, and more economical than low-speed turbines, third, within certain well-defined limits, low speeds are conducive to high efficiency in ship propellers; fourth, electric transmission affords an ideally simple and practical means of speed reduction in almost any ratio which may be desired in such cases; fifth, electric transmission also affords means of reversal by a simple change of electrical connections, without mechanical devices, complication of piping, or auxiliary prime movers for reversing; sixth, electric transmission affords means by which the ratio of speed reduction is changeable simply through the medium of electric connections, thus making possible the economical use of the same apparatus both under low-speed conditions and high-speed conditions; seventh, electric transmission makes convenient the use of multiple propelling and generating units which can be used independently, so that damage to one or more parts may not disable the vessel.

Mr. Emmet recently submitted to a firm of British shipbuilders a proposition for the equipment of a vessel which may be considered representative of the best possible application of electric propulsion to a merchant vessel. The ship is designed for propulsion by reciprocating engines at a speed of 17.5 knots with twin screws operating at 82 r.p.m., the total indicated horse power at this speed being 17,000. The proposed electrical equipment, which was designed for the same propeller speed and laid out in such a manner that it could be connected to the same propeller shaft without appreciable change, would have weighed considerably less than half the reciprocating engine equipment, and would have had a water rate of 11.5 pounds per shaft horse-power-hour, a net saving of 15 per cent. The figures as to water rate, be it said, were not based upon any theoretical expectations, but upon the actual tests of generating units of similar capacity and speed as those proposed.

The first example of turbo-electric propulsion on any scale is afforded by the City of Chicago fireboats *Joseph Medill* and *Graeme Stewart*, the equipments for which were designed by Mr. Emmet and installed in 1908. The second application is found in the case of the U. S. Collier Jupiter, a vessel provided with a shaft horse power of 7000 for a steaming speed of 14 knots. This ship is now building in a government yard in California, while the generating and propelling machinery has just passed successfully through some very searching tests in the Schenectady factory. The Jupiter will not be completed until the early summer of 1913, so that some time must elapse before we can add the name of this ship to the small list of vessels in which the soundness of these proposals has been vindicated. An article by Mr. Eskil Berg appearing on page 490 describes in detail the apparatus employed on the Jupiter, and will probably be read with the greatest interest.

The equipment of the Jupiter was undertaken not because this ship afforded the best opportunity for electric propulsion, but rather because it was the only large vessel for which a contract could be obtained in America. If electric propulsion is a success in a relatively unfavorable instance of this kind it should be easy to demonstrate its overwhelming advantages in the case of a large battleship. It is for the big battleship that electric propulsion is most admirably suited. The case for the large mercantile liner we think we have already proved. For a battleship all these arguments hold good, with the addition of another even more important. A certain modern warship may be said to have a speed of 21 knots. How many times in a year is such a speed ever reached? The vessel runs its full speed trials for the stated time, and after that it may be years before ever she is called upon for anything beyond her cruising speed of 14 knots. The turbines meantime have to be capable of their maximum for an indefinite period; so that, if the propellers and turbines are direct-connected, then from the nature of a turbine the steam consumption for all practical purposes is many per cent higher than it is when steaming at a maximum speed hardly ever called for in its working life. Actually we may say that at the 14-knot speed the consumption may be around 19 lb. per h.p.-hr; while it would not exceed 11 or 12 lb. were the turbines run at their most efficient load corresponding to 21 knots. By means of the electric system, on the other hand, the change in propeller speed is achieved by a simple change-over in the electrical connections of the motors, while the turbines will be run constantly at full speed; and even under varying loads the consumption per horse-power-hour will not greatly exceed the full load value.

OUTDOOR SUBSTATIONS

By C. M. Hackett

Power and Mining Engineering Department, General Electric Company

The outdoor substation, or rather electrical apparatus for substation use adapted for open-air service with the necessary auxiliaries, is a comparatively recent development. This article first touches on some of the economic considerations determining the feasibility of the scheme, and the climatic conditions most favorable to its use. It then considers the apparatus and its arrangement on the ground: spacing of conductors; location with respect to direction of transmission line; towers for carrying high tension wiring, interconnecting trusses to which the electrical equipment is attached, and precautions for guarding against undue strains therein; anchorage of line wires; type and location of line disconnecting switches, choke-coils, oil-switches, etc.; running of transformer cables and facilities for handling transformers, switch-tanks, etc. The article then gives some general rules with regard to carrying out the work, as well as to such matters as low-tension switch house, erecting shop, walk-ways, drainages, etc.—Editor.

The demand for electrical equipment constructed so as to be suitable for satisfactory installation and operation in the open air is one of the normal results of large capacity and high potential power developments, and also, though to a less extent, the necessity for taking care of the small power consumer where voltage may be lower.

With comparatively low voltage, i.e., not above 66,000, the distances to ground and between phases are sufficient to permit wiring as complicated as should ever be necessary, without occupying an unnecessary amount of room, and the housing of the whole equipment does not involve an unwarranted expense per kilowatt if the substation is of medium or large capacity. When, therefore, it is found economical to adopt the more costly apparatus suitable for open air installation, together with risks and annoyances which are its natural operating accompaniment, it is reasonable to assume that the potential will be high; or, if medium or low, that the amount of power taken off at that particular point will be too small to warrant the outlay necessary for a building to house the apparatus.

In this latter case the whole power system may be of small size, or the consumer may be on a branch of the main system, and adequate protection will be provided where the tap is made to the main supply. In cases of this nature the installation can hardly be considered as rising to the dignity of a substation, as it will generally consist of a set of combined fuse and disconnecting switches with necessary framework (preferably of steel) for supporting them; and a three-phase oil-cooled transformer, with secondaries passing directly into an adjacent building from which distribution of the feeder circuits can be made. The furnishing of lightning arresters, choke coils, or high tension switches are refinements which need not be seriously considered in an installation of this kind, unless there are line conditions which make it advisable that means be provided at this particular point for either sectioning power circuits, or tying into another source of power supply.

Conditions most favorable to the placing of substation apparatus in the open air, are: Climate which has a range of temperature between plus 32 deg. and 90 deg. F.; absence of salt mists and severe sleet storms; and also an absence of rainstorms accompanied by high winds. Localities in which such a combination of advantages may be found are, unfortunately, very limited as to area and number; and it may be assumed that, in order to meet the conditions of the average installation, the design of the equipment as well as its arrangement on the ground must be such that it will be capable of satisfactory operation under very adverse weather conditions.

In the design of an open-air substation the spacing of electrical conductors, as well as that of the apparatus, should be liberal but not large. The occupying of air space involves cost, and this may become excessive if an unnecessary distance to ground or between phases is used. Eight feet between phases and four feet to ground may be regarded as the maximum for 110,000 volts; and these can be reduced by 25 per cent. at points where conditions are favorable, i.e., where phases do not run parallel, and where wiring is not involved and does not parallel grounded surfaces.

The intermediate substation should, if possible, be so placed that interference with the transmission line is reduced to a minimum; and it will generally be found possible to locate the station so as to avoid changing the direction of the line or making lateral taps to it. This can frequently be accomplished by slightly raising or lowering the wires, bringing them into a common plane, and anchoring them to the structure which carries the disconnecting switches, arrester horn-gaps, and busses. A careful study should be made of this part of the work with the idea of eliminating all complications of wiring and control equipment.

The structure employed for carrying the high tension part of the wiring, together with disconnecting switches, choke-coils and horn-gaps, may consist of masts or towers which support the interconnecting trusses to which the electrical equipment is attached. The placing of the towers as well as the type of truss employed will be governed by the scheme of control adopted. For instance, an elaborate supporting structure will be required if two or more parallel lines are to be sectioned and arranged so that a section of any line between stations can be cut out or thrown into service at pleasure; while a very simple structure will take care of the equipment and control of the same if a tap to a single line is all that is required. The simplest possible arrangement, however, should have the line wires properly arranged and anchored for taking off taps, as no strain is permissible for the wire which forms the connection between the line and rigid supports. Furthermore, enough slack should be allowed in this connection to insure not only that movement of the line wires does not bring a strain upon rigid insulators, but that wearing and stretching of the anchorage insulator fittings is compensated for.

In addition to taking care of the usual loads and stresses which occur in the supporting structure, consideration must also be given to deflections which will result from unequal strains. In addition to the likelihood of there being unequal settlement of supporting tower or mast foundations, there will also be unequal line pull; and, in cases where busses and connections supported by post insulators are drawn tight when installed, there is likely to be interruption of service as the result of broken insulators. Among the precautions used to guard against this trouble may be mentioned delaying the final fastening of all electrical connections between rigid insulating supports, until line and other stresses have been applied to the structure and a state of permanent distortion and deflection reached. The general rules for the location of apparatus in enclosed substations also apply here, viz., avoiding unnecessary crossing of phases, and placing the various parts of the equipment so that they are in their proper order, in a direction which is always away from the power supply and toward its distribution.

The line disconnecting switches should be of a form which can be opened under line charging load. They should preferably be mounted on a bridge truss between supporting towers, and arranged for operating all phases simultaneously with the operator standing on the ground. The operation should be positive, with no possibility of any phase remaining wholly or partially open or closed when the control lever is thrown to its limit either way. If desired, disconnecting switches may be provided for lightning arresters; but they will be seldom used as the horn-gaps can generally be so placed as to serve the purpose of switches. The choke coils may be of the rigidly-supported type, or can be suspended in the connection between the disconnecting switch and the terminal of the oil-switch. Those of the former type are more expensive and will, in most cases, cost more for mounting; but there is no question that they make a better mechanical job of the installation as a whole, to say nothing of electrical advantages. The suspended choke should have especially solid supports for the connection of which it forms a part, and this connection should be made short between supports so that high winds will not cause injurious whipping.

The oil-switches should be so placed that the tops of the terminals will be at a safe height above the operator's head, and connections to them should run as nearly vertical as possible. The switch tanks should be placed on a concrete platform, or base, of sufficient height to make certain that it will always be clear of water. This platform ought also to be so constructed that the switch tanks can be conveniently shifted from it to a truck on which they can be removed to the erecting shop. Transformers should also be placed on a concrete platform, and a track on which they can be moved should be provided. Wheels, if placed under transformers, should be of such gauge and base that ample stability is given, and arrangements should be made for blocking the transformer in service position. Oil-piping for transformers and switches, and also water piping to water-cooled transformers, must be so located that connections can be made or broken quickly, and so that emergency work can be done on transformers and switches without causing damage to it. The tanks for good and damaged oil, as well as pumps for oil and water, should have space provided for them in the basement of the erecting shop. The running of low voltage connections between the transformers and the low-tension switching-house can be done in the open air if low-tension switches are arranged so that crosses in circuits and of phases are avoided, and satisfactory elevations can be obtained. A somewhat neater but more expensive method of treating these connections is to put them in conduits running from the transformers to the basement of the switching house; or, if a basement is not practicable, each set of conduits can be laid to give the shortest possible run between the transformer bank and the low-tension transformer switch.

Owing to the necessity of using lead sheathing on conductors if run in conduits, an added cost and complication will result if the capacity of the transformer bank is so large that it is impractical to make a single triple-conductor cable of sufficient size to carry the load. The most practical way out of this difficulty is to use three triple-conductors, and divide the load between them so that the current of each phase is divided between the three cables. Liberal space must be provided at both ends of the cables to give safe distances for the necessary crossing of phases and the proper placing of end-bells. The open-air end will have some special features in the way of waterproof end-bells and wiring, and particular care must be taken to have the work rugged and well protected.

In a general way, if the work is carried out as outlined above, the structures and apparatus composing the substation will be grouped as follows: The transmission lines will pass over the high-tension structure, with such breaks and switches in them as are required to meet the conditions of sectioning desired. The transformer busses will be arranged so that a single or double row of banks can be fed from them, and the lines of transformer banks will be at right angles to the transmission lines. The connections from the busses through the switches to the transformers will be parallel to the transmission lines. The secondaries from transformers to the low-tension switching station will run at right angles to the transmission line; and, if in the air, may be either grouped above the aisle between the two rows, or be in separate groups above the aisles at the back of the transformer groups. Lightning arresters will be placed directly below the lines, and the connections to them through horn-gaps should be as direct as possible. Both oil and air-break switches should be arranged for opening and closing by hand, with the operator standing on the ground; but a permanently attached operating handle for oil-switches should not be necessary, as the oil-switches will normally be electrically-operated from a control board located in the low-tension switching-house. This board should be placed so that the operator can see the switches he is operating.

All of the main members of the supporting structure should be well bonded together, using the pin expanded bond. Holes for bonding should be drilled and not punched, and bonds should be put in as soon as holes are drilled. If for any reason there is a delay of over an hour before bond can be applied, the holes should be lightly reamed before bonding. Work of this kind should only be done in dry weather. Grounding should be ample, and thoroughly done. If the supporting towers or masts are composed of four main members, at least two of them should be connected to ground, and the other legs should be cross-bonded to the ones that are grounded. The ground connection should be carried up the tower legs far enough to be above the area of high corrosion, viz., $2\frac{1}{2}$ to 3 feet; and if the material of the tower leg is less than $\frac{1}{2}$ in. thick a double bond should be used. Soldered joints should be avoided wherever possible.

The general scheme of lighting should be along similar lines to that of the indoor station; that is to say, there should be at least two sources of light, one being from a battery, and the distribution should be such that emergency conditions will be met as far as possible. Arrangements should be made for attaching portable lights at all important points, the receptacles for this service being protected from the weather. All lighting wiring should be run in conduit, and this conduit should be, as far as possible, placed in protected locations on the supporting structure.

The low-tension switching-house will be placed conveniently close to the high-tension structure and at right angles to the aisle between the transformer banks. An erecting house should be provided at the opposite end of this aisle, and into this will be run the tracks which are provided for the trucks that carry the transformer and switch tanks, as well as other heavy parts. This building should have all the space and equipment necessary to dry out transformers, treat oil, and disassemble or assemble any apparatus used at the station, and should also have a moderate equipment of machinery for doing small repairs.

Cement walk-ways should be laid on that portion of the ground over which the operator will most frequently pass in his inspection trips and work about the place. These walk-ways should be elevated and sloped so that water will not stand on them; and the adjacent ground should be graded away sharply from them and a drainage system provided with necessary catch basins to carry away storm water. These walk-ways and the drainage system will have special advantages in a region of frost and snow, and here care should be taken to have the drain discharge so placed that it will never freeze.

The type of enclosure which should be provided for an outdoor station will, to some extent, depend on its importance and location; but in a general way it may be assumed that the enclosure should be capable of meeting, completely, conditions for which it is erected, and should be built to harmonize with the balance of the plant and to improve, rather than detract from, its appearance.

REVIEW OF GRAPHICAL AND ANALYTICAL METHODS FOR PREDETERMINING OPERATING CHARACTERISTICS OF INDUCTION MOTORS

By C. R. Moore

School of Electrical Engineering, Purdue University

Owing to the extent to which the polyphase induction motor has now been applied industrially and owing also to the difficulty and expense of carrying out complete tests on all such machines, either at the factory or on site, it has become highly desirable to evolve some method of predetermining the performance of any given machine from the results of a few simple tests. Many such methods have been proposed and are in use, although their practical utility is often discounted by the fact that the degree of accuracy obtained by the different methods varies considerably, to an extent which is not generally realized. The consulting engineer and the manufacturer therefore frequently obtain conflicting results in their predictions of a motor's capabilities; and there is certainly room for standardization of simple method or for a wider knowledge of the accuracy which may reasonably be expected from the methods commonly employed. The purpose of this paper is to collect together and compare various graphical and analytical for predetermining a motor's characteristics. Along with this the author publishes the results of an extensive experimental investigation, carried out on actual machines to elucidate or demonstrate various points which are introduced. The paper has been specially prepared by Professor Moore for the Review and will be completed in probably three issues. The first part is confined to a consideration of the rotating field and a comparison of the induction motor with the static transformer.—Editor.

NOTATION

- E, impressed voltage per phase.
- I_p, primary current per phase.
- I_{eng}, energy component of primary current.
- I_m, magnetizing component of exciting current.
- I_h, hysteresis component of exciting current.
- I_e, exciting current.
- I_s, secondary current.
- F, friction and windage per phase in watts.
- P, mechanical power developed in rotor per phase.
- X_p, primary leakage reactance per phase.
- X_s, secondary leakage reactance per phase.
- R_p, primary resistance per phase.
- R_s, secondary resistance per phase.
- X_t, total leakage reactance of transformer or motor $=X_s+X_p$.
- X, load reactance.
- R, load resistance.
- s, slip in per cent. of synchronous speed.
- T, ratio of transformation.
- e, primary counter e.m.f. due to flux interlinked with primary and secondary (mutual induction).
- g, conductance of exciting circuit.
- x_1, reactance of exciting circuit.
- b, susceptance of exciting circuit.
- r_1, resistance of exciting circuit.

INTRODUCTION

The purpose of this disquisition is to bring together and compare various methods, graphical and analytical, having to do with the predetermination of the operating characteristics of induction motors.

The induction motor enjoys a wider application to industrial uses than any other type of alternating current motor. Its importance has consistently grown at an increasing rate, until at the present time it may be found doing all kinds of work and operating under all sorts of conditions. Considering the length of time that has elapsed since the invention of the rotating field, the commercial growth of the induction motor industry has been nothing short of phenominal.

The theory of the rotating field as produced by alternating currents, and the practical application of this theory to a commercial mechanism, have been the subjects of many treatises and have elicited much discussion. Many of these treatises are very thorough, but as one peruses this literature the lack of uniformity of treatment is at once apparent. This criticism applies not so much to discussions regarding principles of operation as to methods for the predetermination of performance. If one wishes to solve a specific problem, the question as to which method yields the best results must be settled. At first thought this may seem to be of little importance, but when the large number of motors that are being installed each year, and the rigid guarantees under which they are sold, are considered, the value of a uniform method by which the operating characteristics may be determined from test or design data is obvious. The difficulty of making a complete test either at the factory or at the place of installation is appreciated by all. It is highly desirable, therefore, to be able to estimate the performance of a given machine from the results of a few simple and easily made tests. Fortunately, the induction motor permits of this to a certain degree, the accuracy of such estimates depending mainly upon the premises taken and the accuracy of the few initial tests required.

Since several of these methods have been proposed it is not surprising that consulting engineers, after testing motors which they have recommended to their clients, sometimes fail to check the performance quoted by the manufacturers. While the initial tests made by the builders may be practically the same as those made by the engineer, it does not necessarily follow that the performance characteristics will check unless the same method of solution is employed by both. Instances have been known where the manufacturers, having guaranteed results within one or two per cent. of their estimated values, have found that a larger percentage difference exists between the methods used by them and engineers in the field; so that the question resolves itself to one of method rather than actual machine operation. A discussion of this point is the province of this paper. It is of course assumed that the construction and operation of induction motors as well as the theory of the rotating field are well understood by the reader.

The multi-phase induction motor being by far the most important type, this review will be confined to motors of that kind.

THE TRANSFORMER AND INDUCTION MOTOR CIRCUITS COMPARED

Since the induction motor operates by virtue of mutual induction, it is essentially a transformer. Therefore, methods of calculation that apply to the static transformer should with certain modifications be applicable to the induction motor.

Experience shows that the simplest means of handling transformer problems is to replace the entire circuit in which the transformer is placed (including the transformer itself) by another circuit containing no transformer, but which has the same operating characteristics as the original circuit. This procedure permits the problem to be regarded as one involving series and parallel circuits containing resistances and reactances upon which a constant electromotive force of definite frequency may be impressed.

The primary and secondary transformer coils possess both resistance and reactance, and the secondary values may be reduced to primary terms by multiplying them by the square of the ratio of transformation. This applies to the load resistance and reactance as well. Thus, consider a circuit containing transformer, load, etc., as shown in Fig. 1. Obviously, to maintain the core flux (which

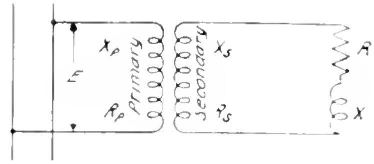

Fig. 1. Transformer Circuit

reduces slightly with load), a magnetizing current is required, which of course must pass through the primary winding. The equivalent circuit must therefore be connected up as shown in Fig. 2. This circuit is generally considered as the exact duplicate of the transformer circuit so far as operating characteristics are concerned. In this discussion this circuit will be known as circuit A_t.

Some writers, disagreeing with the representation shown in Fig. 2, claim that the term T^2X_s should be included in X_p. A

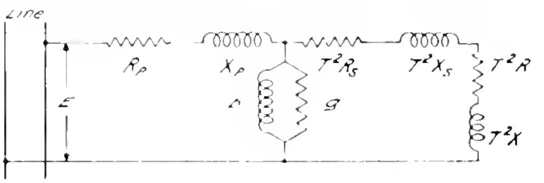

Fig. 2. Series-Parallel Circuit, the equivalent of Fig. 1. Circuit A_t

statement setting forth the reasoning on which this change is based will be found in Franklin and Esty's *Elements of Electrical Engineering*, page 239. As will be shown later, these authors also develop their induction motor theory on the same assumption. This change simplifies the calculations somewhat, but introduces a slight error. Such a circuit is shown in Fig. 3 and will be known here as circuit B_t.

Circuits A_t and B_t are usually modified on the assumption that the voltage impressed on the exciting circuit is constant, i.e., magnetic flux in core constant, the exciting circuit being connected as shown in Fig. 4. The circuit shown in this figure will be designated as circuit C_t.

If now the induction motor is to be considered a special form of transformer, the above circuits with certain modifications as to values used should be applicable. The principal difference between the transformer and induction motor is that the transformer is a static piece of apparatus, whereas the induction motor is a machine, i.e., one coil, usually the primary, is stationary and one is arranged so that it may move. Both

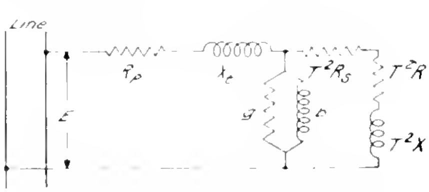

Fig. 3. Series-Parallel Circuit, approximately equivalent to Fig. 1. Circuit B_t

primary and secondary coils of an induction motor usually consist of a number of circuits displaced angularly around the outer periphery of the rotor and inner periphery of the stator, upon which e.m.f's are impressed differing in phase by the same angle.

The effect of this arrangement is to set up a rotating field at the inner periphery of the primary member, which induces currents in the secondary member. If the secondary member be held stationary the frequency of the secondary currents will equal that of the primary currents. If, however, the secondary member be permitted to respond to the forces acting upon it, it will rotate, and, neglecting for the present friction and windage losses, the speed of rotation will equal the speed of rotation of the rotating field. If this condition obtains there is obviously no relative motion between the secondary member and the rotating field, i.e., no e.m.f's are induced in the secondary winding and the secondary frequency may be considered equal to zero. Therefore the frequency of the secondary currents is directly proportional to the product of the slip (expressed in per cent. of synchronous speed) and primary frequency.

This means that the transformer circuit chosen to represent the performance of an induction motor must contain parts, the values for which must account in some way for the slip. Now experiment shows that an induction motor, when held at standstill, (slip = 100 per cent.), acts in every way like a short circuited transformer upon the application of an e.m.f. to the primary, i.e., all the energy given to the rotor appears as electrical power in the rotor windings. The flow of current in the secondary is therefore limited only by the resistance and inductance of the rotor windings. Both these quantities are regarded as constant, although the latter changes slightly with the rotor current. Therefore circuit A_t (Fig. 2) holds for this condition if the load resistance and reactance be omitted.

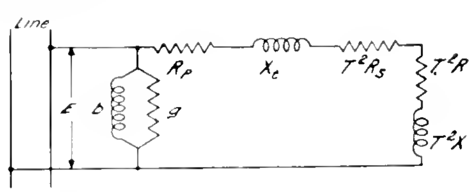

Fig. 4. Modified Transformer Circuit, commonly used in the graphical solution of transformer problems. Circuit C_t

The leakage flux along the air gap is a function of the rotor and stator currents, so that if resistance be introduced into the rotor circuit while the rotor is at standstill, the current values and leakage fluxes obtaining at any slip s may be duplicated. Since the induced rotor voltage is proportional to the slip, the rotor circuit resistance must vary inversely as the slip, if a given current condition is to be kept constant. The expression for this is rotor resistance ÷ slip.

From the above reasoning it is clear that circuit A_1 (Fig. 2) may be made to hold for any slip s by simply replacing $T^2R_s + T^2R_r$ by $\frac{T^2R_s}{s}$. Since the term T^2R_s represents the secondary resistance reduced to primary terms, it is convenient to assume at the outset a ratio of transformation of one to one. We are at liberty to do this on account of the fact that a change in the number of rotor conductors would in no way affect the electrical characteristics of the machine so long as the weight of copper in the rotor bars remains unchanged.

Therefore the circuit which most nearly duplicates running conditions of an induction motor is shown in Fig. 5. This circuit will be known as circuit A.

As in the case of the transformers, certain writers place the entire reactance in the primary, i.e., on the line side of the exciting circuit. This introduces a slight error on account of the fact that the forcing of the leakage flux along the air gap by the primary and secondary currents makes it unnecessary for the magnetizing current to force this flux through the rotor iron. (See Franklin and Esty, *Elements of Electrical Engineering* page 289). The circuit incorporating this change is shown in Fig. 6 and will be known here as circuit B.

Another important change which is usually made in the fundamental circuit (circuit A) and which greatly simplifies calculations, is to place the exciting circuit directly across the line. This circuit is shown in Fig. 7, and will be designated as circuit C. It assumes

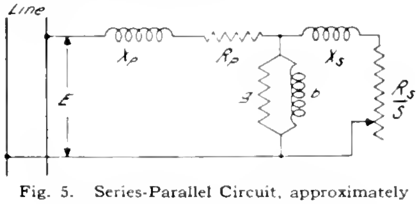

Fig. 5. Series-Parallel Circuit, approximately equivalent to induction motor operating at slip s. Circuit A

that the exciting current is constant for all loads, i.e., primary core loss and counter electromotive force are constant.

Circuits A, B and C have all been used in the solution of induction motor problems. All are admittedly defective, but they are here given in the order of exactness. Circuit A is sufficiently exact for all practical purposes, and may be taken as the standard circuit with which to compare the others. Circuit B has not found wide application on account of the fact that it is almost as

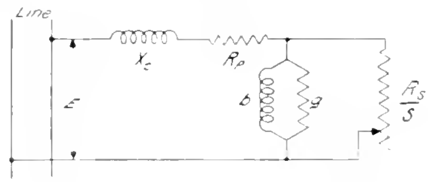

Fig. 6. Series-Parallel Circuit, approximately equivalent to induction motor operating at slip s. Circuit B

difficult to solve as A, while the results are less exact. Circuit C has been and is widely used. It is easily solved, and although the results obtained from it are approximate, yet for many practical purposes they are sufficiently exact.

Each of the representative circuits may be solved either analytically or graphically. Graphical solutions, while very clear and instructive to the student, do not yield accurate results, so that there is introduced not only the inherent errors in the circuit representation, but also those due to graphical processes. The graphical error is magnified by the fact that some of the quantities to be represented are very small, and others large. The analytical method is, of course, more lengthy, but its results are quite exact for the circuit chosen.

None of the solutions can be regarded as exact so far as the actual performance is concerned, for the reason that they are all based on the assumption that the impressed e.m.f. and flux waves are sinusoidal. If the

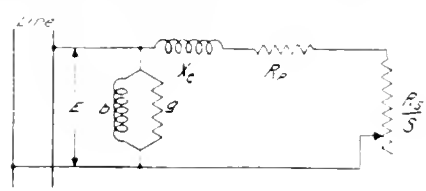

Fig. 7. Modified Circuit for Induction Motor, commonly used in the geographical solution of induction motor problems. Circuit C

impressed e.m.f. wave be sinusoidal, the flux wave will not be, owing to the effect of the reluctance in the iron parts. However, the principal reluctance is in the air gap, so that with sinusoidal e.m.f. impressed, the magnetizing current is practically sinusoidal also.

The rotor currents, however, are usually badly distorted. On account of the difficulty of arriving at even a close approximation of the wave shape of rotor currents, no attempt has yet been made (as far as the writer is aware) to correct for this deviation from the sine law.

With the hope of throwing some light on the subject of wave shapes of current, voltage and flux, etc., as applied to induction motors, the experiments as set forth in the next paragraph were planned and made.

FLUX STUDIES

In order to determine experimentally the manner in which the air gap flux in an induction motor varies under running conditions and locked test, a commercial machine was equipped with exploring coils and the currents induced therein by the rotating field studied by means of an oscillograph. These exploring coils, two in number, consisted of 10 turns each of fine wire, one coil being mounted on the stator and the other on the rotor at the air gap surfaces. Both coils were placed on top of the wedges in the slot openings, in order to get them as near the air gap as possible. The stator coil was given a pitch equal to a pole arc (90 degrees or 12 slots), but the pitch of the rotor coil was slightly greater. A larger pitch for the rotor coil was necessary in view of the fact that the rotor had 39 slots. A pitch of 10 slots for the rotor coil made it more nearly the equivalent of the stator coil than would have been the case if a pitch of 9 slots had been used. All slots were of the overhanging or partially closed type. Connection from the rotor coil to the oscillograph was made by means of slip rings and brushes.

The air gap flux in linking with these coils induced voltages therein, a record of which could be made on a revolving film in the ordinary way. The current set up in the circuit containing the exploring coil and the oscillograph galvanometer was practically in phase with these voltages, since the circuit as a whole was practically non-inductive.

The motor thus equipped was of $7\frac{1}{2}$ h.p. capacity, 3-phase, 110 volts, 4 poles, 1800 r.p.m., 60 cycles, and was run under load in the usual manner. A prony brake absorbed the mechanical energy generated.

The frequency of the rotor being very small, except on lock test (or high loads), it was not convenient to get a complete half cycle of rotor voltage in all cases when the rotor was allowed to revolve. However, by reducing the speed of the revolving film and loading the motor well up to full load, a half cycle of rotor voltage could be obtained. This procedure caused the irregularities on both waves to come so close together as to render the picture of little value so far as measurements were concerned. For general inspection, however, such films are of considerable importance, and a few were taken. Fig. 8 shows such a film taken under normal running conditions, the output being approximately full rated load. It will be noted that the wave shapes for both rotor and stator are generally regular, but both are broken up badly by higher harmonics caused obviously by the slotting. It is evident that any method designed to predetermine operating characteristics can conveniently deal with the general shape only. Obviously, the rotor frequency is a measure

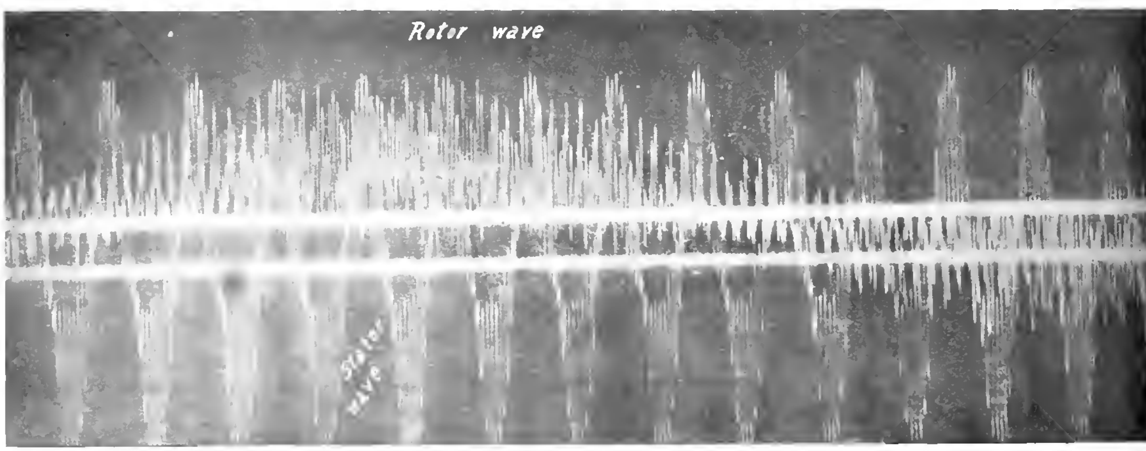

Fig. 8. Rotor and Stator Waves. Full voltage and approximately full load

of the slip, so that by counting the number of stator half cycles occurring in the time required for a rotor half cycle, the slip may be accurately determined from the film. The slip shown in Fig. 8 is about $5\frac{1}{2}$ per cent.

In order to study a little more closely the irregularities caused by slotting, the speed of the film was increased until about two whole cycles of the stator current were included at each exposure. The rotor wave was in each case also taken but it is useful only for general inspection, since no particular portion of it could be obtained.

Fig. 9 shows the stator wave when 32.5 volts per phase were impressed at the terminals, this being about the lowest voltage at which the motor would run satisfactorily. The rotor was allowed to run idle when this exposure was made. Since the impressed voltage was very much reduced, the flux per pole was also very much reduced and the teeth were in no wise saturated. The irregularities have somewhat rounded tops and present an even appearance.

The wave in Fig. 10 resulted when the motor carried approximately 0.6 rated load with full voltage impressed on the stator. The irregularities in the wave now present a notched appearance at the top. This same notching appeared on all waves taken at full voltage, partial load, but disappeared again at full load output, as will be shown in Fig. 11.

Fig. 11 was made with the motor operating under normal full load conditions. In this

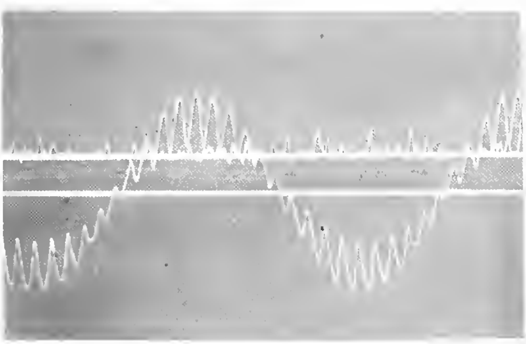

Fig. 9. Stator Wave, 32.5 volts impressed on stator, machine running light

oscillogram a portion of the rotor wave appears, showing the character of its irregularities. It will be noted that the tops of the stator irregularities are somewhat rounded, the notching effect having almost entirely disappeared.

Careful measurements show that the stator waves (reduced to the same scale) decrease slightly in size as the load comes on the motor. A numerical value of this decrease cannot be given here, since the films were not sufficiently numerous and the measurements of

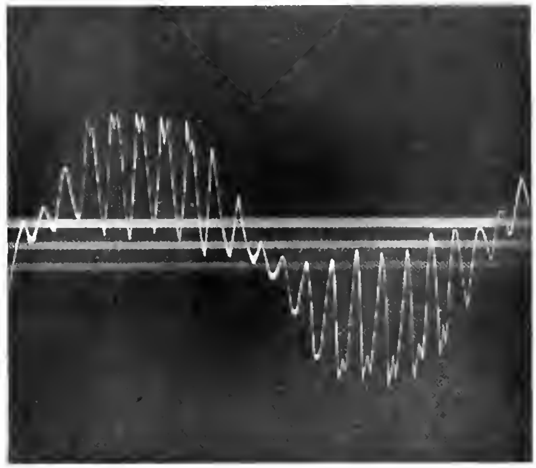

Fig. 10. Stator Wave, full voltage impressed, machine running at about 0.6 full load

areas of such irregular curves were not sufficiently accurate to give conclusive data.

In general shape both rotor and stator waves may be regarded as sinusoidal, but the higher harmonics are very much in

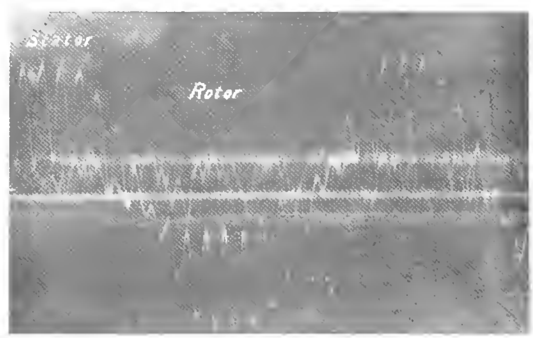

Fig. 11. Stator Wave, full voltage impressed, approximately full load (6.7 h.p.)

evidence, and conditions under which these harmonics might interfere with satisfactory operation of a motor can easily be conceived. If the irregularities appearing on the stator wave are counted, it will be found that their number per half cycle checks with the number of rotor slots per pole. This means that as each rotor tooth passes the slot containing the test coil the local flux finds a path of very much reduced reluctance, and hence increases in value. In all films taken under running conditions the mutual effect

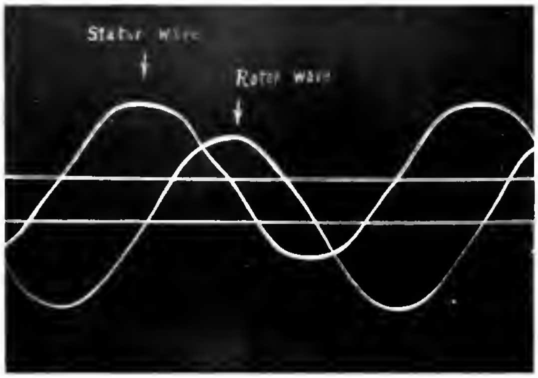

Fig. 12. Rotor and Stator Waves; 26.5 volts impressed; rotor locked in position

of rotor and stator teeth upon the resulting waves is very pronounced. Obviously a smoother curve will be obtained if closed slots are used in rotor and stator, but the films as shown may be regarded as typical for induction motors of American manufacture.

Fig. 12 was taken with the rotor locked in position and 26.5 volts impressed on the stator. From this film values of total flux per pole for both rotor and stator could be secured, since the oscillograph was calibrated (in terms of volts applied to its terminals) after each exposure. From this record the ratio of stator flux to rotor flux is 3.25, showing a large leakage. In all, some 10 oscillograms were taken, covering the locked test phenomena at various voltages. Measurements from all films gave values ranging from 3.7 to 2.6 for the above ratio. This large leakage is no doubt due to the fact that in squirrel cage motors the rotor coils are not similar in shape to the stator coils, except where both cross the effective iron parts. The test coils used in these experiments were made to follow the general shape of the coils regularly wound upon the part they were to give values for. Hence the leakage shown by these oscillograms represents reasonably well the actual leakage of the machine.

It will be observed that the curves shown in Fig. 12 are regular in shape and that the higher harmonics, so pronounced in the oscillograms covering the running condition, are absent. This was true of all films taken under locked test conditions.

ELECTRICAL EQUIPMENT FOR THE PROPULSION OF THE U. S. COLLIER JUPITER

By Eskil Berg

Lighting Engineering Department, General Electric Company

The author first mentions the more important stipulations in the contract for the equipment of the Jupiter with electrical propelling machinery, and then proceeds with a brief description of the vessel and a comparison in tabulated form of the three sister ships, the Jupiter, the Cyclops and the Neptune. The principal features in the design and operation of the generating unit and motors for the Jupiter are outlined in detail, and the results of complete tests made under conditions identical with those of ultimate operation are included in the form of curves.—Editor.

In July, 1911, the United States Government closed a contract with the General Electric Company for the equipment of the new naval collier Jupiter with electric propelling machinery, according to the system proposed and designed by Mr. W. L. R. Emmet. In this contract the manufacturers are required to guarantee under penalty, time of delivery, water rate for shaft horse power at 14 knots and at 10 knots, and that the weight of the electrical equipment will not exceed that of the engines proposed for this ship. In case the machinery is rejected by the Government, due to failure of the boat to meet the contract requirements, all the apparatus is to be removed by the manufacturer, and the Government will then install the engines which were originally intended for the vessel. The electrical machinery was therefore made to conform in outline to the engine layout, and the fact that this was possible, with lots of room to spare, was without doubt one of the main reasons why the Government felt justified in trying this new method of propulsion.

All of the apparatus has now been thoroughly tested and the results indicate that all guarantees have been met, with a large margin. As will be seen from Fig. 5, the tested water rates at 14 and 10 knots are respectively

12 and 14.2 lb. per brake horse power, which is about 1 lb. better than was guaranteed. The actual weight of the equipment is 156 tons, which represents a saving of about 40 per cent. over the reciprocating engines upon which the guarantee was based.

The smooth running qualities of the installation, the ease of operation, and the rapidity with which reversing may be effected, have been admired by all who have witnessed the exhibits made here during the last two months, and all evidence indicates that this installation will be an unqualified success.

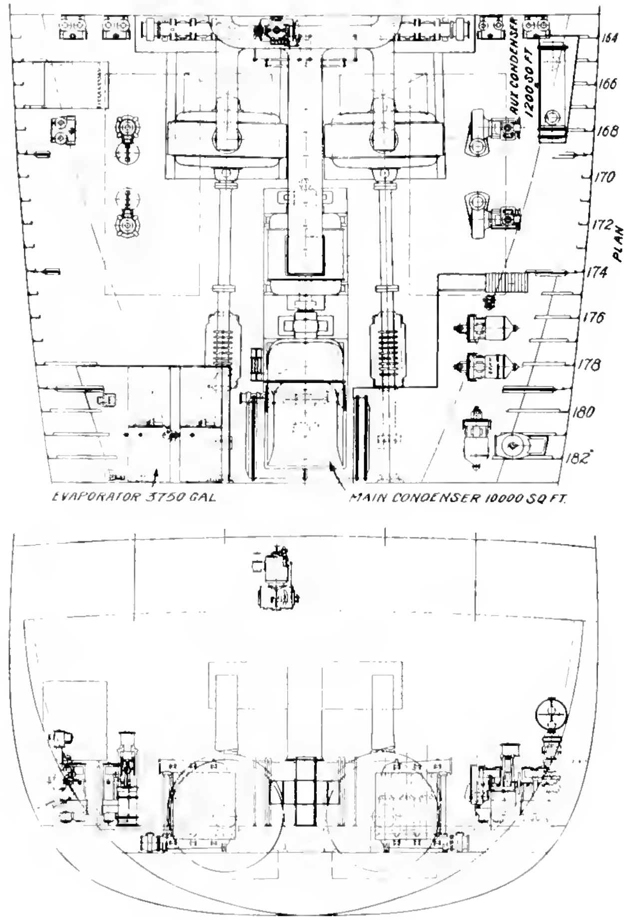

Fig. 1. Arrangement of Electrical Propelling Machinery shown in Plan and Elevation

Description of the Jupiter

The Jupiter is a sister ship to the Neptune and the Cyclops, the latter being equipped with two triple-expansion engines, and the former with a turbine connected to the propellers by mechanical gearing. These vessels have a displacement of about 20,000 tons, carry 12,000 tons of cargo, and are designed to operate at 14 knots. The table below gives a comparison of the known data concerning the equipments of these three vessels.

Published reports of the Neptune state that she did not meet the contract requirements as to speed and economy. This was no doubt due to inefficient propellers and turbines, and changes are now being made with a view to improving these parts of the equipment. The operation of the gearing seems to have been satisfactory; but this was to be expected, as the gear ratio was made low, viz., 1250 r.p.m. to 135 r.p.m., the former being too low for an efficient turbine design and the latter rather too high for the most efficient propeller.

Turbo-Generator

The generating unit consists of a 6-stage Curtis turbine connected to a bi-polar alternating current generator; the speed of this unit at 14 knots being about 2000 r.p.m. and the voltage about 2200. The turbine is so designed that all of its parts are accessible and replaceable. New buckets can be attached to any of the wheels by simply removing the top half of the turbine casing, as may be seen from Fig. 3. Any one of the six stages will run the ship at about half speed, so that the loss of one or more stages will not entirely disable the vessel. A sufficient number of extra parts will be carried on

	Cyclops	Jupiter	Neptune
Displacement, tons	20,000	20,000	20,000
Indicated H.P. at 14 knots	5600		
Engine or turbine speed at 14 knots	88 r.p.m.	2000 r.p.m.	1250 r.p.m.
Propeller R.P.M. at 14 knots	88	110	135
Weight driving machinery, tons	280	156	
Character of driving machinery	2 Triple Expansion Engines	1 Turbo-Generator and 2 Motors	2 Turbines, each with gearing
Steam consumption in lb. per shaft horse-power hour	14 (estimated)	12 (tested)	.....

the vessel to prevent any serious interruption of service from failure of the turbine.

The generator is a two pole, 5450 kv-a., 2300 volt machine. The field spider is made from a solid forging, while the field winding is of the distributed type and consists of copper strips insulated with asbestos and mica, this construction making an absolutely fireproof insulation. The end windings are held in place by a one piece nickel steel ring. On the outer end of this ring is mounted a fan, which draws air in from the bottom of the machine, through the air gap, and forces it through the stator air ducts to the top of the generator, whence it is led away. The armature, or stator, is Y connected and wound for 2300 volts, regular bar winding being used and each slot having two bars. The insulation is mica and asbestos. The laminations are made from the best quality of silicon steel, so as to reduce the losses and thus obtain an efficient and cool operating machine.

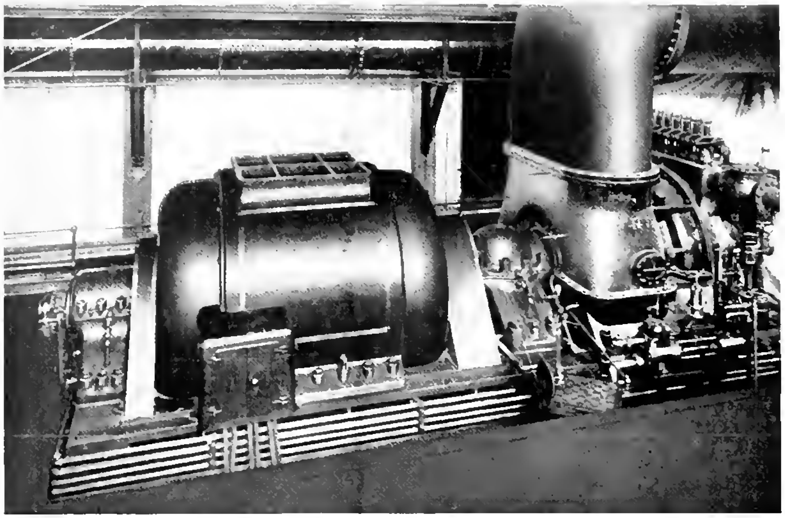

Fig. 2. Turbo-generator Unit in Testing Department of Manufacturer

Motors

The generator delivers current to two motors, each rated 36 poles, 2750 h.p., 110 r.p.m. 2300 volts, one motor being connected directly to each propeller shaft. The motors are of the shield bearing type and are provided with wound rotors and slip rings. They are made entirely of steel, the stator spider consisting of cast steel sub-divided into four sections, while the stator and rotor laminations are of silicon steel. The stator has two coils per slot, formed of rectangular conductors insulated with mica and tape, and varnished to make them waterproof. The rotor is wound with two bars per slot, the insulation of which is similar to that of the stator winding.

The ratio of synchronous speed reduction between generator and motors is 18 to 1, the propeller turning 110 r.p.m. at 14 knots.

Water-cooled Resistances

A water-cooled resistance is supplied for each motor, which is connected in series with the rotor circuit during the process of reversing, and also when maneuvering the boat. For straight running it is cut out by means of a slider on the motor shaft, which is operated by a lever attached to the frame of the motor. These resistances are made of non-corrosive material and are the

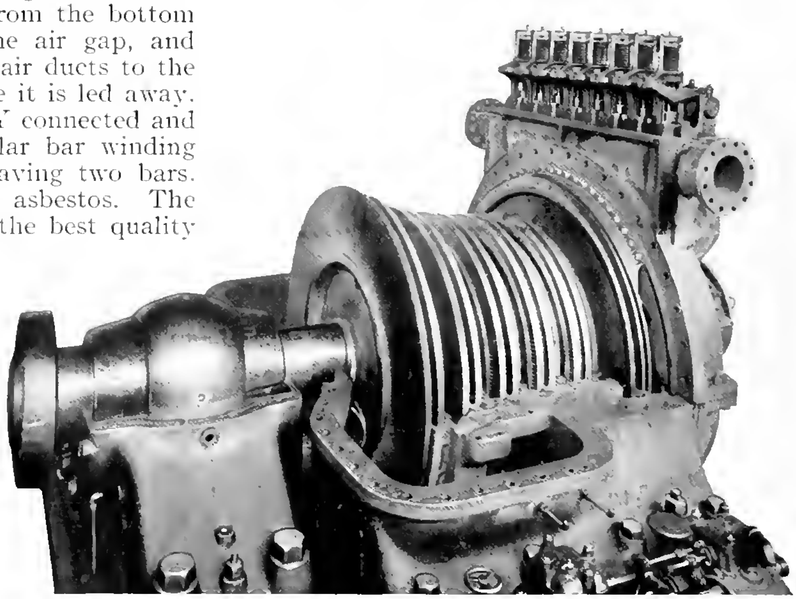

Fig. 3. Turbine with Top Half of Casing Removed

result of much careful experimenting. The heat generated in them is delivered to the sea water, which is forced through a 3 in. pipe by the condenser circulating pump. The rheostat is easily disconnected and taken apart, and any part can be renewed should it be desired. Tests have shown that the rheostat functions perfectly and has ample margin for any emergency. Fig. 3 shows a group of resistances for one induction motor.

Operation

There are two distinct positions of the control equipment for operating the ship. The first is the maneuvering position, in which the resistances are left in the circuit of the motor rotors. Thus connected, the motors can be started, stopped or reversed practically instantly by simply opening or closing the proper switches; while the boat can be run at any speed up to about 9 knots. The next position is the running position, in which the motors are run without the resistance in the armature circuit. The speed of the motors is changed by variation in the speed of the generating unit, the ratio of speed reduction remaining fixed (approximately 18 to 1). The change of speed, however, is not made by throttling, as is usual with ship turbines. Instead, the turbine is equipped with a governor of novel construction, which is so arranged that it is capable of automatically holding the speed at any point from about 5 knots, up to the maximum. Arrangements will also be made by means of which the operator can open or close the main throttle valve or close the emergency throttle, should he desire to shut off the steam instantly.

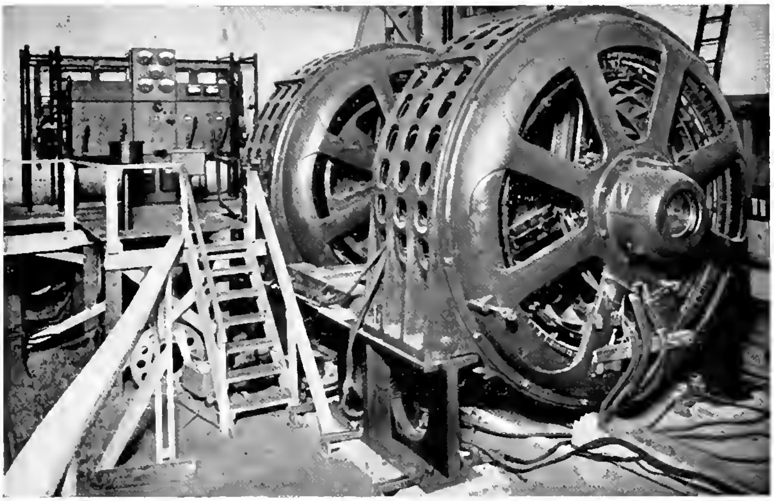

Fig. 4. Induction Motors in Testing Department of Manufacturer

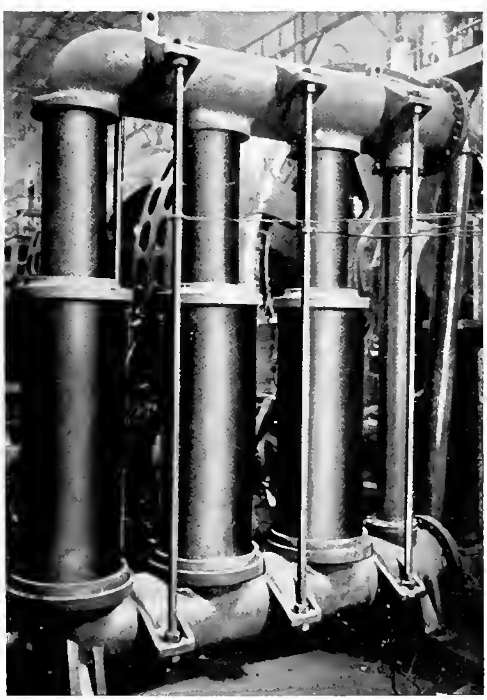

Fig. 3. Water-cooled Resistance for One Induction Motor

Lubrication and Ventilation

The generating unit and motors are self-lubricating and self-ventilating. Sheet metal ducts will be connected to their air outlets in such a manner that the heated air will be led to the suction of the fire room blowers and thus will not be released in the engine room.

Safety Interlocks

The generator is of special design, with rather high armature reaction and relatively low ampere turns per pole; this construction limiting the short circuited current so that no destructive current can flow in case of wrong connections. In addition to this, mechanical or electrical interlocks have been provided, in order to prevent the closing or opening of wrong switches. It is thus impossible to close the go-ahead switch if the reverse switch is closed, and neither switch can be closed without the resistance being in series with the motor armature. Magnetic locks, energized by the field circuit of the generator, are attached to the levers which connect and disconnect the resistance. These locks prevent the movement of these levers until the generator has lost its field, thus preventing any possibility of burning contacts by switching at the wrong time or improperly.

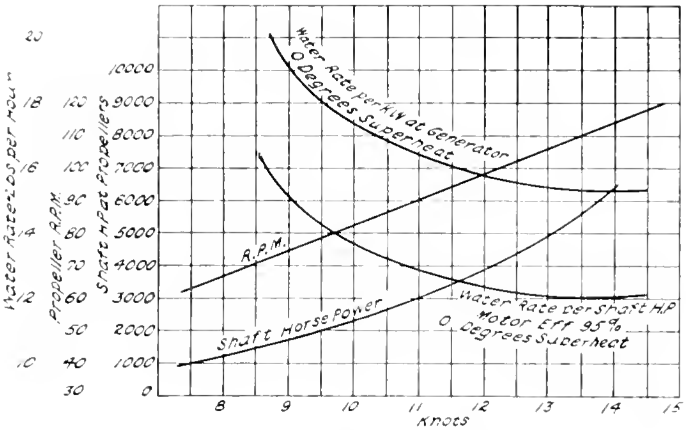

Fig. 5. Performance Curve, U. S. Collier Jupiter. From test of generating unit run under proper conditions of speed, load and voltage and reduced by known efficiency of motors

Tests

Fig. 4 shows the two motors as set up in the power station of the manufacturer, the turbine being connected to a condenser, and one motor being installed in the same position, with relation to the switchboard controlling mechanism, that it will occupy on board ship. The other motor was run as a generator and was coupled to the first motor as load. By means of this arrangement it was possible to test the motor for all conditions under which it might be called upon to operate, and to show the ease with which it could be started, stopped and reversed. The water rates of the turbo-generator unit were taken under the exact conditions of operation, viz., 190 lb. gauge, condensing to 28½ in. vacuum; the generator being loaded on a water box in the usual way. Fig. 5 shows the results obtained during this test, while Fig. 6 gives the characteristic curves of the motors.

Cost

The contract price of electrical propelling machinery for the collier Jupiter is $13.75 per horse power. This compares very favorably with the cost of reciprocating engines as supplied to the Cyclops. For larger ships this comparison is still more in favor of the electric propulsion.

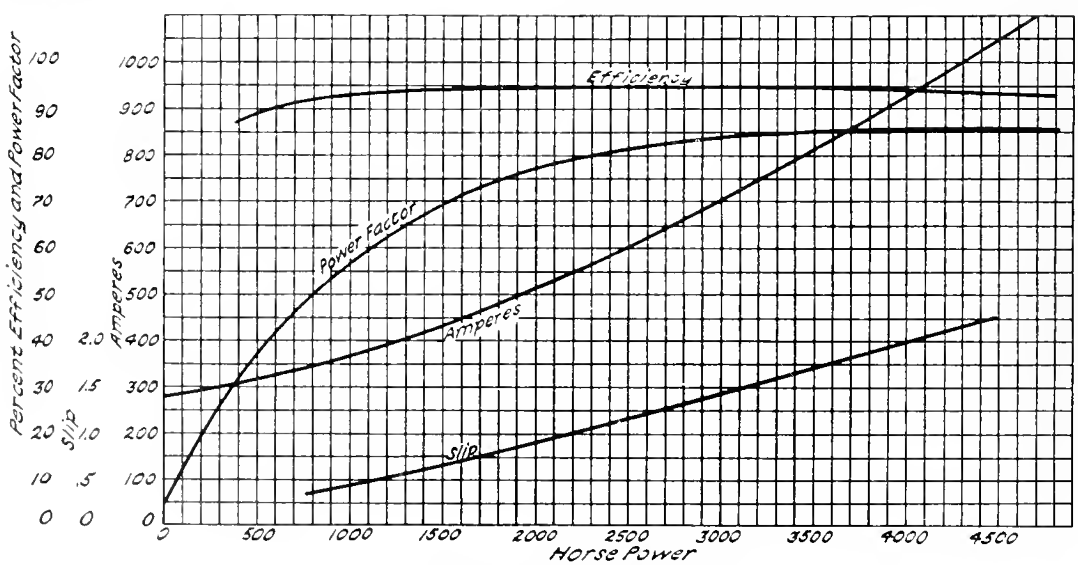

Fig. 6. Characteristic Curves of Induction Motors

COST AND EFFICIENCY OF ALTERNATING VERSUS DIRECT CURRENT MOTORS FOR STEEL MILL AUXILIARIES

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Edward J. Cheney, Power and Mining Eng. Dept., General Electric Company

The tables published on pages 502 to 504 give comparative figures of first costs and annual costs for two systems of modern steel mill drive; the first being the all-a.c. system in which a.c. motors are used throughout, and the second the mixed system, in which a.c. motors are used for the main rolls, etc. and d.c. motors for some of the smaller drives. The tables represent the result of an exhaustive study of the subject, in which no factor which could possibly influence the conclusions was left out of consideration. A plant of modern design, of which the full plans were available, was selected for study; and complete lay-outs for both systems made to determine the size and type of each motor and control equipment, the size and length of all wiring and conduit, the location and apparatus for each substation, etc. In the paper itself will be found full details as to the method of procedure in estimating the costs, and local considerations (such as gas engines or turbines for prime-movers, location of power house, power-factor of main load, etc.) which affect the various sixteen cases for which comparisons have been made. Immediately before the tabulated costs the authors present the general conclusions to which their investigation has led them. This paper was originally presented before the Association of Iron and Steel Electrical Engineers.—Editor.

The time has gone by when it was necessary to discuss the advantages of electric motors in steel plants. There are, however, a great many problems concerned with their application which are not yet fully solved. One of these is concerned with the proper type of motors to use. There is usually no question but that induction motors should be used for driving the main rolls, and that induction or synchronous motors should be used for pumps and various other places about the plant where comparatively large size motors are necessary. There is, however, a diversity of opinion as to whether the so-called auxiliaries should be driven by alternating or direct current motors, and there have come to be two recognized systems. These are known as the all-a.c. system, where no direct current is used, and the mixed system, where direct current is used for the small motors. There are a great many factors which must be considered in comparing the two systems.

In the first place, it is to be assumed that power will primarily be alternating current, as the transmission distances ordinarily preclude the use of direct current generators. It would therefore seem to be simplest and most efficient to step down to a suitable voltage through static transformers and use alternating current motors. The mixed system involves additional expense for motor-generator sets and entails considerable power loss due to the low efficiency of conversion. On the other hand, however, direct current motors are lower in first cost than induction motors and a higher power-factor is maintained on the entire system where they are used. In the mixed system an increase in power-factor is effected by eliminating the lagging current of the induction motors, and, in addition, the motor-generator sets can easily be equipped with synchronous motors which will take a leading current from the line and offset part of the lagging current on the rest of the system. The increase in power-factor enables a reduction to be made in the size and cost of transformers and generators, and also increases their efficiency due to the lower currents which they are required to handle and to the decreased excitation required by the generators.

It is perfectly possible to prove that either system is superior by selecting the proper factors for consideration. The performance of both direct current and alternating current motors is quite generally known, but the various factors affecting cost and efficiency are not so well understood. In order to make as nearly as possible a general determination of these factors, it was decided to make an exhaustive study which should include a consideration of everything which might influence the result. To make the investigation thoroughly practical a plant of modern design, of which the complete plans were available, was selected for the study.

General Layout

This plant consisted of six merchant mills, comprising the ordinary run of sizes, and included the usual equipment of heating furnaces, shipping yards, etc. It is felt that the plant was fairly representative of the ordinary type of steel mill and was neither too large nor too small to be in any way exceptional.

Complete layouts for both systems were made to determine the size and type of each motor and control equipment, the size and length of all wiring and conduit, the location and apparatus for each substation; in short, every detail, except actual working drawings, necessary in order to buy and install a complete electrical equipment.

The power was assumed delivered at 6600 volts, 25 cycles. One large slow-speed induction motor, wound for 6600 volts, was required for the main roll drive in each mill, the aggregate capacity of these motors being 7700 h.p. In addition to this load there was about 800 h.p. in pumps, lights, etc., which would be alternating current in any case. Of the small motors on tables, punches, shears, cranes, shop tools, etc., there was a total of 182 motors and an aggregate of 4973 h.p., giving an average of 27.3 h.p. per motor. On the all-a.c. system, it was assumed that all these small motors would be wound for 220 volts and power supplied by two substations, stepping down from 6600 to 240 volts, each substation having three 350 kv-a. oil-cooled transformers and suitable switchboard. On the mixed system it was assumed that all these motors would be wound for 230 volts direct current and that power would be supplied by two substations, transforming from 6600 volts alternating current to 250 volts direct current, each substation having one 750 kw. synchronous motor-generator set and suitable switchboard.

All layouts were made in accordance with what was considered the best electrical practice of today in steel mills; but no unduly elaborate or unnecessary apparatus was included, and all economies were effected which were possible without sacrificing reliability. Each system was considered separately and benefit was taken of every advantage inherent in the particular system being considered; but great pains were taken to see that both systems were considered on exactly the same basis.

Mill type motors were used on all tables, transfers, cranes, etc., and motors of open construction for shears, fans, shop tools, etc. The alternating current mill type motors were all of the wound rotor type, and the corresponding direct current motors were either series or compound wound as required by the duty. The open alternating current motors were assumed to be of the squirrel cage induction type, and the corresponding direct current motors were assumed to be shunt wound. Suitable control equipment was determined in each case, most of the variable speed motors having magnetic controllers, but a few of the smaller ones having hand controllers. On the direct current system use was made, wherever possible, of the series type contactor. The constant speed induction motors were furnished with starting compensators having no-voltage and overload protection, and the corresponding direct current motors were furnished with standard starting equipments. In laying out the wiring the load on the various feeders was estimated by taking into account reasonable load factors, and the size of all wires determined in accordance with the Carnegie Steel Company's standard wiring rules, all wires being run in conduit.

The only instances where the motors might possibly need to be of different capacities for the different systems are in the cases of hoist motors on the cranes. A careful study of the cranes was made and it was found that the majority of them would operate at light loads almost all of the time, so that the same size motor could be used in each case, geared for the same light load speed, the speed of the alternating current motor being reduced on heavy loads by rotor resistance. On the billet yard cranes it was found advisable to put on larger motors for alternating current than for direct current. The total horse power capacity given is for the mixed system.

The layouts having been carefully made, an estimate was made of the cost of each system. In these estimates the large motors, which would be alternating current in any case, were not considered, but all details which were in any way affected by the difference in the systems, including motor-generator sets, transformers, foundations, motors, control, cables, installation and wiring up were included. Great pains were taken to use fair current market prices on all material and apparatus. The cost of installation was carefully figured on the basis of actual costs for similar work. The total figures arrived at represent the total cost to the purchaser of the entire equipments installed and ready to operate. A tabulation of costs for the two systems is given at the end of this paper.

Power Supply System

Having determined the apparatus located in the plant itself, a layout of the power supply system was made with a view to finding how much it was affected by the difference between the two systems. It was found that power should be generated at 6600 volts and stepped up to 22,000 volts for transmission to the plant, where it would be stepped down again to 6600 volts. The calculations of the power system will be followed through briefly, the all-a.c. system being considered first.

The sizes of generators and transformers are properly fixed by the maximum load conditions, and these maximum load conditions were carefully determined for the case in question. The duty of the mills under various conditions of rolling were studied, together with the characteristics of the large motors; and it was found that the maximum steady load which could be sustained for any length of time on the large motors, together with the other portions of load which would be alternating current in either case, amounted to 7510 kw. at 84.7 per cent. power-factor. The total small motor load was found to be 1500 kw. on the 240 volt bus. Allowing for transformer losses on the basis of 98.2 per cent. efficiency at unity power-factor, this load amounts to 1538 kw. at 70 per cent. power-factor on the 6600 volt bus. Combining the two loads, we have a total on the 6600 volt bus of 9048 kw. at 82 per cent. power-factor, or 11,000 kv-a.

As this is the maximum load, we can assume that it represents 25 per cent. overload on the transformers. Normal load on the transformers will, therefore, be 8800 kv-a., or 2930 kv-a. for each of three transformers. It was therefore decided to use three 3000 kv-a. water-cooled transformers for stepping down from 22,000 to 6600 volts. Duplicate transformers would be used at the generating station for stepping up and one spare would be provided, making a total of seven transformers required.

In figuring the transmission line it was found that the size of copper was fixed by the economical loss and not by the voltage drop. It will be unnecessary to go into the details of this calculation, but it will be sufficient to say that the line decided upon had a resistance of 0.762 ohms per phase. Knowing the kv-a. load and the resistance of the transmission line, and taking transformer efficiencies at 98.7 per cent. at unity power-factor, we have 286 kw. loss in the two banks of transformers and 195 kw. loss in the transmission line.

Adding the losses to the original load we come to the generator terminals with 9529 kw. and 11,410 kv-a. or 83.4 per cent. power-factor. Assuming we have four gas engine-driven generators, we would have 2382 kw. and 2852 kv-a. on each unit under the maximum conditions. These conditions may be assumed to represent 10 per cent. overload on the generators, and it was therefore determined to use four 2200 kw., 85 per cent. power-factor generators. These machines would have a normal capacity of 2590 kv-a. each, and at 10 per cent. overload a capacity of 2850 kv-a. each.

The same general method was used on the mixed system. The main portion of the load (7510 kw. at 84.7 per cent. power-factor) remains as before. The small motor load is 1500 kw. on the 250 volt bus. At a motor-generator efficiency of 87.7 per cent. and taking 80 per cent. leading power-factor on the synchronous motors, we have a load on the 6600 volt bus due to the small motors of 1730 kw. and 2160 kv-a. The total load therefore amounts to 9240 kw. at 93.8 per cent. power-factor, or 9860 kv-a. Taking this as representing 25 per cent. overload on the transformers, the normal load will be 7900 kv-a. or 2630 kv-a. for each of three, and it was therefore decided to use 2700 kv-a. transformers, a total of seven being required.

The transmission line works out to require the same size copper as for the other system; and as a general note it may be remarked that in no case does the difference between the two systems warrant a change in size of wire on the transmission line; so that in each case the lines are identical for the two systems, although the energy loss is, of course, different due to the different power-factors.

Figuring as before, the transmission losses amount to 256 kw., the line losses to 157 kw. and we come to the generator terminals with a total load of 9653 kw. and 11,250 kv-a. at 94.2 per cent. power-factor. This gives a load on each of four generators of 2413 kw. and 2562 kv-a., which represents 10 per cent. overload. It was therefore determined to use four 2200 kw., 95 per cent. power-factor generators which would have a normal rating of 2310 kv-a., and at 10 per cent. overload a capacity of 2550 kv-a. each.

From the above data the cost of the power system was estimated. Since the kilowatt load is so nearly the same there will evidently be no difference between the two systems in the gas engines or gas cleaning plant. The transmission lines are identical and there will be no practical difference in cost of switchboards. The only points of difference will therefore be in the generators and transformers, and they only were considered. The generators were assumed to be 83$\frac{1}{3}$ r.p.m. engine type, and the transformers were assumed to be water-cooled with full capacity primary taps for voltage adjustment. The costs for each system delivered and installed are as follows:

	All-A.C.	Mixed
Transformers	$38,360	$36,960
Generators	76,000	70,800
Total	$114,360	$107,760

A summation of all the first costs will be found under Case I, page 502.

Calculation of Efficiency

So far, maximum load conditions, which determine the size of the apparatus required, and the first costs have been considered. In figuring efficiency and operating costs it is necessary to take load conditions which are fairly representative of the yearly average.

The small motor load was considered the same as before, since little change would be made in it by varying conditions, provided the plant were working full time. The difference between maximum and average conditions lies in the different character of work in the mills and the consequent difference in load on the large motors, but this will not materially affect the small motor load as all of the apparatus in the plant is assumed to be working at full output. In explanation of the fact that the same load is used at the substation busbars for both systems it should be said that the losses in the various feeders and motor cables were checked up and found to be the same for both systems. This was to be expected since the wiring was laid out on the same basis for each case. The average efficiencies for alternating current and direct current motors are practically identical.

The average load on the large motors would, however, be considerably lower than the maximum and the power-factor would be decreased in consequence. Careful consideration of all the factors showed a fair average of the main load to be 5320 kw. at 80.5 per cent. power-factor, or 6600 kv-a. Adding the small motor load and the losses in transformers, line and generators, which were computed by taking into account the per cent. load and power-factor on each unit, the output required at the engine shaft was obtained. This was 7663 kw. for the all-a.c. system and 7678 kw. for the mixed system, or a saving of 15 kw. in favor of the alternating current system.

Annual Costs

The real basis for comparison between the two systems is, of course, that of annual costs, which are made up of fixed charges, maintenance and power costs. In comparing the fixed charges the following percentages have been used:

	Motors and Control	Other Apparatus
Depreciation	10.0%	8.0%
Interest	5.5%	5.5%
Taxes and Insurance	1.5%	1.5%
Total	17.0%	15.0%

There would be no appreciable difference in maintenance between the two systems except on the motors. The maintenance figures were based on the records of motors of about the same capacity which had been in actual operation for some time and on which accurate records of delays and repairs had been kept. These records were all for direct current motors, as no reliable records were available on alternating current motors for a sufficiently long period to be considered representative.

It was therefore necessary to estimate the maintenance cost for alternating current motors from the records of the direct current motors. It was assumed that the care and inspection would be equal for the two classes. The delays and repairs for the direct current motors were segregated as follows:

(1) Commutator troubles and repairs directly or indirectly due to same.
(2) Brush-holder troubles and repairs directly or indirectly due to same.
(3) Bearing troubles and repairs directly or indirectly due to same.
(4) All other troubles and repairs.

It was assumed that for alternating current motors all commutator troubles and repairs would be eliminated, all bearing troubles and repairs doubled, and all other troubles and repairs remain the same as for direct current motors. Figuring on this basis, it was found that there would be an annual saving in favor of alternating current motors, as follows:

Repairs	$15.83 per motor
Delays	3.4 minutes per motor

Applying these figures to the particular case in consideration showed an annual saving in repairs of $182 \times 15.83 = \$2881$, and an annual saving in delays of $182 \times 3.4 = 619$ minutes. As the average output of the various mills would be about 1.5 tons per minute, the saving in output resulting from alternating current motors would be $619 \times 1.5 = 929$ tons annually. This saving in output has, of course, a real value; but as both the tonnage and value of same vary so much in different cases and are hard to arrive at in any case, no effort has been made to capitalize it.

The difference in power requirements between the two systems was so small that there could not conceivably be any difference in the size of engines or gas handling plant, and the only amount properly chargeable to the difference in power is that due to the actual difference in gas used. On the basis of 300 working days per year, of 20 hours each, valuing gas in the standard manner and considering the actual efficiency of the engines it was found that the fuel cost of power at the engine shaft amounted to $6 per kilowatt-year.

Figuring on the various items of annual costs with the methods outlined above, it was found that there would be a net saving of $2147 per year in favor of the all-a.c. system, as itemized under Case I later in this paper.

Other Cases

Case II is similar to Case I except that the generator station is assumed to be located at the steel plant so that no transformers or transmission line are required. Cases III and IV are the same as Cases I and II, except that turbine generators have been substituted for gas engine generators.

In Case I the power-factor of the main load is comparatively high due to the good load factor of the mills under consideration. While this figure ought usually to be reached in properly motored merchant mills and others of similar load factor, it is probably higher than can be obtained in billet mills, bar mills, plate mills and the like, where the load factor is lower. Case V has therefore been worked out for a power-factor of 70 per cent. on the main load, which is believed to be as low as the power-factor would go in a properly motored plant. In Cases I and V the percentage of small motor load is comparatively high, due to the large amount of motor-driven machinery in the plant considered. In some instances this percentage might be considerably less, and Cases IX and XIII have been calculated to cover such instances. In order to avoid recalculating the small motor installation it was assumed that this would remain unchanged and that the main load would be doubled, thus bringing the percentage of small motor load down from 22.4 to 12.6. The other cases are modifications of the ones mentioned above, the differences consisting in omitting the transmission line and transformers in some cases, and substituting turbines for gas engines in other cases. The same methods of calculation were used in each case as those already explained for Case I.

It is, of course, impossible to work out all the possible cases, but from the general ones given here it will be possible to draw fairly close conclusions for any particular case which it is desired to study. Relative sizes of installations will not affect comparisons to any great extent. The system studied required the transforming equipment to be divided into two substations. A smaller system would require only one substation and fewer generators, while a larger one would require more; so that a change in size of the system would affect the number of units, but the relative proportion would remain practically the same.

General Notes

In making comparisons of the kind undertaken, the results are apt to be distorted on account of the limited number of sizes which are commercially available in any line of apparatus. For instance, in Case I it was calculated that 2700 kv-a. transformers and 2310 kv-a. generators would be required. These sizes might not be standard for any manufacturer, and if the system were actually installed it might be necessary to purchase the next higher standard rating. It can be readily seen that this might handicap one system more than the other, depending upon which happened to most nearly fit standard ratings. In order to entirely eliminate this difficulty cost curves were drawn up for each class of apparatus. In each case the costs were taken from these curves, and represent the cost which would be theoretically expected if the machines were designed for exactly the capacities required. All the costs are for machines installed and ready to operate. Generator costs do not include the engine or turbine.

In order to make sure that the efficiencies were consistent throughout all the cases, curves were plotted showing losses per kv-a. for different loads and power-factors for each class of apparatus, and the losses were taken from the curves. It will be observed that no cost of buildings has been included. It was found that the difference in floor space between the two systems was so small in each case as to be negligible, so that there would be no cost difference on this account. In every case the size of the apparatus is based on the maximum steady load. The efficiency in each case is based on the average steady load.

The reactance and magnetizing current of transformers and transmission line have been neglected, so that the calculations show a higher power-factor at the generators than at the distribution end. This would probably not be true in actual practice; but an accurate consideration of these factors would have involved considerable additional work, and their effect would have been so nearly the same on each system as to make the difference in the final results negligible.

No spares have been figured for the substation equipments. In case a spare unit is considered desirable it would add considerably to the cost of the mixed system, as one motor-generator set would cost much more than one transformer. In the substation equipments there would undoubtedly be more expense for maintenance and repairs on the motor-generator sets than on the transformers, so that the mixed system ought properly to be charged something for this difference. It would not, however, be a very large amount and has not been included. No figures have been included for attendance for the motor-generator sets. In the case considered the substation apparatus would be located in the same rooms with the large motors so that no additional attendants would be necessary with the mixed system. This would usually be the case, although in some instances it might be that the mixed system should be charged an additional amount for this item.

It is reasonable to suppose that there would be more shutdowns with the mixed system due to the substation equipments, as motor-generator sets are naturally more subject to trouble than static transformers. This amount would probably not be large and no effort has been made to capitalize it.

In estimating the cost of power the minimum possible amount, viz., the cost of fuel alone, has been considered. To be absolutely accurate it should be considered that any difference in power between the two systems would cause a corresponding difference in first cost of engines, boilers or gas cleaning plant, etc., also in the operating cost as regards lubricants, attendance, repairs and maintenance. The value of all these would depend upon the relative proportions between the total power required for the plant under consideration and the total capacity of the power plant. For instance, if, in the case considered, the power station furnished power for this one installation alone, the small difference in the total amount of power required by the two systems would probably make no difference in the first cost of the power station, nor would there likely be any difference in the total operating expense of the station. If, however, the power plant furnished considerable power in addition to the requirements of this installation, these items would have to be considered, because any difference in capacity due to the difference in power requirements of the two systems becomes available for supplying the additional load.

Any increase in cost of power, due to a consideration of the items mentioned above, would be to the advantage of the all-a.c. system in twelve, and in favor of the mixed system in four, of the cases considered.

The difference in tonnage output due to delays has not been capitalized.

Conclusions

A study of the sixteen cases tabulated would indicate the following:

1. The all-a.c. system costs slightly more than the mixed system.
   (a) Excess first cost higher for 22,000 volts transmission than for 6600.
   (b) Excess first cost higher for gas engines than for turbines. From this it appears that the higher the first cost of power supply the less favorable is the use of the all-a.c. system.
2. The lower the power-factor, the greater is the excess cost of the all-a.c. system for both percentages of auxiliary load.
3. The less the percentage of auxiliary load the less the excess cost of the all-a.c. system for both power-factors.
4. The annual costs of the all-a.c. system considered are lower than those of the mixed system.
5. The actual operating costs, i.e. excluding interest, depreciation, taxes and insurance, of the all-a.c. system are considerably less than those of the mixed system.
6. The excess cost of maintenance of the mixed system is based on an estimate and not on actual records. Should this item be entirely neglected, the results in nine out of sixteen cases would show an excess of annual costs for the all-a.c. system, but the amount is so small that accurate calculations for any individual case would be necessary to determine the relative advantages.
7. When the saving in output due to the reduced delays in the all-a.c. system is taken into consideration the saving in annual costs, as tabulated, will be largely increased; and

even should the difference in motor maintenance be neglected there would still be a considerable saving in annual costs for the all-a.c. system.

In conclusion, then, for a rolling mill properly motored, where the percentage of power required for auxiliary apparatus (exclusive of pumps, etc.) is 25 per cent. or less of the total power delivered to that mill, and where the power-factor of the entire mill including both main and auxiliary apparatus, is 70 per cent. or over, the authors feel amply justified in saying that the all-a.c. system will show a saving in annual cost, to say nothing of its greater simplicity and more satisfactory operation.

GENERAL DATA COMMON TO ALL CASES

Number of small motors	182
Total h.p. of small motors	4973
Average h.p. of small motors	27.3

ALL-A.C. SYSTEM

Number of substations	2
Voltage at substations	240
Number of transformers per substation	3
Capacity of each transformer	350 kv-a.
Capacity of each substation	1050 kv-a.

MIXED SYSTEM

Number of substations	2
Voltage at substations	250
Number of motor-generator sets per substation	1
Capacity of each substation	750 kw.

	All-A.C.	Mixed
Load at substation bus	1500 kw.	1500 kw.
Transformation losses	38 kw.	230 kw.
Load on 6600 volt bus	1538 kw.	1730 kw.
Power-factor	70%	+80%

FIRST COSTS

ALL-A.C. SYSTEM

Transformers and switchboards	$15,120	
Freight, cable, foundations and installation	1,300	
Total for two substations		$16,420
Motors and control equipments	117,635	
Cable, conduit and installation	21,315	
Total motor equipment		138,950
Total for alternating current system		$155,370

MIXED SYSTEM

Motor-generator sets and switchboards	$34,860	
Freight, cable foundations and installation	2,160	
Total for two substations		$37,020
Motors and control equipments	104,740	
Cable, conduit and installation	17,010	
Total motor equipment		121,750
Total for mixed system		$158,770

ANNUAL SAVINGS FOR ALTERNATING CURRENT SYSTEM

Repairs—182×$15.83=$2881.
Delays —182×3.4=619 minutes.
Output —619×1.5=929 tons.

CASE I

General.—Generate and distribute at 6600 volts.—Transmit at 22,000 volts.—Gas engine generators.—Auxiliary load 22.4% of total.—Main load at 80.5% power-factor.

	ALL-A.C. Kw.	P-F.	Kv-a.	MIXED Kw.	P-F.	Kv-a.
MAXIMUM CONDITIONS						
Main load	7510	84.7	8870	7510	84.7	8870
Auxiliary load	1538	70	2200	1730	+80	2165
Total load	9048	82	11000	9240	93.8	9860
Transformer losses	286			256		
Line losses	195			157		
Load on generators	9529	83.4	11410	9653	94.2	10250

	All-A.C.	Mixed
Number of transformers	7	7
Normal capacity of each	3000 kv-a.	2700 kv-a.
Total capacity of each set	9000 kv-a.	8100 kv-a.
Overload capacity of each set	11250 kv-a.	10125 kv-a.
Number of generators	4	4
Power-factor of generators	85%	95%
Normal capacity of each	2200 kw.	2200 kw.
Normal capacity of each	2590 kv-a.	2310 kv-a.
Total capacity of generators	10360 kv-a.	9240 kv-a.
Overload capacity of generators	11396 kv-a.	10164 kv-a.
FIRST COSTS:		
Motors, etc.	$138,950	$121,750
Substations	16,420	37,020
Transformers	38,360	36,960
Generators	76,000	70,800
Total	$269,730	$266,530
Saving in first cost		$3,200

	ALL-A.C. Kw.	P-F.	Kv-a.	MIXED Kw.	P-F.	Kv-a.
AVERAGE CONDITIONS:						
Main load	5320	80.5	6600	5320	80.5	6600
Auxiliary load	1538	70	2200	1730	+80	2165
Total load	6858	78.2	8790	7050	93.8	7500
Transformer losses	228			195		
Line losses	124			91		
Load on generators	7210	79.6	9060	7336	94.2	7780
Generator losses	453			342		
Load on engines	7663			7678		
Saving in load		15 kw.				
Per cent. load on transformers		97.6			92.6	
Per cent. load on generators		87.5			84.2	

	All-A.C.	Mixed
ANNUAL COSTS:		
Small motors, etc., at 17 per cent.	$24,621	$20,697
Other apparatus at 15 per cent.	19,617	21,717
Excess motor maintenance		2,881
Excess power at $6 per kw.		90
Total	$43,238	$45,385
Annual saving	$2,147	

CASE II

General.—Same as Case I, except there is no transmission line.—Power is distributed directly from the generating station at 6600 volts.—Size of generators taken same as Case I.

	All-A.C.	Mixed
FIRST COSTS:		
Motors, etc.	$138,950	$121,750
Substations	16,420	37,020
Generators	76,000	70,800
Total	$231,375	$229,570
Saving in first cost		$1,805
Load on generators	6858 kw.	7050 kw.
Generator losses	440 kw.	330 kw.
Load on engines	7298 kw.	7380 kw.
Saving in load	82 kw.	
ANNUAL COSTS:		
Small motors, etc., at 17 per cent.	$23,621	$20,697
Other apparatus at 15 per cent.	13,863	16,173
Excess motor maintenance		2,881
Excess power at $6 per kw.		492
Total	$37,484	$42,043
Annual saving	$2,759	

CASE III

General.—Same as Case I, except turbine-driven generators.

	All-A.C.	Mixed
Number of generators	3	3
Power-factor of generators	85%	95%
Maximum capacity of each	3200 kw.	3200 kw.
Maximum capacity of each	3770 kv-a.	3370 kv-a.
Total capacity of generators	11310 kv-a.	10110 kv-a.
FIRST COSTS:		
Motors, etc.	$138,950	$121,750
Substations	16,420	37,020
Transformers	38,360	36,960
Generators	46,050	42,300
Total	$239,780	$238,030
Saving in first cost		$1,750
Load on generators	7210 kw.	7336 kw.
Generator losses	565 kw.	525 kw.
Load on turbines	7775 kw.	7861 kw.
Saving in load	86 kw.	
ANNUAL COSTS:		
Small motors, etc., at 17 per cent.	$23,621	$20,697
Other apparatus at 15 per cent.	15,124	17,442
Excess motor maintenance		2,881
Excess power at $12 per kw.		1,032
Total	$38,745	$42,052
Annual saving	$3,307	

CASE IV

General.—Same as Case II, except turbine-driven generators.—Size of generators taken same as Case III.

	All-A.C.	Mixed
FIRST COSTS:		
Motors etc.	$138,950	$121,750
Substations	16,420	37,020
Generators	46,050	42,300
Total	$201,420	$201,070
Saving in first cost		$350
Load on generators	6858 kw.	7050 kw.
Generator losses	550 kw.	506 kw.
Load on turbines	7408 kw.	7556 kw.
Saving in load	148 kw.	
ANNUAL COSTS:		
Small motors, etc., at 17 per cent.	$23,621	$20,697
Other apparatus at 15 per cent.	9,371	11,898
Excess motor maintenance		2881
Excess power at $12 per kw.		1,776
Total	$32,992	$37,252
Annual saving	$4,260	

CASE V

General.—Generate and distribute at 6600 volts.—Transmit at 22,000 volts.—Gas engine generators.—Auxiliary load 22.4 per cent. of total.—Main load at 70 per cent. power-factor.

	ALL-A.C. Kw.	P-F.	Kv-a.	MIXED Kw.	P-F.	Kv-a.
MAXIMUM CONDITIONS:						
Main load	7510	80	9390	7510	80	9390
Auxiliary load	1538	70	2200	1730	+80	2165
Total load	9048	78.2	11550	9240	90.5	10200
Transformer losses	300			266		
Line losses	216			168		
Load on generators	9564	79.7	11970	9674	91.3	10590

	All-A.C.	Mixed
Number of transformers	7	7
Normal capacity of each	3300 kv-a.	2800 kv-a.
Total capacity of each set	9900 kv-a.	8400 kv-a.
Overload capacity of each set	12375 kv-a.	10500 kv-a.
Number of generators	4	4
Power-factor of generators	80%	90%
Normal capacity of each	2200 kw.	2200 kw.
Normal capacity of each	2750 kv-a.	2445 kv-a.
Total capacity of generators	11000 kv-a.	9780 kv-a.
Overload capacity of generators	12100 kv-a.	10758 kv-a.
FIRST COSTS:		
Motors, etc.	$138,950	$121,750
Substations	16,420	37,020
Transformers	39,550	37,520
Generators	78,800	73,200
Total	$273,720	$269,490
Saving in first cost		$4,230

CASE V (Continued)

	ALL-A.C. Kw.	ALL-A.C. P-F.	ALL-A.C. Kv-a.	MIXED Kw.	MIXED P-F.	MIXED Kv-a.
AVERAGE CONDITIONS:						
Main load	5320	70	7600	5320	70	7600
Auxiliary load	1528	70	2200	1730	+80	2165
Total load	6858	70	9800	7050	86.4	8170
Transformer losses	254			212		
Line losses	155			108		
Load on generators	7267	72	10080	7370	87.3	8440
Generator losses	535			392		
Load on engines	7802			7762		
Saving in load			40 kw.			
Per cent. load on transformers			99.0			97.2
Per cent. load on generators			91.7			86.4

ANNUAL COSTS:	All-A.C.	Mixed
Small motors, etc., at 17 per cent.	$23,621	$20,697
Other apparatus at 15 per cent.	20,216	22,161
Excess motor maintenance		2,881
Excess power at $6 per kw.	240	
Total	$44,077	$45,739
Annual saving	$1,662	

CASE VI

General.—Same as Case V, except there is no transmission line.—Power is distributed directly from the generating station at 6600 volts.—Size of generators taken, same as Case V.

FIRST COSTS:	All-A.C.	Mixed
Motors, etc.	$138,950	$121,750
Substations	16,420	37,020
Generators	78,800	73,200
Total	$234,170	$231,970
Saving in first cost		$2,200
Load on generators	6858 kw.	7050 kw.
Generator losses	519 kw.	380 kw.
Load on engines	7377 kw.	7430 kw.
Saving in load	53 kw.	
ANNUAL COSTS:		
Small motors, etc., at 17 per cent.	$23,621	$20,697
Other apparatus at 15 per cent.	14,283	16,533
Excess motor maintenance		2,881
Excess power at 16 per kw.		318
Total	$37,704	$40,429
Annual saving	$2,725	

CASE VII

General.—Same as Case V, except turbine-driven generators.

	All-A.C.	Mixed
Number of generators	3	3
Power-factor of generators	80 %	90 %
Maximum capacity of each	3200 kw.	3200 kw.
Maximum capacity of each	4000 kv-a.	3555 kv-a.
Total capacity of generators	12000 kv-a.	10665 kv-a.
FIRST COSTS:		
Motors, etc.	$138,950	$121,750
Substations	16,420	37,020
Transformers	39,550	37,520
Generators	48,300	44,100
Total	$243,220	$240,390
Saving in first cost		$2,830
Load on generators	7267 kw.	7370 kw.
Generator losses	681 kw.	566 kw.
Load on turbines	7948 kw.	7936 kw.
Saving in load		12 kw.
ANNUAL COSTS:		
Small motors, etc., at 17 per cent.	$ 23,621	$20,697
Other apparatus at 15 per cent.	15,641	17,796
Excess motor maintenance		2881
Excess power at $12 per kw.	144	
Total	$39,406	$41,374
Annual saving	$1,968	

CASE VIII

General.—Same as Case VI, except turbine-driven generators.—Size of generators taken same as Case VII.

FIRST COSTS:	All-A.C.	Mixed
Motors, etc.	$138,950	$121,750
Substations	16,420	37,020
Generators	48,300	44,100
Total	$203,670	$202,870
Saving in first cost		$800
Load on generators	6858 kw.	7050 kw.
Generator losses	662 kw.	547 kw.
Load on turbines	7520 kw.	7597 kw.
Saving in load	77 kw.	

CASE VIII (Continued)

ANNUAL COSTS:		
Small motors, etc., at 17 per cent.	$23,621	$20,697
Other apparatus at 15 per cent.	9,708	12,168
Excess motor maintenance		2,881
Excess power at $12 per kw.		924
Total	$33,329	$36,670
Annual saving	$3,341	

CASE IX

General.—Generate and distribute at 6600 volts.—Transmit at 22,000 volts.—Gas engine generators.—Auxiliary load 12.6 per cent. of total.—Main load at 80.5 per cent. power-factor.

	ALL-A.C. Kw.	ALL-A.C. P-F.	ALL-A.C. Kv-a.	MIXED Kw.	MIXED P-F.	MIXED Kv-a.
MAXIMUM CONDITIONS.						
Main load	15020	84.7	17740	15020	84.7	17740
Auxiliary load	1538	70	2200	1730	+80	2165
Total load	16558	83.3	19870	16750	90	18630
Transformer losses	516			484		
Line losses	319			282		
Load on generators	17393	84.4	20570	17516	90.7	19300

	All-A.C.	Mixed
Number of transformers	13	13
Normal capacity of each	2750 kv-a.	2600 kv-a.
Total capacity of each set	16500 kv-a.	15600 kv-a.
Overload capacity of each set	20625 kv-a.	19500 kv-a.
Number of generators	7	7
Power-factor of generators	85 %	90 %
Normal capacity of each	2300 kw.	2300 kw.
Normal capacity of each	2705 kv-a.	2555 kv-a.
Total capacity of generators	18935 kv-a.	17885 kv-a.
Overload capacity of generators	20828 kv-a.	19673 kv-a.
FIRST COSTS:		
Motors, etc.	$138,950	$121,750
Substations	16,420	37,020
Transformers	69,160	67,600
Generators	136,500	131,600
Total	$361,030	$357,970
Saving in first cost		$3,060

	ALL-A.C. Kw.	ALL-A.C. P-F.	ALL-A.C. Kv-a.	MIXED Kw.	MIXED P-F.	MIXED Kv-a.
AVERAGE CONDITIONS:						
Main load	10640	80.5	13200	10640	80.5	13200
Auxiliary load	1538	70	2200	1730	+80	2165
Total load	12178	79.2	15380	12370	88.4	13980
Transformer losses	400			364		
Line losses	191			158		
Load on generators	12769	80.5	15860	12892	89.2	14460
Generator losses	793			673		
Load on engines	13562			13565		
Saving in load			3 kw.			
Per cent. load on transformers			93.3			89.7
Per cent. load on generators			84.0			80.8

ANNUAL COSTS:	All-A.C.	Mixed
Small motors, etc., at 17 per cent.	$23,621	$20,697
Other apparatus at 15 per cent.	33,312	35,433
Excess motor maintenance		2881
Excess power at $6 per kw.		18
Total	$56,933	$59,029
Annual saving	$2,096	

CASE X

General.—Same as Case IX, except there is no transmission line.—Power is distributed directly from the generating station at 6600 volts.—Size of generators taken same as Case IX.

FIRST COSTS:	All-A.C.	Mixed
Motors, etc.	$138,950	$121,750
Substations	16,420	37,020
Generators	136,500	131,600
Total	$291,870	$290,370
Saving in first cost		$1,500
Load on generators	12178 kw.	12370 kw.
Generator losses	769 kw.	651 kw.
Load on engines	12947 kw.	13021 kw.
Saving in load	74 kw.	

CASE IX (Continued)

	All-A.C.	Mixed
ANNUAL COSTS:		
Small motors, etc., at 17 per cent.	$23,621	$20,697
Other apparatus at 15 per cent.	22,938	25,293
Excess motor maintenance		2,881
Excess power at $6 per kw.		444
Total	$46,559	$49,315
Annual saving	$2,756	

CASE XI

General.—Same as Case IX, except turbine-driven generators.

	All-A.C.	Mixed
Number of generators	5	5
Power-factor of generators	85%	90%
Maximum capacity of each	3500 kw.	3500 kw.
Maximum capacity of each	4120 kv-a.	3890 kv-a.
Total capacity of generators	20600 kv-a.	19450 kv-a
FIRST COSTS:		
Motors, etc.	$138,950	$121,750
Substations	16,420	37,020
Transformers	69,160	67,600
Generators	82,50.	79,000
Total	$307,030	$305,370
Saving in first cost		$1,660
Load on generators	12769 kw.	12892 kw.
Generator losses	1110 kw.	1010 kw.
Load on turbines	13879 kw.	13902 kw.
Saving in load	23 kw.	
ANNUAL COSTS:		
Small motors, etc., at 17 per cent.	$23,621	$20,697
Other apparatus at 15 per cent.	25,212	27,543
Excess motor maintenance		2,881
Excess power at $12 per kw.		276
Total	$48,833	$51,487
Annual saving	$2,654	

CASE XII

General.—Same as Case X, except turbine-driven generators.—Size of generators taken same as Case XI.

	All-A.C.	Mixed
FIRST COSTS:		
Motors, etc.	$138,950	$121,750
Substations	16,420	37,020
Generators	82,500	79,000
Total	$237,870	$237,770
Saving in first cost		$100
Load on generators	12178 kw.	12370 kw.
Generator losses	1078 kw.	977 kw.
Load on turbines	13256 kw.	13347 kw.
Saving in load	91 kw.	
ANNUAL COSTS:		
Small motors, etc., at 17 per cent.	$23,621	$20,697
Other apparatus at 15 per cent.	14,838	17,403
Excess motor maintenance		2,881
Excess power at $12 per kw.		1,092
Total	$38,459	$42,073
Annual saving	$3,614	

CASE XIII

General.—Generate and distribute at 6600 volts.—Transmit at 22,000 volts.—Gas engine generators.—Auxiliary load 12.6 per cent. of total.—Main load at 70 per cent. power-factor.

	ALL-A.C. Kw.	P-F.	Kv-a.	MIXED Kw.	P-F.	Kv-a.
MAXIMUM CONDITIONS						
Main load	15020	80	18780	15020	80	18780
Auxiliary load	1538	70	2200	1730	+80	2165
Total load	16558	79	20950	16750	85.8	19470
Transformer losses	544			506		
Line losses	355			307		
Load on generators	17457	80.6	21650	17563	87	20200

	All-A.C.	Mixed
Number of transformers	13	13
Normal capacity of each	2900 kv-a.	2700 kv-a.
Total capacity of each set	17400 kv-a.	16200 kv-a.
Overload capacity of each set	21750 kv-a.	20250 kv-a.
Number of generators	7	7
Power-factor of generators	80%	85%
Normal capacity of each	2300 kw.	2300 kw.
Normal capacity of each	2875 kv-a.	2705 kv-a.
Total capacity of generators	20125 kv-a.	18935 kv-a.
Overload capacity of generators	22137 kv-a.	20828 kv-a.
FIRST COSTS:		
Motors, etc.	$138,950	$121,750
Substations	16,420	37,020
Transformers	70,460	68,640
Generators	142,100	136,500
Total	$367,930	$363,910
Saving in first cost		$4,020

CASE XIII (Continued)

	ALL-A.C. Kw.	P-F.	Kv-a.	MIXED Kw.	P-F.	Kv-a.
AVERAGE CONDITIONS:						
Main load	10640	70	15200	10640	70	15200
Auxiliary load	1538	70	2200	1730	+80	2165
Total load	12178	70	17400	12370	79.2	15630
Transformer losses	452			406		
Line losses	244			197		
Load on generators	12874	72	17870	12973	80.5	16120
Generator losses	956			806		
Load on engines	13830			13779		
Saving in load						51 kw.
Per cent. load on transformers			100			96.5
Per cent. load on generators			88.8			85.3

	All-A.C.	Mixed
ANNUAL COSTS:		
Small motors, etc., at 17 per cent.	$23,621	$20,697
Other apparatus at 15 per cent.	34,347	36,324
Excess motor maintenance		2,881
Excess power at $6 per kw.	306	
Total	$58,274	$59,902
Annual saving	$1,628	

CASE XIV

General.—Same as Case XIII, except there is no transmission line.—Power is distributed directly from the generating station at 6600 volts.—Size of generators taken same as Case XIII.

	All-A.C.	Mixed
FIRST COSTS:		
Motors, etc.	$138,950	$121,750
Substations	16,420	37,020
Generators	142,100	136,500
Total	$297,470	$295,270
Saving in first cost		$2,200
Load on generators	12178 kw.	12370 kw.
Generator losses	931 kw.	782 kw.
Load on engines	13109 kw.	13152 kw.
Saving in load	43 kw.	
ANNUAL COSTS:		
Small motors, etc., at 17 per cent.	$23,621	$20,697
Other apparatus at 15 per cent.	23,778	26,028
Excess motor maintenance		2,881
Excess power at $6 per kw.		258
Total	$47,399	$49,854
Annual saving	$2,465	

CASE XV

General.—Same as Case XIII, except turbine-driven generators.

	All-A.C.	Mixed
Number of generators	5	5
Power-factor of generators	80%	85%
Maximum capacity of each	3500 kw.	3500 kw.
Maximum capacity of each	4370 kv-a.	4120 kv-a.
Total capacity of generators	21850 kv-a.	20600 kv-a.
FIRST COSTS:		
Motors, etc.	$138,950	$121,750
Substations	16,420	37,020
Transformers	70,460	68,640
Generators	86,250	82,500
Total	$312,080	$309,910
Saving in first cost		$2,170
Load on generators	12874 kw.	12973 kw.
Generator losses	1232 kw.	1113 kw.
Load on turbines	14106 kw.	14086 kw.
Saving in load		20 kw.
ANNUAL COSTS:		
Small motors, etc., at 17 per cent.	$23,621	$20,697
Other apparatus at 15 per cent.	25,970	28,224
Excess motor maintenance		2,881
Excess power at $12 per kw.	240	
Total	$49,831	$51,802
Annual saving	$1,971	

CASE XVI

General.—Same as Case XIV, except turbine-driven generators.—Size of generators taken same as Case XV.

	All-A.C.	Mixed
FIRST COSTS:		
Motors, etc.	$138,950	$121,750
Substations	16,420	37,020
Generators	86,250	82,500
Total	$241,620	$241,270
Saving in first cost		$350
Load on generators	12178 kw.	12370 kw.
Generator losses	1201 kw.	1078 kw.
Load on turbines	13379 kw.	13448 kw.
Saving in load	69 kw.	
ANNUAL COSTS:		
Small motors, etc., at 17 per cent.	$23,681	$20,697
Other apparatus at 15 per cent.	15,400	17,928
Excess motor maintenance		2,881
Excess power at $12 per kw.		828
Total	$39,081	$42,334
Annual saving	$3,253	

ACUITY TESTS IN A PARTICULAR ROOM ILLUMINATED IN TURN WITH DIRECT AND INDIRECT LIGHTING

By Prof. Sydney W. Ashe

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We are all familiar with the general forms of direct, indirect and semi-indirect lighting at present in vogue; but we unfortunately do not possess authoritative data on the exact relative illuminating efficiencies of these systems. This article presents the results of careful tests made by Prof. Ashe to determine these quantities. The information is now being published for the first time with the hope that it may prove of service to those interested in the physiological aspects of lighting engineering.—Editor.

It has been realized in a general way in the past that indirect lighting required a greater expenditure of energy than direct in order to produce the same intensity of illumination on the working plane. Little concrete data of actual working conditions, however, have been published covering this point. To off-set the loss in efficiency of indirect lighting the claim has been made that, owing to better diffusion, it was possible with this system to read with the same facility with less illumination than with direct. Having had considerable experience in acuity tests, and having the facilities at hand with which to make measurements, the writer, with the co-operation of his assistants, carried on a series of tests which are indicated in the following conclusions:

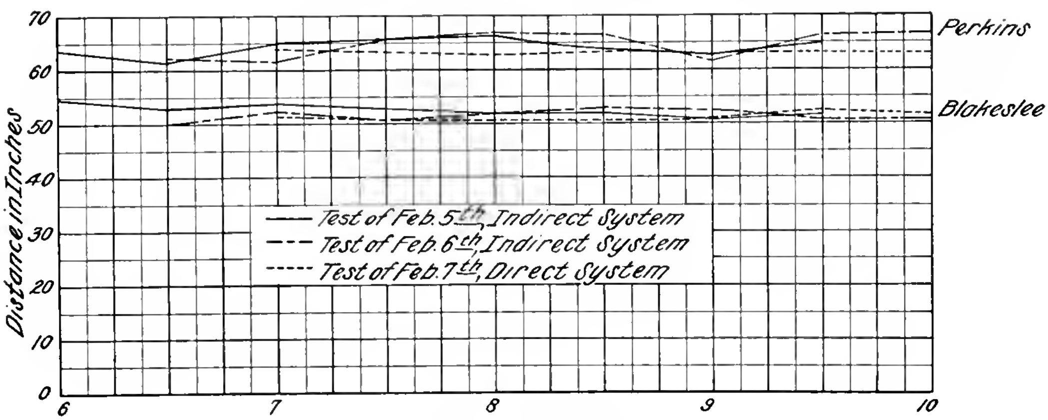


Fig. 1. Acuity Fatigue Curves for Two Separate Individuals

Conclusions

First. To produce the same intensity on the working plane with indirect as with direct lighting, the expenditure of approximately 100 per cent. more energy is required. Thus, a 250-watt direct unit and a 500-watt indirect unit, where the walls and ceilings are white, will produce about the same intensity on the working plane. Where the walls and ceilings are colored the absorption will be greater for indirect lighting, requiring a still greater expenditure of energy. Tests which we conducted, however, were made only with white walls and ceilings.

Second. Where the intensity on the working plane is the same for either indirect or direct lighting, with white walls and ceilings, there is no difference in acuity for initial reading values; i.e., one can read with the same ease and can distinguish detail at the same distance from the reading object for initial values, irrespective of which mode of lighting is used.

Third. Tests made over a period of four hours on consecutive evenings indicate that at the expiration of this time, one can read with practically the same facility as at the beginning. In other words, the so-called claim for fatigue which has been charged against direct lighting does not exist. The readings taken for direct lighting give a slightly more uniform acuity than the indirect lighting. These facts are indicated on the attached curve (Fig. 1).

Theory of Acuity Measurements which Affected Mode of Test

The study of acuity is not new. Some idea of the magnitude of the investigations carried on in the past may be indicated from the list of researches which are given as references in Javal's French translation of Helmholtz' *Physiological Optics* on page 303. These are partially listed as follows:

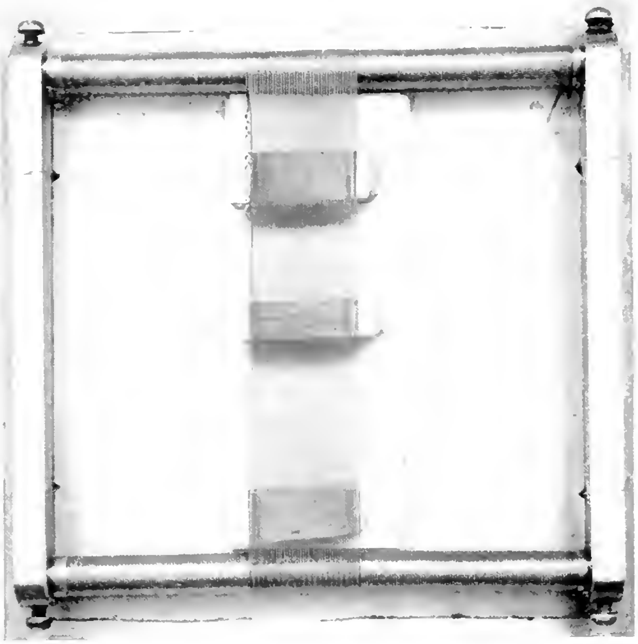


Fig. 2. Grille Used in Acuity Tests

Date	*Author*
1705	Hooke
1754	Tobias Mayer
1846	Volkmann
1852	Volkmann
1857	Bergmann
1857	Aubert and Forster
1862	Snellen
1862	Volkmann
1864	Aubert
1864	Donders

As one studies these various investigations, it will be found that almost every source of error, both physical and physiological, that enters into acuity measurements has been noted and apparently investigated. Some of the factors which influence acuity readings and which must be considered are the following: the form of test chart used; the color of the light; the amount of glare present; the size of the pupil of the eye; whether we employ near or distant vision; the effect of adaptation; the effect of fatigue; and the physical condition of the individual.

Probably the most important factor which should be considered is the form of the test plate used. Many investigators of recent date have used test objects consisting of rectangular or circular forms painted black on a white background. Others, including the writer, have used a series of standard letters prepared in special form and known as Snellen's chart. Still others have used printed type cut from some magazine. Of all these methods the Snellen's test chart is probably the best, as it represents the results of a long investigation carried on by its inventor. On the chart used by him the letters were constructed so that the thickness of the letter would be one-fifth of its height, and the entire letter was to be distinguishable under an angle of five minutes. Take the letter E, for instance. Starting from the bottom, each of the five spaces, white and black, correspond to an angle of one minute when a person having normal vision is reading the letter at the distance indicated in feet or centimeters on the chart. If a test object of a certain size is used, the distance with which one can read this object under a given illumination is a measure of his acuity. If one can read this chart at half the distance required by another, his visual angle will be twice as great. His acuity is rated at two, although his ability to read is only one-half as great judged by circular measurements.

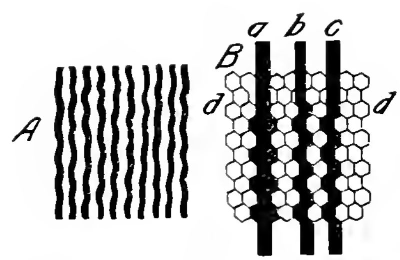


Fig. 3. Diagram Showing Appearance on the Retina of the Eye of a System of Thin Parallel Lines at the Limit of Clear Vision. B Shows Arrangement of Cones on Retina with Image of Wires Superimposed. A Shows Physiological Effect of Looking at Wires at Limit of Vision

Figs. 4 and 5. These Views are Reproduced from Photographs Taken on the Same Evening in the Same Room and with the Same Camera Exposure. Fig. 4 is for the Indirect Lighting Unit, and Fig. 5 for the Direct Lighting Unit

A still better test object, however, is the grille shown in Fig. 2, consisting of a series of dull black parallel wires with white spaces between, the spaces being equal in size to the wires. The reason for its superiority is due to a physiological effect which appears at the limit of distinct vision and causes the wires to look waved as in the illustration given in Fig. 3 (a tracing from Helmholtz' book). A similar form of test plate was used by many early investigators, such as Tobias Mayer, Volkmann, Weber, Helmholtz and Bergmann. With this grille the thickness of the black spaces is equal to .4167 mils. At the limit of vision the black spaces form an image on the retina of the eye which subtends an angle of about one minute. If it is considered that the cones in the fovea of the eye are responsible for vision, it will be realized that the image of the black spaces on the retina will be slightly larger than the individual cones, as an angle of one minute corresponds to a distance of .004 mms. on the retina of the eye. If we take the nodal point of the eye, i.e., the distance between the center of the lens and the retina as 15 mms., the angular size of a minute

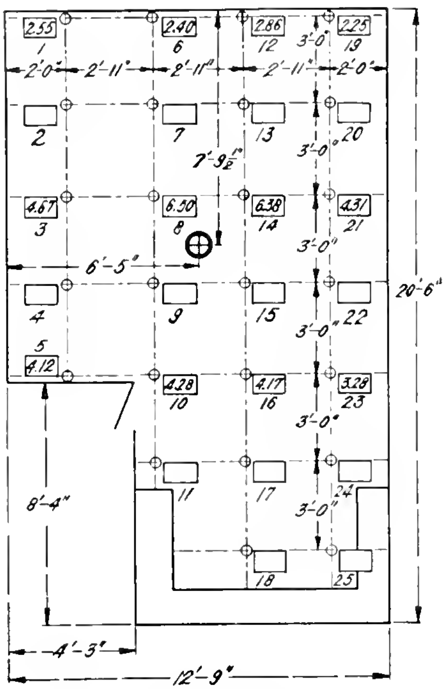


Fig. 6. Layout and Intensities for Indirect Illumination

Location	Office
Number of Fixtures	1
Lamps per Fixture	1
Reflector	M.M. 21 Dif.
Style of Lamps	Mazda
Top Efficiency	1.13
Color of Walls	White
Color of Ceiling	White
Height of Ceiling	13′ 3½″
Height of Lamp	11′ 3½″
Height of Plane Investigated	3′ 3½″
Distance of Lamp from Ceiling	2′
Average Foot-Candles	3.63
Total Watts	500
Voltage of Service	124

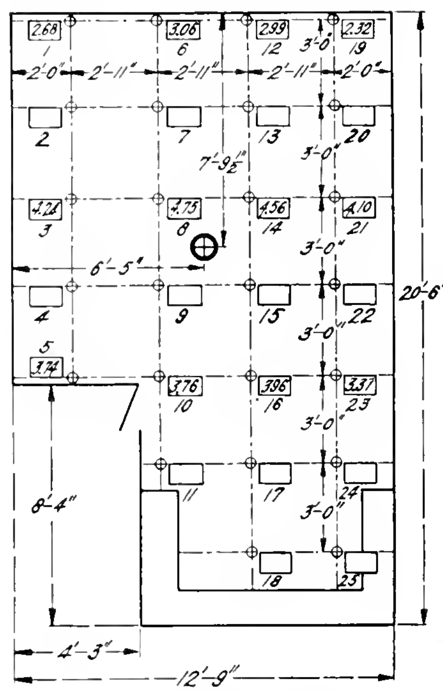


Fig. 7. Layout and Intensities for Direct Illumination

Location	Office
Number of Fixtures	1
Lamps per Fixture	1
Reflector	M.M. 21 Dif.
Style of Lamps	Mazda
Top Efficiency	1.13
Color of Walls	White
Color of Ceiling	White
Height of Ceiling	13′ 3½″
Height of Lamp	11′ 3½″
Height of Plane Investigated	3′ 3½″
Distance of Lamp from Ceiling	2′
Average Foot-Candles	4.02
Total Watts	250
Voltage of Service	118

equals .004 mms. $\left(\frac{2\times 15\pi}{60\times 360}=.004\right)$. According to the measurements of Schultze, Muller and Walker, the diameter of the cones in fovea are as follows:

Schultze from 0.0020 to 0.0025 mms.
Muller from 0.0015 to 0.0020 mms.
Walker from 0.0031 to 0.0036 mms.

It will be noted, therefore, that there is a slight overlapping of the images of the wires over a few of the cones, which are arranged symmetrically as shown in Fig. 3. According to Helmholtz it is not necessary for an entire cone of the retina to be illuminated by the image to give the impression of brightness. At the limit of distinct vision, at which we feel that we can just clearly distinguish the outline of the dark and white spaces of the grille, the optical effect shown in A, Fig. 3, is produced. In other words the wires instead of looking parallel take on a waved appearance.

Elimination of Errors

In making the tests no diaphragms or sight-boxes of any kind were used, the idea being to allow the pupil of the eye to function normally. The walls of the room were painted white, and drawn wire tungsten lamps were used and operated approximately at high efficiency to eliminate color differences. The intensities in both cases on the working plane were approximately the same viz., about three foot-candles; and these intensities were not varied throughout a given test, so that errors due to adaptation were eliminated. Adaptation takes from four to ten minutes depending upon whether light or dark adaptation is used. Any method of test, therefore, which involves varying the intensity of the light is liable to incur errors of this kind. To eliminate the effects of fatigue, readings were only taken at short intervals, the observers changing frequently. No foreign substances were used in the eye, such as mydriatic or myotic, to vary the size of the pupil; so that no source of error due to a variation of the sensitiveness of the eye was encountered. With the Helmholtz grille it was necessary to use near vision; but as the same grille was used for all measurements the results were comparative. The voltmeter and the Sharp-Millar luminometer were carefully standardized.

The lamps were operated from a storage battery whose voltage was carefully noted throughout the tests to see that no variations of voltage occurred. Lamps were operated at practically the same efficiency, so that no error due to a variation of color of the light source was introduced. The fact that the walls and ceilings of the room were white also tended to eliminate any color differences. On consecutive evenings readings were taken in the reverse direction so as to discover any unseen errors that might have crept in. It will thus be seen that every possible precaution was taken to eliminate errors both physical and physiological. The most striking thing in making the acuity measurements was the remarkable accuracy with which it was possible to duplicate readings. This was due not only to the care which was taken in making the readings, but also undoubtedly to the interesting physiological effect of the waved lines previously referred to. The tests were carried on by the writer with the cooperation of Messrs. Perkins, Richards, Blakeslee and Lurtey. In the curves are shown only the values of Messrs. Perkins and Blakeslee, as they were the only two who participated in all the measurements taken. In making the fatigue tests the individuals read during the evening, acuity measurements being taken at ½-hour intervals.

Detailed Description of Apparatus

For an indirect lighting unit a lamp diffuser was suspended in an inverted position with ordinary picture wire run through small holes punched near the rim. Figs. 4 and 5 are reproduced from photographs of the room taken on the same evening and with the same camera exposure for the two lighting arrangements, Fig. 4 being for the indirect and Fig. 5 for the direct unit. A 500-watt, 124-volt tungsten lamp burning at high efficiency was the light-giving element. A preliminary survey was made of the room with a Sharp-Millar luminometer to determine the intensities at the various test stations. These stations were laid out as in Figs. 6 and 7, which show the intensities for the direct and indirect units. For a direct unit the diffuser was reversed, i.e., placed in its usual burning position; a 250-watt, 118-volt lamp being placed in the same fixture, and the survey made with this combination. Station 10 was well adapted for reading purposes, and it was therefore chosen for the acuity measurements. By slightly varying the voltage it was possible to produce an intensity on the inclined grille of 3.2 foot-candles, either direct or indirect. The test object or Helmholtz grille was made of two screws cut 32 threads to the inch, 6 inches long. These screws were mounted on two steel side-pieces, as shown in Fig. 2 and fastened with set screws, the whole forming a square. Mild-steel black-finished wire 1/34 in. in diameter was wound on the screws, the threads serving as a guide (Fig. 2). This wire was wound under tension and calipered in several places under this same tension. The diameter of the wire as calipered measured $16\frac{1}{2}$ mils, while the maximum variation was not over .15 mils. Between tops of teeth we had $\frac{1}{32}$ in. or 31.25 mils; so that the spaces between the wires was 14.75 mils, or 1.75 mils difference between width of space and width of wire. A white sheet of paper was placed under these wires and held in place by wooden wedges. One square inch of the reading surface of the grille was exposed by covering the grille with a card-board, painted jet black and having an opening as shown in Fig. 8; which gave the effect of white spaces and black lines uniformly spaced. For reading, the grille was mounted on a small box and pivoted so as to be swung to a position normal to the direction of reading. The box and grille were then placed on a small table draped in black, and adjusted for the normal reading of an individual standing erect; and the luminometer was set up with its test plate in the same plane as the grille (Fig. 8), the center of reading area on the grille being 3 ft. 3 in. from the floor.

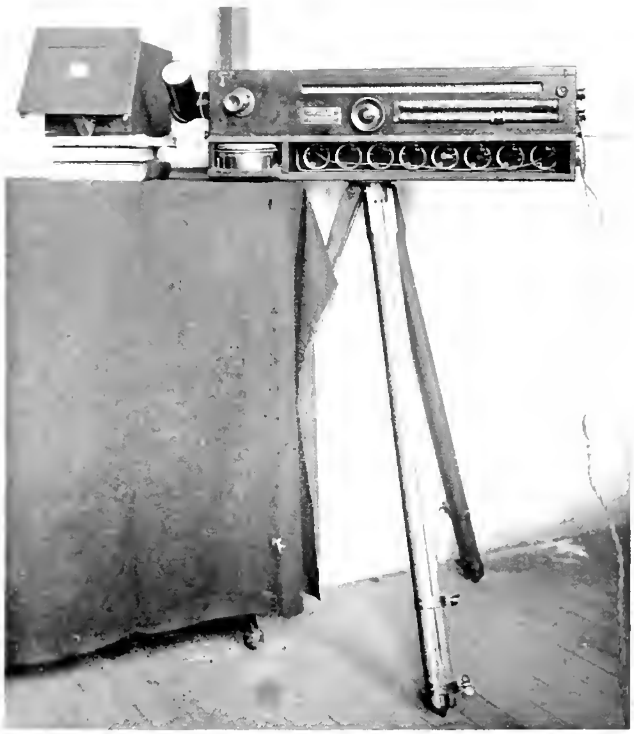


Fig. 8. Luminometer, Draped Table and Grille Used in Acuity Tests

In taking the readings, the average intensity as determined by four separate observers was first taken by the luminometer. Acuity measurements were then made, two men using the tape to measure the distance of the eye of the observer from the screen, and a fourth recording the results. Observations were taken on a line drawn from station 10 midway between stations 14 and 15. When the form of lighting was changed luminometer readings were again taken, the luminometer test plate not being moved from its position. The voltage of the lamp under test was adjusted until the intensities for direct or indirect on the test plate were the same. When initial readings of acuity were taken, indirect readings were first taken and then direct. In the second set the order was reversed. Mr. Blakeslee and the writer wore glasses, and their acuity values were lower than either Mr. Richards' or Mr. Perkins'. Throughout one evening's test Mr. Lurty worked on a drawing which he was tracing and his acuity values were measured at various intervals. The acuity curves show the reading distance for different observers for different forms of lighting over extended periods of time.

In conclusion it may be mentioned that care should be taken not to use the factor of 100 per cent. difference between direct and indirect lighting generally; as with a regular commercial indirect lighting unit it is probable that the difference would not be quite so great. It may be stated, however, that this same result was obtained recently by Mr. Sweet for white walls and ceilings, although his method of test has been subjected to some criticism.

An interesting series of experiments is now being conducted with this same apparatus to obtain acuity values for various color contrasts. The results of these tests will be given in a later edition of the Review.

SOME PHYSIOLOGICAL CONSIDERATIONS IN LIGHTING PROBLEMS

By W. F. Schaller

Graduate Student, University of Illinois

After a note on the physical construction of the eye the author recounts three of the most generally-accepted theories of the phenomenon of sight; all of which agree that vision is the result of a destruction of certain retinal elements by the chemical action of the incident light, a nervous impulse being set up which is carried to the cerebrum and sensed. The author explains what is meant by glare, and shows the various ways in which it may be occasioned. He considers some points which tend toward relieving the strain imposed on the eye when working by artificial illumination; and shows that, since the physiological peculiarities of the individuals to be served by any one installation are so varied, there is a very real function to be performed by the modern illuminating engineer who devises the lighting scheme.—Editor.

The importance of physiological considerations in the design of systems of illumination has not generally been realized by engineers. This phase of the problem particularly merits attention in the lighting of libraries, schools, offices, and textile mills, where, very often, the quality and quantity of work done depend directly on eye comfort—or discomfort. The problem, in any case, is efficiency. Efficiency of illumination may be defined simply and specifically by the purpose of illumination; i.e., the end sought is a physiological process—sight.

The eye is a physiological camera. The light flux entering the eye is varied in its physical quantity by the reaction of the eye on the light flux density, in contracting or expanding the pupil, i.e., in changing the size of the aperture. The retina, on the rear interior of the eyeball, is comprised of two classes of nerve terminals, designated as rods and cones, which are sensitive to the light flux which has entered and serve as the origin of the sense of sight. Behind the iris, the muscular sheet which carries and controls the pupil, is a converging lens hung in a circular muscle by whose contraction or distention focus is varied to accommodate for the distance of the objects viewed.

Three theories, those of Hering, Ladd-Franklin and König, are now most generally accepted to account for the phenomenon of sight. As given, the first two are color theories and the third one explains *seh-schärfe*, the ability of distinction. Prof. Ewald Hering maintains that the retina contains three chemical substances, each of which is capable of two opposed processes, decomposition and recomposition. With the assumption of four primary colors, red, green, blue and yellow, with white and black, one pair such as red and green may act on a substance, red destroying and green building it up. The other two pairs act similarly on the other two substances. A theory advanced by Mrs. Ladd-Franklin of Johns Hopkins University states that the retinal rods are sensitive to white light only and the cones to the colors. Accepting the theory that there are three primary colors, red, yellow and blue*, she says that the cones are composed of three kinds of molecules, each one being sensitive to light of one of the three colors. When light of any one of these colors enters the eye it breaks away or decomposes a number of the molecules sensitive to it, in proportion to its intensity. The violence of the action then is transmitted to the brain as distinctness of vision.

The following explanation of the phenomenon of sight was presented by Dr. Arthur König of the University of Berlin before the Royal Academy of Sciences at Berlin in May, 1897. This scientist made an elaborate set of tests to determine the relation between the ability of perception and the intensity of the illumination. Briefly, his method consisted in using the eye to distinguish characters, similar to those used by the oculist, under varying illumination intensities of the colors white, red, green and blue. The ability to see was measured in some arbitrary units and plotted as *seh-schärfe* against *beleuchtung* or illumination, with results as shown in Fig. 1. The following general equation is found to fit the curves:

$$S = \alpha\ (\log B - \log C)$$

where

S is ability to distinguish, *seh-scharfe*

B is intensity of illumination

α is a constant depending on the nature of the light, and is about ten times as great after the bend in the curve as before.

C is a constant inversely proportional to the *helligkeitswerth*, or "brightness" of the light. Based on these results the logarithmic law of sensation as applicable to the eye was

* Red, yellow and blue were the three primary colors used by artists, and are sometimes given now as pigment primaries. The light primaries, however, are red, green and violet. The old primaries (red, yellow and blue) were obtained by a negative method, and are really the complementaries of the actual positive light primaries.—Editor.

discovered and the following theory evolved: That the rods of the retina are affected by the lower values of light entering the eye and the cones by the higher values. Thus the factor α is smaller when the rods are

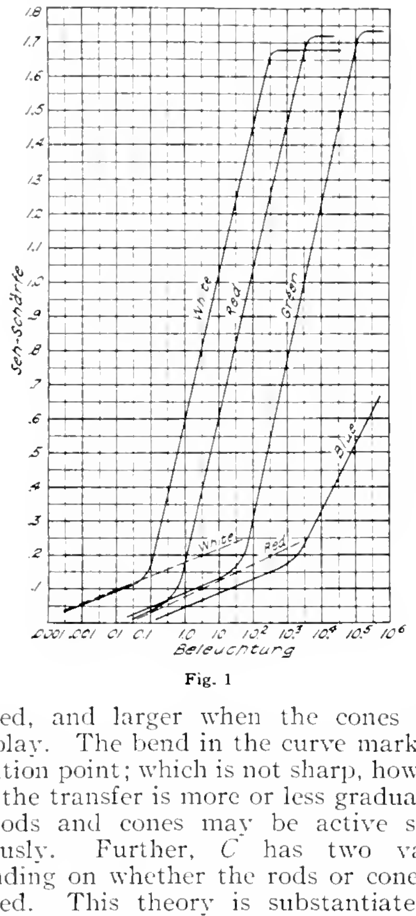


Fig. 1

affected, and larger when the cones come into play. The bend in the curve marks the transition point; which is not sharp, however, since the transfer is more or less gradual and the rods and cones may be active simultaneously. Further, C has two values, depending on whether the rods or cones are affected. This theory is substantiated by tests carried on with a totally color-blind person, whose retina should contain no cones. The results are shown by the dotted lines. It will be noticed that the abscissae of these curves are plotted to a logarithmic scale. If they had been plotted to a regular scale the result would have been a series of curves of the general shape shown in Fig. 2. Each curve consists of two sections, each a logarithmic curve, the lower one representing conditions when the rods are in use and the upper when the cones are working. The different curves were taken for the various colors of light as indicated in the figure. They have no practical value, but serve simply to bring out the fact that there is a marked change-over from rods to cones (at point A), and show the range through which each works.

All are agreed, however, that vision is a result of a destruction of certain retinal elements by the chemical action of the incident light. This destruction induces a nervous impulse which is carried to the occipital lobe of the cerebrum and there sensed. Distinction partially results from differences in light flux density from the objects perceived. i.e., differences in illumination. These may be differences in quality, i.e. in color, or differences in quantity, i.e. in intensity or brightness. As such, distinction includes the effect of shadows as causing the differences in intensity at the edge of objects.

It is the change in pupil opening that, in part, explains the marvelous adaptability of the eye to the enormous range of intensities of illumination met in nature. Under favorable conditions small print may be read by the light of a small candle or by the light of the blazing sun, which has an intensity varying from one thousand foot-candles one hour after daylight, to eight or nine thousand foot-candles at noon. Inherent retinal adaptability, fatigue, and the logarithmic law of sensation also help to account for the wide variation of light which the eye will accept.

Experiment has shown that the sensitiveness of the retina to impressions is enormously increased by protecting the eye from all light. Recently it was found that in the dark the eye increases, during the course of an hour, several thousand fold in sensitiveness. It is a fact that if the eyes are bandaged for twenty minutes they will be able to perceive a glimmer of light that ordinarily is not perceptible. On the other hand, the eye becomes fatigued when the active retinal elements cannot be replaced fast enough for the amount of light flux entering, i.e., the nerves become less sensitive when exposed to high intensity of illumination. The con-

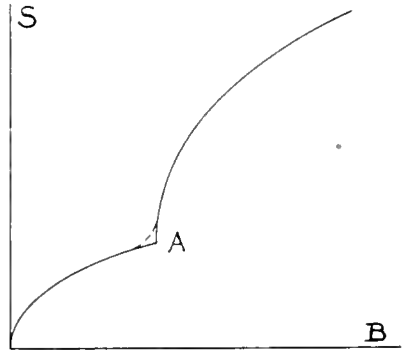


Fig. 2

sequence is that a much greater change of intensity of illumination is necessary to produce conscious impression, under circumstances where the eye is exposed. This, of course, is the only condition found, and it becomes necessary for the illuminating engineer to keep his light sources out of the field of vision.

No paper on this subject is complete without a discussion of "glare." In general, glare is discomfort or depression of the visual functions associated with strong light sensation. Glare is experienced when a light source in the field of vision causes discomfort; because, in the attempt to distinguish objects upon which the intensity of illumination is low, the pupil is distended to such an extent that the amount of light flux entering from the exposed source becomes excessive and causes pain. The headlights of a motor-car approaching along a straight road do not cause glare, because the eye, in watching it come, has adapted itself to the intensity of the lamps. When the car turns a corner, however, and flashes the lights into the eyes, glare is experienced because the pupils have been wide open in order to allow distinction of objects in the faint light.

*This definition of glare is rather narrow, and should perhaps be modified to include the influence of a light source in the field of vision, or any extreme contrast in intensity of illumination which may cause pain or interfere with vision. This must not, however, be interpreted to mean that the excessive intrinsic brilliancy of a light source causes glare, because under proper circumstances glare may be occasioned by the light of a candle. If the headlights of a motor-car approaching along a straight road cause discomfort it is either because, when looking directly at them, the pupil cannot narrow sufficiently to shut out excessive light flux, or because the observer is attempting to distinguish objects other than the lights, as, for instance, the outline of the car itself. Glare, when defined as physical discomfort, should probably include also the physical and nervous strain caused by brow puckering when holding the eye fixed on an object, the iris being maintained in a state of constant contraction to exclude the light, and the muscles which carry the eyeball continually trying to turn the eye away from the source of irritation.

Glare may be occasioned by regular reflection from polished surfaces. The avoidance of this becomes a problem of some importance in library illumination, on account of the use of polished tables and the fact that the paper of books and magazines is always more or less perfectly glazed. That this form is particularly annoying is because the eye has become habituated through the experience of centuries to light coming obliquely from above. Glare due to a light source above the horizontal is very often prevented by the mechanical construction of the eye and by the use of an eye shade, as the brim of a hat. Nevertheless a light above the horizontal and in the field of vision causes less discomfort than one below. This is a well-known fact, and may be illustrated by referring to theater experiences, the chandeliers and exposed footlights being the sources of light above and below the horizontal. After due allowance is made for the difference in intensity of illumination furnished by the two the result is still marked. This is one of the reasons why reflection from a snow field or sheet of water is particularly distressing. In any case, glare results in an obscuration of vision caused by scattered light in the eye. Dr. Percy W. Cobb, of the N. E. L. A., Cleveland, has made an interesting study of the subject from this side, by considering the extent of the retinal surface stimulated by a side-light and the result of high intrinsic side-light brilliancy. He, with other investigators, came to the conclusion that the glare-effect does not become noteworthy unless the side-light makes an angle of less than twenty-six degrees with the line of vision.

Glare is undesirable, not only on account of its painful physiological effects, but also because its presence always makes necessary a greater intensity of illumination on the work. Steinmetz says, "If points or areas of high brilliancy are in the field of vision, especially if near to the object at which the eye looks, the pupil contracts and thereby reduces the amount of light flux which enters the eye. The same result is produced as if the objective illumination were reduced. The existence of points of high brilliancy results in a great waste of light flux." It has been shown that the presence of a 16 c-p. lamp in the field of vision decreases one's ability to read by approximately thirty per cent. The effect would be more marked if the intensity of the lamp were greater. The same holds true with regard to excessive light on surfaces within the field of vision, as the walls of a room. Thus over-illumination almost always results in glare. Consider the illumination of a printed page. Too bright a light obscures the contrast between the letters and page. No ink is so black that

* There has been a great deal of difference of opinion as to what constitutes "glare." It would appear that the general practice in this country is to consider glare as including the influence of a light source in the field of vision, or any extreme contrast in intensity which may cause pain or interfere with vision. In accordance with this interpretation, the example of the headlights of a motor-car approaching along a straight road will be considered as an instance of glare, although not so excessive as would be obtained were the light flashed suddenly into the eyes.—EDITOR.

no light is reflected from it. By strongly increasing the intensity of the incident light the increase in the reflection of light from the ink becomes greater in proportion than the increase in reflection from the paper, and hence the contrast which is so essential to clear vision is diminished.

Correct illumination is secured by the use of proper shades for the direction, diffusion and diffraction of the light rays and the proper location of the sources from which they issue. It is interesting to consider some points which tend toward relieving the strain imposed on the eye when working by artificial illumination. Such relief may be obtained, granted that the design of the system is such that a proper amount of light is shed on the work, by subjecting the eye to a more or less regular set of "ocular gymnastics." This may be done by offering a place of rest to the eye when it leaves the work, by having a lower intensity on the walls and ceilings than on the work. A slight movement of the muscles takes place in opening the pupil for the lower light value, and this is reversed when going back to the desk. When this idea is carried to the extreme, however, a distinct effort becomes necessary to adapt the pupil to the large change, and muscular fatigue results. A set of experiments, consisting of periodically raising and lowering the voltage on the lights in a room and so varying the illumination very slightly proved very restful to the eyes. If the eye has been fixed on a number or series of objects of the same shape, size, or color for a length of time, distinct relief may, of course, be obtained by fixing it on something having greatly different properties. As an example of this may be cited the relief experienced when, after reading and keeping one's attention on the black letters on a white page, one's eye is directed toward anything brightly colored. The same principle is involved as when a bank clerk, after having handled flat dry papers, takes a moist round orange into his hand.

It is evident that the physiological peculiarities of the various individuals to be served in any one lighting installation are so varied that, after all, the success of the design depends largely on the judgment of the engineer. After consideration of the points brought out it would seem that an ideal system of illumination would be a combination of indirect and direct, producing a condition of low general illumination with a local higher intensity at the places of work.

STORE LIGHTING INSTALLATION WITH TUNGSTEN LAMPS

By A. L. Powell

Harrison Lamp Works, General Electric Company

The New York City store of Messrs. F. A. O. Schwarz is the finest and most up-to-date toy shop in the country. The store is in the form of an L, one half bounded on two sides by 31st Street and Fifth Avenue, and the other portion parallel to Fifth Avenue. Both sections are similar as to lighting requirements, general characteristics and arrangement; and for the discussion of matters of illumination, we will deal with the corner room only. A general plan of this is shown in Fig. 1.

The walls, ceiling and supporting pillars are of smooth white plaster. Counters are arranged with regular aisles over the entire floor space, and show-cases or shelves, with and without glass doors, line the walls. The counters have a sort of shelf above them on which goods are also displayed. Miniature aeroplanes, toy birds, hammocks, etc., are suspended from the ceiling or between pillars. From this it is readily seen that the lighting requirements are rather severe, for the following reasons: *First*, a large number of the toys are small, and hence a relatively high intensity of light is necessary to examine them; *second*, the toys are of every color of the rainbow, and although not a prime essential, the illuminant used should approximate the natural light of day, showing these colors properly; *third*, from the very arrangement of these upper shelves, the light must be well diffused, and not concentrated strongly downward so as to cast a deep shadow on the goods below the shelves; *fourth*, there must be a considerable portion of side flux for lighting the wall show-cases, without the top shelves casting a shadow; *fifth*, an attractive unit must be provided to be in keeping with the general character of the store; *sixth*, as in any store lighting, glare must be eliminated and the store present a bright, cheerful and inviting appearance.

The store was originally illuminated by Westinghouse Nernst ornamental lamps, a cut of which is shown at the left in Fig. 2. These were equipped with a 16-in. roughed inside, heart-shaped globe using 4-glower, 240-volt direct current lamps. The units were located at the points indicated as 400-watt lamps in Fig. 1. It was decided to use incandescent lamps, since maintenance trouble with this illuminant is practically nil. The 400-watt clear Edison Mazda lamp, equipped with a suitable diffusing globe was adopted, this size being chosen, as the outlets were spaced 18 by 22 ft. The 16-in. globe used with the old equipment had a 5-in. fitter, and hence some other diffusing globe was necessary to accommodate the 7-in. diameter 400-watt lamps. The globe finally adopted was the Alba "Acorn", an ornamental ball of a white opalescent glass, roughed outside, 14 in. in diameter with a 9-in. fitter. The Nernst mechanism and globe holder were removed from the housing, and a large Edison socket and shade-holder (for 9-in. fitter) substituted. This holder is painted white on the inside surface to assist in redirecting the light. The new lighting unit is also shown in

Fig. 2. On Left, Original Lamp; On Right, Present Lamp

Fig. 2 (right). The distribution of light from the unit is similar to that shown in Fig. 4, which refers to the 10-in. globe with 100-watt clear Edison Mazda lamp. The building was wired on the 3-wire system, and changing a few connections at the panel box enabled the use of 120-volt Mazdas, which have the advantage of better selection and lower cost over the 240-volt type.

An illumination test was run on the former installation on the evening of April 11, 1912, readings being taken with calibrated instruments. A Sharp-Millar illuminometer was employed, the usual method of procedure in such tests being followed. Lamps were found to be badly out of adjustment; and, at a constant voltage of 242, the wattage of the various lamps of the same type ranged from approximately 240 to 370. At the

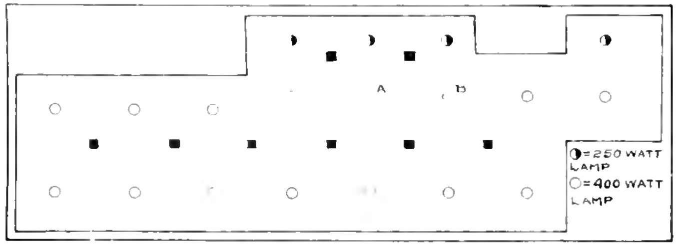


Fig. 1. Lighting Plan

stations taken, the foot-candles varied from 1.2 to 4.5, with an average in the neighborhood of 2.0. On account of the lack of adjustment and the wide variation in the performance of the individual lamps, it was impossible to formulate any idea of the illuminating efficiency of the installation. A similar test was run on the Mazda installation on the evening of May 3, 1912. The Mazda lamps had been in service only a few weeks, and hence were practically new. The globe equipment was clean. The following results were obtained in the portion of the store shown in Fig. 1.

Color of walls and ceiling	white
Height of ceiling	16′ 10″
Height of center of lamp	12′
Height of working plane (counter height) .	40″
Voltage of lamps	120
Voltage of circuit	120.5
Number of 400 watt lamps	15
Number of 250 " "	4
Wattage consumption, approximately the rated wattage.	
Floor area	6000 sq. ft.
Total wattage	8500
Watts per sq. ft.	1.42
Average foot-candles	5.06
Effective lumens per watt	3.57

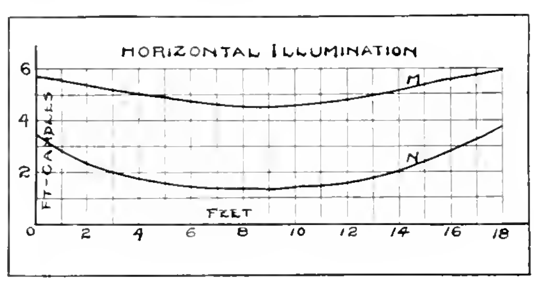


Fig. 3. Illumination Curves. N, Old Installation; M, 400 Watt Mazda Installation

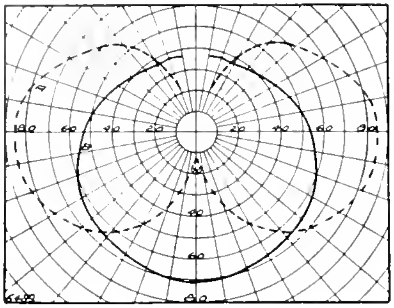


Fig. 4. Illumination Curves of Lighting Unit

To show the variation in intensity of illumination, a set of readings was taken every three feet between lamps A and B (Fig. 1). The variation is shown graphically in Fig. 3, curve M, the actual values being as follows:

Under A.	5.3	foot-candles
3′ from A.	5.25	" "
6′ " "	4.65	" "
9′ " "	4.40	" "
12′ " "	4.60	" "
15′ " "	5.25	" "
Under B.	5.8	" "

Curve "N" is empirically calculated from the readings on the original installation and shows the approximate average variation under the same conditions. Night photographs were taken of two portions of the building and an untouched view is shown in Fig. 5. It can be readily seen that the installation is very pleasing in appearance, diffusion is perfect, glare eliminated, harsh shadows are not found, detail is readily discernible, and shelves and counters are equally well illuminated. The test results show the uniformity of illumination and illuminating efficiency.

Fig. 5. Store of F. A. O. Schwarz Illuminated by 400 Watt Mazda Lamps with Alba "Acorn" Globes

BUS AND SWITCH COMPARTMENTS FOR POWER STATIONS

By Emil Bern

Switchboard Department, General Electric Company

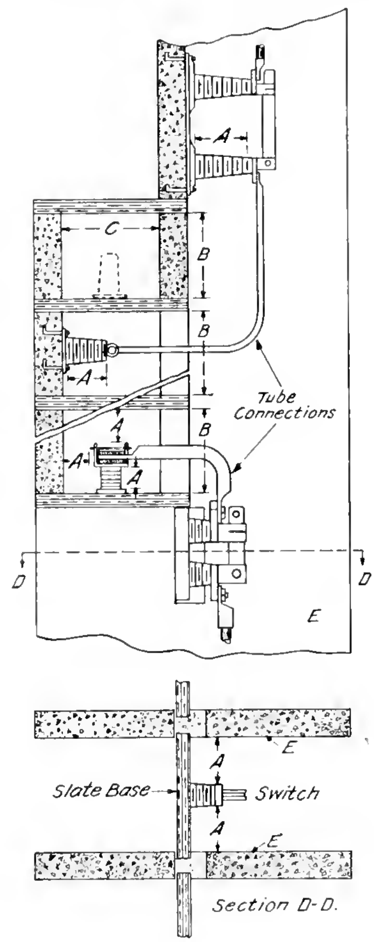
This article discusses designs of fireproof compartments for medium high voltage apparatus; states some of the advantages of brick and concrete bus compartments, the dimensions being usually governed by allowable distance to "ground," and to a less extent by the apparatus to be housed; gives approximate dimensions for various voltages; discusses and illustrates types of disconnecting switches and methods of mounting, and location of oil-switches with respect to busses.—Editor.

The object of this article is to discuss briefly a few typical designs of fireproof compartments for medium high voltage busses and switching apparatus; not considering high voltage arrangements to any extent, since the present practice seems to lean towards open wiring suspended under station roofs for this class of work.

In the early days, as is often the case now, bus compartments were built of brick, with partitions and shelves of soapstone or slate. Nowadays concrete and concrete slabs are used a great deal. Several advantages are claimed for each of the two constructions, and hence one has not excluded the other. Where expert men on concrete work can be obtained, and the expense of complicated forms is not considered prohibitive, solid concrete gives, of course, the most desirable construction. Concrete slabs set in cement have also been used to a great extent, thereby reducing considerably the cost of forms.

Where the obtainable size of brick is suitable for the construction of the compartments, and the design is not too complicated, brick construction is doubtless the most convenient. The expense of laying brick is, however, materially increased if the design is such as to require great accuracy. The bricks usually vary appreciably in size, so that a close adherence to certain dimensions often necessitates cutting the bricks or resorting to abnormal bonds, both of which are very slow processes. It is a good plan to bear this in mind when detailing busses and connections, so as to allow, if possible, liberal lengths for variation. It is well to take this precaution even for concrete compartments, as great accuracy is always expensive.

The general dimensions of bus and switch compartments are determined primarily by the minimum distance allowable between conductors and ground, the brick or concrete being considered as ground. The switching apparatus also governs to a great extent the dimensions of the compartments, although even here it is generally a matter of ground distance in the apparatus. For mechanical reasons and accessibility the distances are generally stretched somewhat; this also to



Sections of Typical Bus Compartment

Volts	A Ground Dist.	B	C
15,000	3½"	12½"	14"
22,000	6 "	19 "	19"
35,000	10 "	25 "	25"
45,000	14 "	34 "	34"
70,000	21 "	45 "	45"
90,000	27 "	56 "	56"
110,000	33 "	72 "	72"

Fig. 1

guard against joints, clamps or bolts acting as spill-ways at times of abnormal voltages or surges on the system. Low-voltage compartments where relatively heavy copper is used have proportionately more liberal distances than those for equal capacities, but of higher voltages, with connections of smaller size. Fig. 1 gives a few general dimensions of bus compartments for different voltages. These are, of course, very approximate, being dependent upon the type of bus supports and the size of busses and connections as pointed out above.

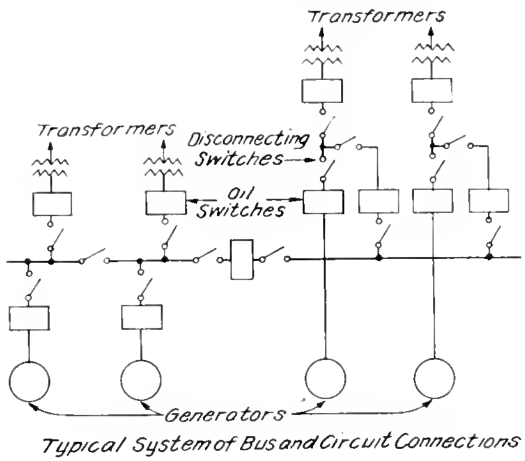


Fig. 2

A type of disconnecting switch having its two insulators clamped to a common base of sheet steel has many advantages over other types for mounting in compartments. The rigid base preserves the adjustment of the switch during shipment and mounting. By setting the supporting bolts by means of wooden templates, as shown in the upper part of Fig. 1, the switch need not be mounted until the compartment has been finished, and therefore runs less risk of injury during construction work. It can safely be taken down for repairs and set up again.

The type of disconnecting switch with insulators cemented into a slate base requires ordinarily a somewhat different mounting. Bolting it to the compartment wall involves the risk of breaking the base, while setting the base when building the compartment exposes the switch to injury. Furthermore, this construction does not so readily permit of taking out the switch for repair. A simple construction, shown in the lower part of Fig. 1, has been used occasionally to eliminate these difficulties. In building the compartment barriers, openings are provided slightly higher than the height of the base, having a width of about twice the thickness of the base. The width of the base is approximately one inch more on each side than the distance between the barriers—in other words, such that the base extends into the barriers about one inch on each side. The switch bases are mounted after the compartments are finished, and are held in place by wooden wedges, afterwards covered with cement. In order to dismount a switch, the cement is chipped out, the wooden block on each side removed, and the base moved over to one side and taken out.

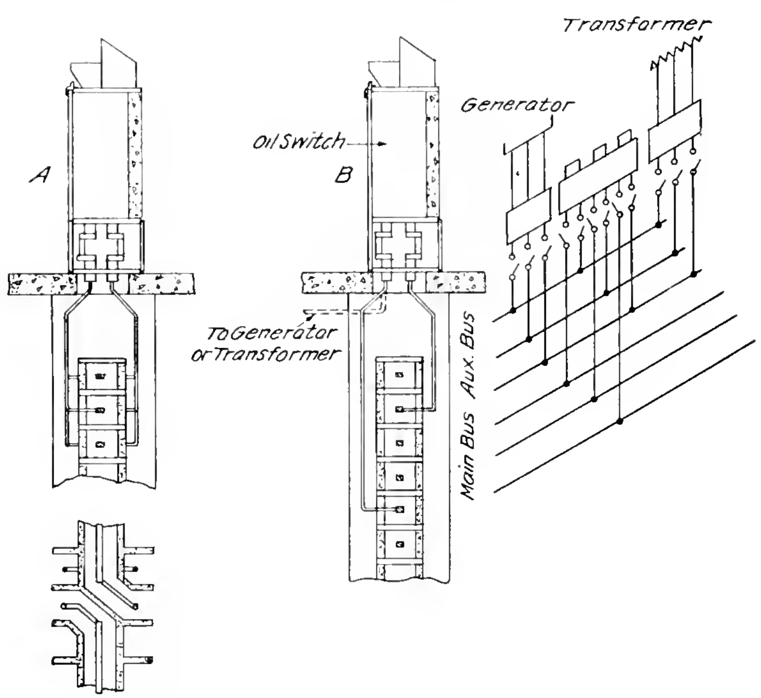
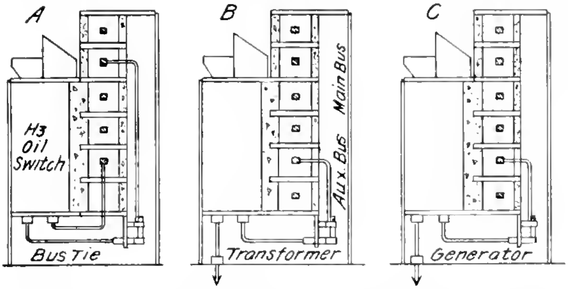


Fig. 3. Disconnecting Switches Mounted in Sub-compartment in bottom of Oil Switch Cell

Disconnecting switches are occasionally used for isolating horizontal sections of a bus, and are in this case located in the compartment in a straight line with the bus. If the section of the bus is heavy enough it can be made to serve as hinges and clips for the switch, thereby simplifying the construction.



In this case, however, care should be taken to anchor the busses so that strains incidental to the opening and closing of the switch cannot disturb its location nor injure the supports. Where the busses are of a lighter construction the bus switches are usually of the same type as the circuit switches, with their bases mounted on the back wall inside the compartment. Whatever type of switch is used, thought should be given to the proper ground distance between the compartment wall and the switch blade in any position from closed to open.

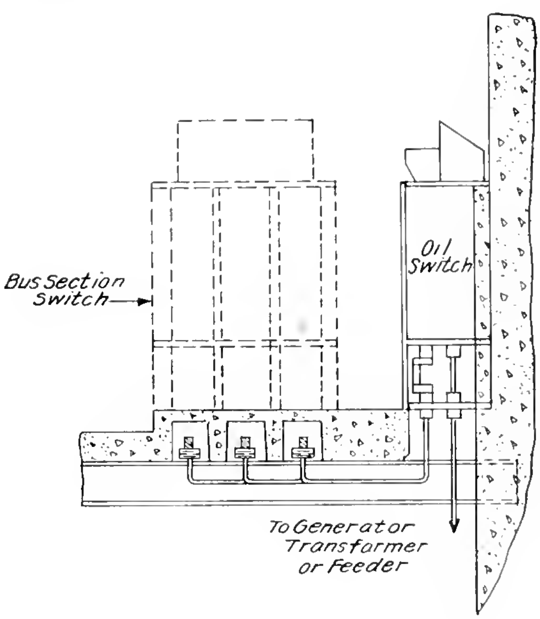


Fig. 4. Compartment Design for Small Substations or Power Houses

Oil-switches, when used in different combinations and with disconnecting switches for isolating them from busses and circuits, as shown in Fig. 2, introduce a great variety in designs of switch and bus compartments. The available space determines to a great extent the design of the compartments, which may ordinarily be divided into two groups

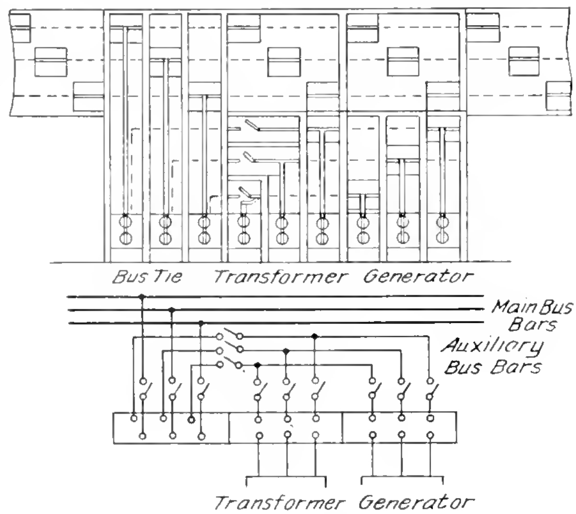


Fig. 5. Design for Locating Switching Equipment on Gallery Forming Roof of Transformer Room

according to whether the switch and bus compartments are located on different floors or on the same floor. With bottom-connected oil-switches several advantages may be claimed for the arrangement in which the bus compartments are on the floor below the oil-switches. It is, however, a disadvantage to have the disconnecting switches located in a place from which it is not possible to see whether the corresponding oil-switch is open or closed; as this introduces the danger of an operator opening the wrong disconnecting switch on attempting to isolate an open oil-switch. This difficulty may be overcome by providing a sub-compartment for the disconnecting switches in the bottom of the oil-switch cell, as shown in Fig. 3. A door covering the disconnecting switches belonging to each oil-switch obviates the danger just mentioned. Fig. 3-a shows the application of this arrangement to a bus section oil-switch. Fig. 3-b shows a similar arrangement for a generator and transformer circuit with auxiliary bus, and is equally applicable to feeder circuits. If the room containing the bus compartments is also used for other purposes, it is advisable to provide doors between the barriers, (as for the oil switches) to guard against accidental contact with the connections.

Fig. 4 shows a simple compartment design for substations or power houses with simple connections and small capacity. The busses are here located in the floor, and are supported and accessible from below. Removable asbestos barriers can easily be arranged between the different phases of the connections if desired; or the connections may be taped with varnished cambric and painted after installation.

compartments, as shown in the elevation. If the available longitudinal space permits, passages can easily be arranged for through the compartments between each bank of three oil switches.

Another arrangement providing for the same electrical connections is shown in Fig. 6, a, b, c. The false floor covering the

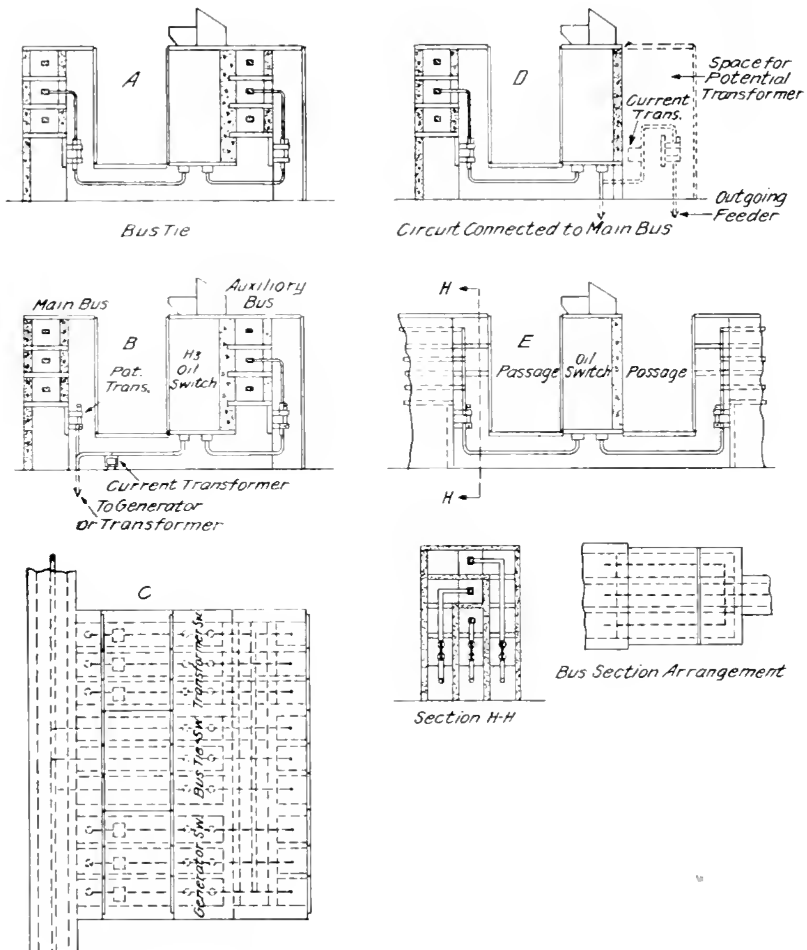


Fig. 6. Arrangements Providing for Same Connections as Shown in Fig. 5

In many instances it is not possible to obtain suitable space on two floors for compartments of the design shown in Fig. 3; and in the majority of these cases the switchboard and the whole switching equipment is located on a gallery forming the roof of the transformer rooms. A compact arrangement for this condition is shown in Fig. 5, which also covers connections for generator and transformer circuits with auxiliary bus. This design requires three of the disconnecting switches to be mounted horizontally in the

connections between the oil-switch and the main bus may in some cases be omitted where these connections can be run underneath the floor. This again introduces the complication of bushings where the leads pass through the floor. Fig. 6-d shows the same design adopted for a feeder circuit, with an alternative arrangement of disconnecting switches for underground feeder; and Fig. 6-e shows a bus section oil-switch with isolating disconnecting switches mounted in compartments at the ends of the busses.

ELECTRICAL EQUIPMENT OF THE CALUMET & HECLA MINING CO., CALUMET, MICH.

By John Liston

Publication Bureau, General Electric Company

In the description of the electrical equipment of this, the greatest copper producing mining property in the world, it is of especial interest to note that with electric lighting in use for thirty-four years, and with motor drive first applied twenty years ago, the subsequent additions to the power plant have followed closely the successive improvements in the electrical art as applied to mining work, while in many power applications, with the conspicuous exception of mine haulage, the engineers of the Calumet and Hecla Company have rendered important pioneer service.—Editor.

As early as 1866, active work on the properties of this company was started, and subsequent to 1871, at which time the present company was organized, the development of the mine proceeded rapidly until it became the greatest single producer of copper in the world. Almost from the beginning electrical energy has been used. The engineers of the company have been pioneers in some of the most important applications of electricity which are now commonly used to obtain the high efficiencies combined with maximum safety and economy, that are considered essential in modern metal mining.

The first electrical apparatus consisted of an alternating current arc lamp outfit, which was installed in 1878 and constituted the initial commercial arc lighting system in the United States. It comprised a Siemens & Halske arc generator and twenty lamps, and was imported from Germany by the late Alexander Agassiz, who was at that time president of the company. These lamps were utilized at the mills at Lake Linden, five miles from the mine, where the main generating station was later established. The only prior arc lighting in the United States consisted of a similar set which was shown at the Philadelphia Exposition in 1876, and another installed at Cornell University in the same year.

The lighting system was extended in 1880 by the addition of a Brush arc generator and eight open arc lamps, which were installed at the mine; the lamps being mounted on masts in two groups of four each. The earliest incandescent illumination was provided in 1891 by means of a 600 light, 125 cycle, 1000 volt Thomson-Houston generator, and in the following year electrical pumping was started with an outfit consisting of five 100 h.p., 1000 volt series direct current Brush commutating motors direct geared to reciprocating pumps. This installation was followed by Thomson-Houston motors, applied in the same way. There were eight of these pumping sets in all, each served, in conformity with the common practice of that time, by its own generator developing energy at 1250 volts direct current. The generators were group driven from a line shaft through belting, and each of the eight motors operated a 500 gals. per min. pump against a 500 ft. head. This arrangement gave satisfactory service and remained in operation for a period of nine years, at the end of which time it was superseded by the pumping system now in use.

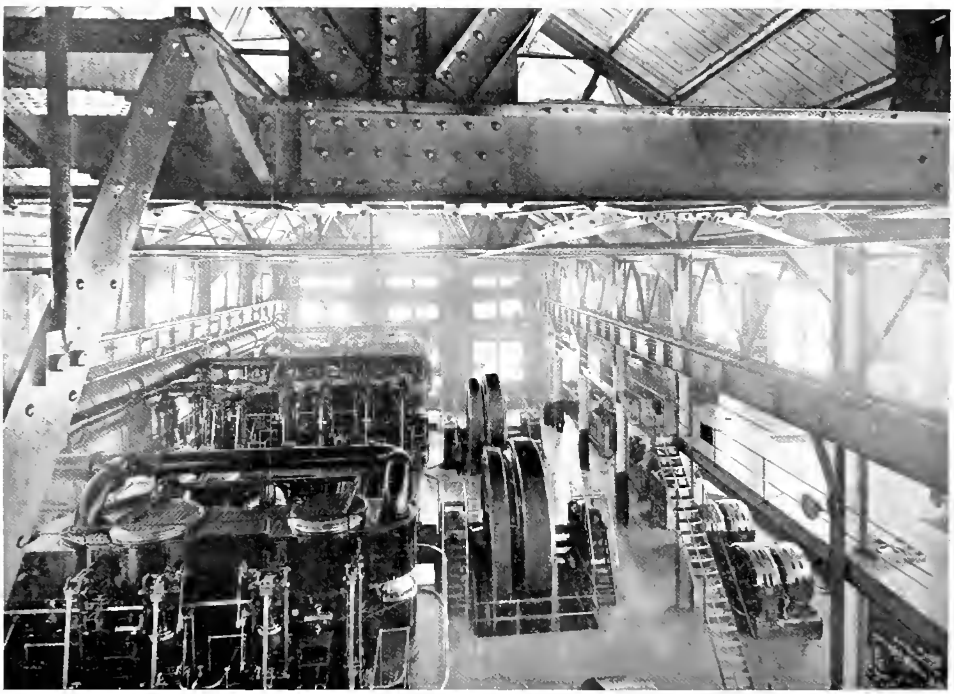
The first modern alternating current machines were provided in 1892 and consisted of eight 60 kw., 1500 r.p.m., 1000 volt single-phase, 133 cycle generators for incandescent lighting on a multiple transformer system; current being also supplied to a few multiple arc lamps. This equipment, consisting of six No. 8 Brush arc dynamos, was utilized in connection with the Brush arc system, until 1905.

In the year 1900, the power plant was equipped with an alternating current polyphase generator rated at 300 kw., 2300 volt, three-phase, 25 cycles; the machine being of the revolving field type and rope driven by an engine. It supplied current to four triplex pumps in the mine, each rated at 400 gals. per min., against a 750 ft. head, and individually gear driven by 110 h.p., 440 volt motors. The water was elevated to the surface from the main sump in four steps through intermediate sumps, the total vertical lift being approximately 3000 ft.

The present system of electrification dates from 1902, and the remarkable efficiencies obtained at the present time, as will be indicated by the context, are due to the fact that the original comprehensive plan was laid out by the engineers of the Calumet & Hecla Company with due regard to future possible requirements. This plan has been systematically followed in adding to the electrical equipment, and has been subjected only to such modifications as were rendered imperative due to successive improvements in the design and efficiencies of electrical apparatus. It was determined at that time to standardize 25 cycles as a frequency for all power applications and two 440 volt three-phase generators, each of 1000 kw. capacity, were then installed and are still in operation. One of these machines was provided with rope drive and connected to a hoisting engine which was converted for this service; the second unit being direct connected to a tandem compound engine.

alternators are each direct driven by three-cylinder compound engines which were originally purchased for hoisting, but not used for that service. The original 440 volt generators are connected with the new 13,200 volt units through transformers, which are floated on the line. All generators are operated in parallel. The old 440 volt main switchboard is now utilized only for distribution in the low tension zone originally established near the power station.

Energy is transmitted at 13,200 volts from the power station to the mine over a



Lake Linden Power Station

From this time on the electrification of mines and mills proceeded rapidly until the power station (which is now equipped with 8000 kw. in generators) was supplying current to about three hundred and twenty-five motors, having an aggregate capacity in excess of 20,000 h.p. About 90 per cent. of the electrical equipment is of General Electric manufacture.

Early in 1905 the present system was extended to the mine, and at that time three 2000 kw., three-phase, 25 cycle, 13,200 volt generators were added to the power station equipment at Lake Linden. These

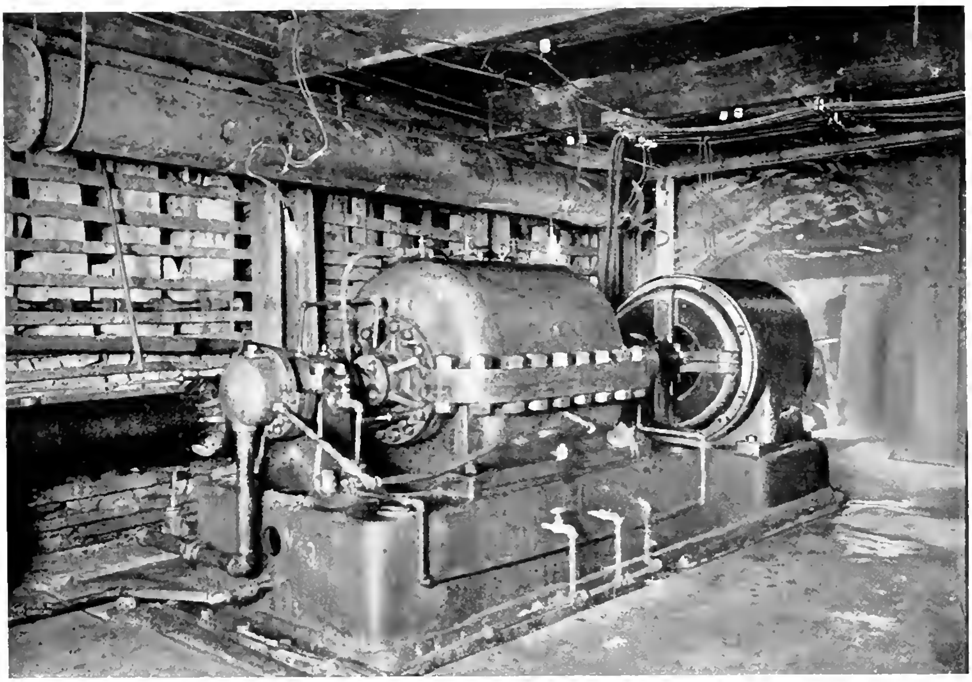
duplicate pole line terminating at a sub-station, where it is stepped down to 2300 volts for local distribution. Each pole line is arranged for carrying twin circuits, but only one circuit has as yet been run. The conductors are of 250,000 cm. 19 strand cable which was made from copper produced by the mine. Each circuit can, if necessary, carry the entire output of the power station at slightly diminished efficiency. Native cedar poles have proven most suitable for the service and have been adopted as the standard. Each pole has one two-pin and one four-pin cross arm with 36 in. delta spacing for the conductors; the average distance between poles being 100 ft.

There is a separate 13,200 volt line running from the power station to the regrinding plants where 2300 volt motors are used throughout, and an additional high tension circuit serving the smelter. Except for the motors in the original 440 volt zone, 2300 volt motors are used throughout for surface work, while 440 volt motors have been adopted for all underground applications.

Inasmuch as there is a considerable amount of available energy in the exhaust from the steam heads of the stamp mills located near the power station, it has been decided to add to the generator capacity by installing a mixed pressure turbo-alternator rated at 7500 kw., which will be operated with about 145,000 pounds per hour of low pressure steam from the stamp head exhaust, and approximately 35,000 pounds per hour of high pressure steam. The two original 440 volt generators will then be held merely as reserves; or, if it is found advisable, one of them will be normally run as a synchronous phase modifier, simply floated on the line for improving the power-factor.

The substation at the mine is provided with four banks of air blast transformers, each consisting of three single-phase 500 kv-a., 13200/2300 volt units, with all the distribution circuits for the mine transmitting energy from this point at 2300 volts. Where motors are used under ground, each is provided with 2300/440 volt oil-cooled step-down transformers. For the lighting service the substation is equipped with two 400 kw., 25/60 cycle frequency changers.

One of the most important motor applications is that connected with the pumping service at the mine. Practically no mine water is encountered, except small amounts in the extreme lower levels, although there is a considerable volume of drainage water which has to be elevated to the surface. There are two main sets of pumps in the mine, the first being located at No. 5 shaft, Calumet Branch, and consisting of four six-stage 1000 gals. per min. centrifugal pumps, designed for operation against an 800 ft. head; each pump being direct driven by a 300 h.p., 1500 r.p.m., 440 volt motor connected to the pump shaft by a solid coupling.

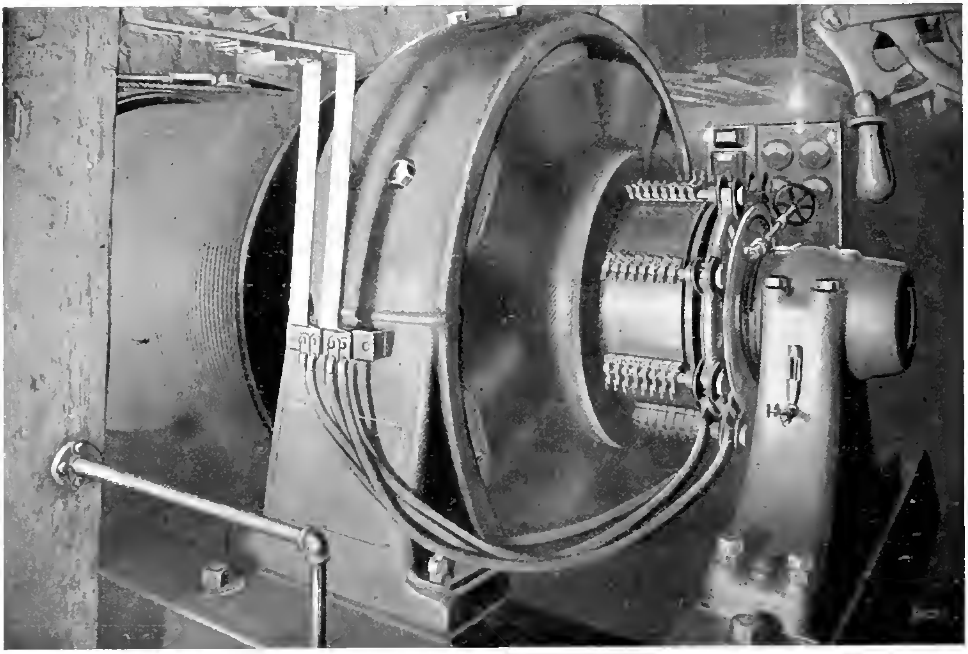


Six-Stage, 1000 G.P.M. Centrifugal Pump Direct Driven by 300 H.P., 440 Volt, 1500 R.P.M. Motor

The main sump, with a normal reserve capacity of thirty-six hours storage is located at the 49th level at a depth of approximately 3000 ft. and the four pumps relay the water to the surface through intermediate sumps, which consist of 2500 gallon tanks 6 ft. by 6 ft. by 10 ft., made of 2 in. planking. The pumps each deliver a volume of 1063 gals. per min. against an actual head of about 750 ft. and are installed in rooms cut in the solid rock of the foot-wall, each room containing a complete pumping set including transformers, control panel, necessary resistance, etc. The roofs of the pumping chambers have a maximum clearance of ten feet, while the side walls have a minimum height of six feet, and inasmuch as the limited air space of the chambers does not permit of complete dissipation of the heat, each chamber has been provided with a motor-driven blower capable of delivering 3000 cu. ft. of air per minute.

The second set of pumps serves No. 7 shaft, Hecla Branch, and comprises four 450 gals. per min. units of the triplex single acting type, each driven through gearing at 42 strokes per minute by a 110 h.p., 500 r.p.m. motor; single reduction gearing (raw hide into cut steel) being used. These pumps are installed in the same manner as the centrifugal sets already referred to, and have been in operation in a downcast shaft for ten years, during which no burnouts have occurred nor has any cost been entailed for maintenance, aside from that involved in the ordinary wear of brushes and contacts. The motors driving these mine pumps are normally in operation from seventeen to eighteen hours per day, and as they are run on holidays and Sundays when the balance of the mine equipment is out of service, one 2000 kw. generator is kept in operation at the power station to supply the current for pumping.

Below the 49th level water is relayed to the main sumps by small air pumps of approximately 100 gals. per min. against 100 ft. head. These will eventually be replaced by motor-driven pumps as the workings are advanced and when the volume and head warrant the substitution of electric pumps. No underground steam pumps are used.

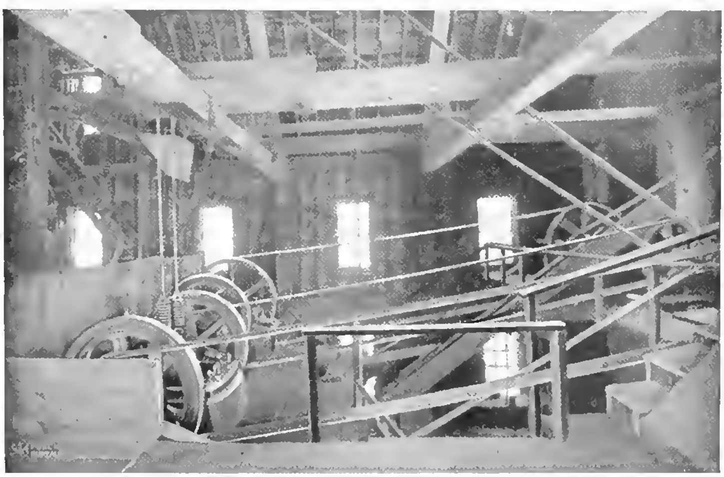


225 H.P., 250 Volt, 65 R.P.M. Direct Current Motor Driving 6 Ft. Single Drum Underground Hoist Serving Red Jacket Shaft

A notable example of the efficiency of motor drive for mine pumps under adverse conditions is found at Red Jacket shaft, where a 12-stage, 150 gals. per min. centrifugal pump, driven by a 50 h.p., 1500 r.p.m. motor against a 600 ft. head ran continuously for an entire year, although the pumping set was coated and filled with grease and soot from miners' lamps. The conditions were such that continuous operation of this set was imperative, and the motor could not be stopped for cleaning. In spite of this, it gave service which was in every way satisfactory.

The water supply for the power plant and for boiler feed at the mine and stamp mills is secured by means of a pumping station located on the shore of Lake Superior, about ten miles from the power plant, where an 8-stage centrifugal pump is used, direct driven by a 650 h.p., 750 r.p.m., 2300 volt motor and delivering 3,400,000 gallons per twenty-four hours against a maximum head of 825 ft. The water is conveyed in pipe lines to a 450,000 gallon stand pipe at the mines, and a 500,000 gallon reservoir at the power station. The town of Calumet is also supplied from this source.

While the main hoisting is at present performed with steam engines, there is an underground electric hoist located at the end of a 3700 ft. drift, serving the Red Jacket shaft. This outfit consists of a 225 h.p., 250 volt, 65 r.p.m. direct current motor mounted on a common shaft with a six foot single drum hoist having a hand operated brake. The equipment hoists three 2½ ton cars of copper rock per trip in a sub-shaft having an average slope of 23 degrees; the hoisting speed being 1200 ft. per minute. The ultimate length of the shaft will be 5000 ft. Direct current for the motor is supplied by a four unit motor-generator set, the main units of which consist of a slip ring induction motor, and a 185 kw., 250 volt generator. The set also includes an exciter for controlling the hoisting speed through the field excitation of the hoist generator. The fourth unit is a 50 kw., 250 volt generator, which will later supply current for a contemplated system of electric locomotive haulage. Both the hoisting set and the motor-generator set are installed in a rock chamber at the 57th level, and have been in operation for a period of four years.



Arrangement of Belting to Crushers in Shaft House

When the copper rock is elevated to the surface it is received in twenty shaft houses, the rock from the conglomerate lode being hoisted in 5 and 7½ ton skips to the dumping chutes. In the shaft houses it first passes over grizzlies, through which the coarse rock falls to the crusher floor, where it is hand fed to 24 in. by 36 in. jaw crushers, the poor rock being assorted by hand, separately fed through a 17 in. by 24 in. crusher and collected in bins; it being thereafter used in road making, concrete work, etc. The copper rock passes through the first crusher to storage bins from which it is chuted to cars and carried to the stamp mills.

In the shaft houses serving the conglomerate lode both crushers are driven from countershafting by a 50 h.p., 2300 volt motor, and an average of 750 tons per day is handled by each shaft house. Tests on the motors in this service show that the friction load averages about 18 h.p., while the normal running load is approximately 35 h.p., although due to the nature of the work the crushers have momentary loads as high as 80 h.p.

The rock from the amygdaloid lode is hoisted in the same way, except that after passing over the grizzlies it falls upon a movable apron, one end of which is elevated by a winch belted to a countershaft, thereby automatically feeding the rock to the crushers, which in this case are 24 in. by 48 in. Two shaft houses are so equipped at the present time and 100 h.p., 2300 volt motors are used. The load on these crushers averages 55.76 h.p., with peaks of 93 h.p., while the friction load is 27.65 h.p. With this equipment a 7½ ton skip of copper rock is crushed and passed in an average of 2.38 minutes, and under normal conditions the motors are not subjected to overloads.

Red Jacket shaft house has a double equipment throughout, consisting of two sets of aprons and crushers, all driven in a group by one 100 h.p. motor. At the present time, it receives about 1800 tons of conglomerate per day.

From the shaft house bins the crushed copper rock is carried by rail to the stamp mills, where it is dumped into receiving hoppers and thereafter fed through chutes to the steam stamp heads, after which it passes through a system of classifiers and jigs, copper being diverted at each step. At the present time there are twenty-eight stamp heads in all, each supplemented by a Chilean mill and auxiliary classifiers, slime pumps, tables, etc. The Chilean mills are individually belt driven by 440 volt motors located with their control equipment on the floor of the stamp mill gallery, as shown in the illustration. Two distinct methods are used in the operation of the auxiliaries: for ten of the stamp heads, the classifiers, tables and slime pumps are driven in separate groups through countershafting by ten motors, so that each stamp head group constitutes an independent set. The remaining eighteen stamp heads have all their auxiliary machines, except the Chilean mills, driven in three groups from line shafting by one 350 h.p. and two 250 h.p., 440 volt motors, the Chilean mills being individually driven throughout.

The motors used in this service range in capacity from 20 to 50 h.p., and are all operated at 440 volts, as they are situated in the original low tension zone. The load on the Wilfley tables remains practically constant at 0.53 h.p., and that imposed by the auxiliary machinery calls for very slight variation in the power demand. The load of the Chilean mills, however, varies in accordance with the rate of feed and also depends to a considerable extent upon the condition of the tires of the grinding wheels. With a daily capacity of 30 tons, the average demand of a mill in good condition is approximately 26 h.p.

440 Volt Motors in Stamp Mill Driving Chilean Mills and Auxiliary Machinery

From the stamp mills the tailings are sluiced to pits served by sand wheels which elevate them to launders. Here the water and sand are either conveyed by gravity to the dumping ground or returned to regrinding mills for further separation. There are five of these sand wheels, all individually motor driven; viz.: one 40 ft. in diameter, utilizing a 200 h.p. motor, and three 54 ft. in diameter, driven by 350 h.p. motors; all motors being belt connected to the driving pinion, which meshes with a gear mounted on the periphery of the wheels. The largest wheel is 64 ft. in diameter, and at the present time is driven by a 700 h.p. induction motor operating at

150 r.p.m. Rope drive is used and the sand wheel makes four revolutions per minute.

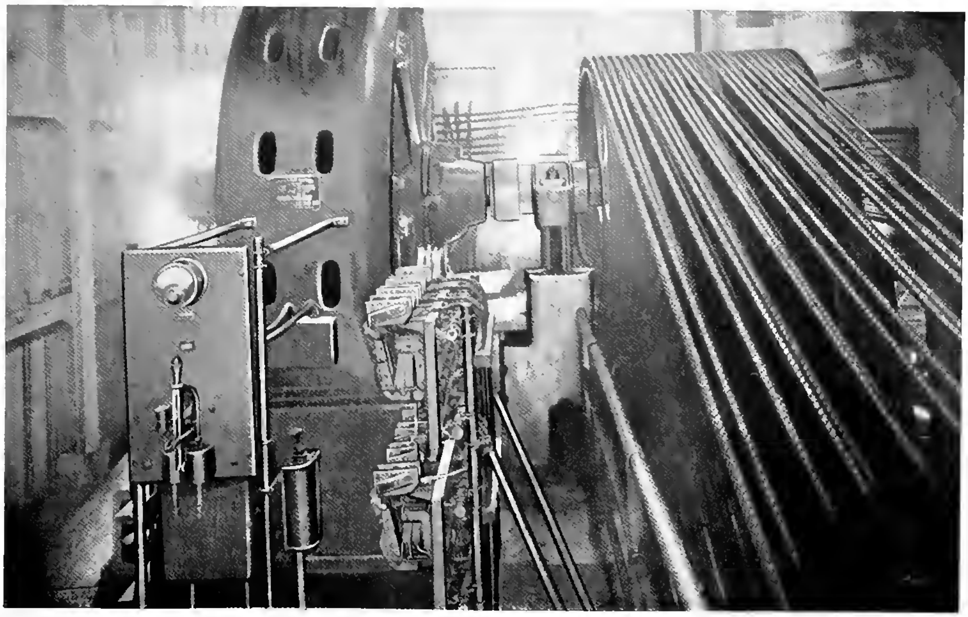
The machinery of the regrinding mill is arranged in eight sections, each equipped with six Chilean mills and thirty-two Wilfley tables, slime pumps, etc., each group being driven through countershafting by a 250 h.p., 2300 volt motor.

In addition to the electrical operation of mine and mills, current is also supplied for the operation of a smelter, machine shop, carpenter shop, pattern shop and foundry, where an up-to-date system of both individual and group electric drive is used.

four months. The reliability of the electric service rendered is clearly indicated by the following summary of a report on shut-downs

REPORT ON SHUT-DOWN OF POWER PLANT

Cause	1906	1907	1908	1909	1910
Electrical	—	—	—	—	—
Mechanical	—	20	—	15	20
Lightning	30	30	23	15	13
Total time in minutes	30	50	23	30	33



700 H.P., 440 Volt, 150 R.P.M. Motor, Rope Driving 64 Ft. Sand Wheel

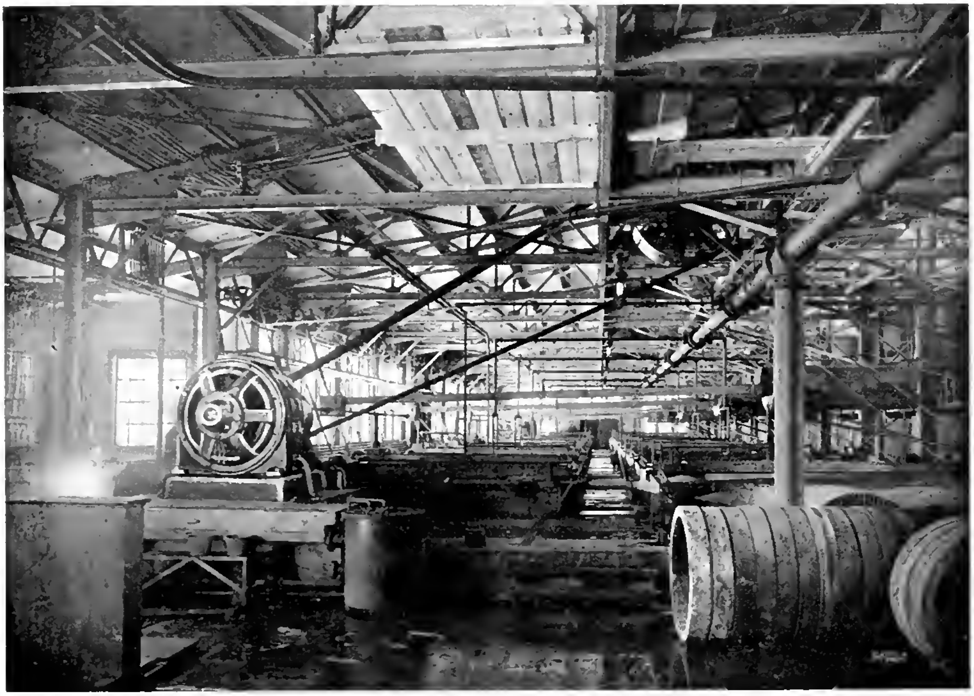
Electric drive has been adopted for all mining and milling operations, except main hoisting and the driving of large compressors and stamp heads. The service rendered is practically continuous, there being a demand on the power system of one hundred and forty-six hours a week. Every effort has been made to maintain the apparatus in first class condition, and all the motors are cleaned daily, while six inspectors are employed to note the condition of all electrical machinery and submit an exhaustive daily report. Oil is ordinarily changed in the transformers once a year, in the compensators twice a year, and in the oil switches every of the power plant, covering a period of five years, during which time the total delay from all causes aggregated two hours and forty-six minutes.

By the centralization of the power plant, rendered possible by electrical distribution, a notable reduction has been effected in the cost of maintenance and labor, and in the amount of fuel formerly required for the operation of isolated steam plants, some of which consumed as high as four pounds of coal per horse power hour, this item being reduced to less than one and three-quarter pounds per horse-power-hour under the new system. The actual cost of power delivered to the motor terminals, including all maintenance and overhead charges, as shown by carefully kept records covering a period of three years, is considerably under an average of six-tenths of a cent per kilowatt-hour. By a careful consideration of the intermittent load demands and a selection of types and sizes of motors which could most efficiently perform the work, the load factor of the system has been maintained at 85 per cent., which is an unusually high figure for mining work; and, in spite of the fact that the entire load is inductive (there being no lighting directly from the power system, nor synchronous motors or phase modifiers used) the power-factor is normally maintained at from 87 to 88 per cent.

All underground wiring is carried in wrought iron conduits, with cast iron junction boxes located at each level and anchor boxes at every 300 feet in the shafts. These boxes are all provided with drainage and ventilating holes. The 2300 volt distribution at the mine has a present radius of one and one-half miles at the substation, with a single circuit running a distance of three miles.

Illumination on the surface is obtained by means of series arc lamps operated in connection with constant current transformers, while in the mine buildings both multiple arc and incandescent lamps are used on 110 volt, 60 cycle circuits, the periodicity being raised by means of frequency changers from 25 cycles to 60 cycles for the lighting circuits. In the mills, on account of the extreme vibration due to the impact of the stamp heads, 52 volt incandescent lamps are used because their thicker filament section minimizes breakage. In the mine only the pump chambers are lighted, current being taken from the power feeders at a frequency of 25 cycles for 110 volt incandescent lamps. Except in these instances, all the lighting feeder distribution is carried over 110 volt, 60 cycle circuits.

An interesting auxiliary to the usual electrical mine equipment is found in twelve shaft houses where man hoists are used. These hoists are each provided with a searchlight on the dashboard of the car, the current for which is supplied by storage batteries, each shaft house which operates a man hoist having a small motor-generator set for charging the battery.



250 H.P., 2300 Volt Motor Driving Section of Regrinding Mill

THE ELECTRIFICATION OF THE BUTTE, ANACONDA AND PACIFIC RAILWAY WITH 2400 VOLT DIRECT CURRENT APPARATUS

By J. J. Linebaugh

Railway and Traction Engineering Department, General Electric Company

Aside from a few introductory remarks descriptive of the properties of the railway company making the change from electric to steam operation, the article consists of a description of the principal electrical apparatus involved in the change-over. The freight and passenger locomotives and the motor-generator sets in the substations contain special features of design necessitated by the extraordinarily high direct current voltage; in fact, all of the equipment—switchboard, lightning arresters, cables, trolley, etc.—has been designed and constructed with special regard to the severe service to which it will be subjected.—Editor.

The Butte, Anaconda and Pacific Railway Company have recently decided upon the electrification of their steam road between Butte and Anaconda, Montana, which consists of about 30 miles of single-track main line with a total single-track mileage of about 114 miles, including sidings, yards, smelter tracks, etc. Approximately 90 miles of the road will be electrified at present, leaving 24 miles of mine tracks on Butte Hill, minor sidings, etc., to be equipped with overhead conductor at a later date.

The 2400 volt direct current system was adopted after a careful study of local conditions, and of the main line service of the Chicago, Milwaukee and Puget Sound Railroad, which jointly operates 16 miles of the main line.

The traffic on this road consists principally of hauling copper ore, together with mine supplies, lumber, etc., from the Butte mines to the smelter at Anaconda, the amount of freight in both directions aggregating approximately 5,000,000 tons per year. The maximum grade against the load is 0.3 per cent, with 1 per cent maximum against the train of empty cars. The heaviest train will consist of 50 loaded steel ore cars weighing 3400 tons. The locomotive unit for the heavy freight service will consist of two locomotives weighing 150 tons.

Freight Locomotives

There will be fifteen freight locomotives of the articulated truck type, each weighing 150,000 lbs. (75 tons), with all the weight on the drivers. Each locomotive will be equipped with four 1200/2400 volt commutating pole, twin geared motors, insulated for 2400 volts and operated two in series. The entire motor has been designed with regard to extra good ventilation, and in addition forced ventilation will be used. The continuous tractive effort of each locomotive will be 25,000 lbs. at 15 miles per hour and the starting tractive effort 45,000 lbs. (not exceeding five minutes duration, 30 per cent. coefficient of adhesion). The wheels will be 46 in. in diameter. A pantograph roller trolley will be used to collect the current.

The control will be somewhat special in character, and a dynamotor will be used to obtain 600 volts for the operation of the contactors, headlights, locomotive lights and air compressor. The dynamotor will have two windings, one for 1800 volts and the other for 600 volts, and will be connected across the 2400 volt trolley circuit. A standard 600 volt air-compressor will be used to supply air for the air brake system.

Passenger Locomotives

There will be two passenger locomotives, which will be duplicates of the freight locomotives with the exception of the gear ratio; these locomotives to be geared for a maximum speed of 45 miles per hour on tangent level track when hauling three passenger coaches. The passenger service consists of local traffic, and a total of eight trains per day will be operated, four in each direction. The passenger cars will be lighted from the 600 volt circuit of the dynamotor and heated from the 2400 volt trolley circuit on the locomotive, using a 600 and 2400 volt train bus line.

Substations

There will be two 2400 volt substations exactly alike, one located at Butte and the other at Anaconda, 26 miles apart. Each substation will contain two 1000 kw. synchronous motor-generator sets, each set consisting of two 500 kw., 720 r.p.m., compound compensated commutating pole 1200 volt generators insulated for 2400 volts and operated two in series, and direct connected to a three-phase, 60 cycle, 2300 volt synchronous motor. Excitation will be supplied by two 50 kw. induction motor exciter sets. The 2400 volt motor-generator sets are guaranteed to stand an overload of 200 per cent. for five minutes without injury, and the service will require the operation of both sets most of the time. Power for the operation of the road will be obtained from the Great Falls Power Company, and will be transmitted at 102,000 volts, 60 cycles, from the water power stations of this Company. The substations will also contain the alternating and direct current switchboard panels, the direct current switchboard to follow the usual 1200 volt practice, with remote control circuit breakers and switches. An automatic voltage regulator will be installed in each substation to automatically maintain constant voltage at the terminals of the synchronous motors by means of change in excitation. Each feeder circuit and generator circuit will be protected by a 2400 volt direct current aluminum cell arrester consisting of ten jars.

A 4/0 trolley, with a special flexible 11-point catenary suspension, will be used for most of the lines, with direct suspension over some of the difficult sidings, smelter tracks, etc. Side-bracket and cross-span construction will be used to suit local conditions. There are a large number of yards to be electrified and at one point it will be necessary to span twelve tracks. This will be accomplished by cross-span construction, using a third pole between the eighth and ninth tracks. The overhead lines will be protected by 2400 volt direct current magnetic blow-out lightning arresters. The 4/0 trolley will be reinforced between the two substations with a 1,000,000 c.m. positive cable, and a 4/0 negative return feeder will be installed on the trolley poles. One 4/0 bond will be installed across each rail joint, with cross-bonds between rails every 1000 feet, and each of the cross-bonds will be connected to the negative feeder.

ESSAYS ON VOLTAGE REGULATION

Part II

By F. W. Shackelford

Supply Department, General Electric Company

Proceeding from a discussion in the July issue of generator voltage regulation and some of the principal points to be observed in laying out new systems of distribution or rebuilding old ones, the author this month takes up the question of voltage control on alternating current feeders by means of the automatic feeder voltage regulator. Seven arrangements of this regulator for feeder use are described, one for single-phase systems, four for three-phase systems, and two for quarter-phase systems; while the general usefulness of the regulator as a voltage balancer is well illustrated in the account of the tying-in of the Oakland station of the Great Western Paper Company with the Fulsom station of San Francisco.—Editor.

For the different systems of distribution feeder regulators must be applied in such a manner that while accomplishing the desired regulation they will not disturb or distort the voltage relations. It will therefore be in order to take up the subject of feeder regulation for the various distribution systems.

Automatic feeder regulators present so many advantages over hand regulation that practically all installations include this type, and for this reason we shall deal with automatic regulators in describing proper methods of regulation. In order to fully understand the control for an automatic regulator it will be necessary to briefly describe the contact-making voltmeter, which displaces the operator and regulates the voltage automatically.

This instrument, shown in Fig. 10, is composed of a solenoid with two windings, viz., a shunt winding which is connected in parallel with the secondary of a potential transformer, and a series winding, differential with respect to the shunt winding, which is connected in series with the secondary of a current transformer, the primary of which is in series with the feeder circuit. A movable core passes through the center of the solenoid, and to the top of this core is attached a pivoted lever. The lever carries at its other end a set of contacts which make contact with an upper and a lower stationary contact. The lever is set by means of a spring acting against the core, so that its contacts are midway between the upper and lower stationary contacts when normal voltage is on the shunt coil of the meter. The stationary contacts form, when closed, a circuit to one or the other of two coils of a relay switch, which in turn controls a motor on the regulator cover. Any deviation of voltage from normal causes contact to be made and the regulator corrects for this change, bringing the voltage back to normal. When compensating for line drop to a distant point the current coil is used, and as the load increases the regulator boosts the voltage by the proper amount. In this manner the meter can be set so that constant voltage can be maintained at a great distance from the regulator.

Single-Phase Feeders

Automatic regulation of single-phase feeders presents no difficulties, in that we have one definite point to regulate and the boost or buck of the regulator is directly added to or subtracted from the voltage of the feeder. If regulation at the station is desired, only a potential transformer is necessary; and if regulation for compensation of drop at some distant point is desired, a current transformer in series with the feeder is added to the equipment.

Three-Phase Feeders

Case I. It is often the case that one phase of a three-phase feeder contains all of the lighting load, and it is satisfactory to use one single-phase regulator on this phase. In making such an installation, however, it should be noted that the regulator has its secondary winding in series with the line,

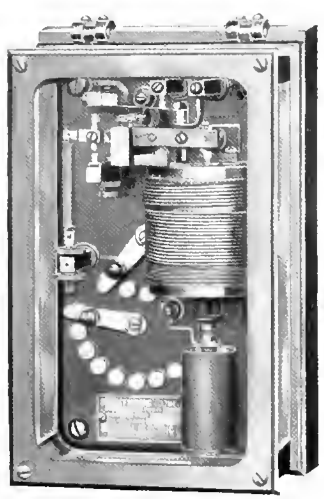


Fig. 10. Contact-making Voltmeter for Automatically Operated Regulators

while its primary is connected across the phase. This is shown in Fig. 11. The triangle $A\ B\ C$ represents the supply voltage, the secondary of the regulator being in A, and its primary across BA. At unity power-factor the line current AE, and consequently the series transformer current, is displaced 30 degrees from the phase voltage AB. If the load on this feeder is purely lighting,

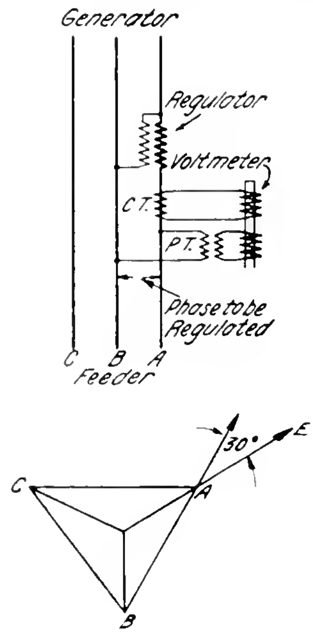


Fig. 11

in which case the power-factor would remain constant and approximately unity, the regulation will be satisfactory. Should the power-factor vary considerably, however, it may cause the current to be out of phase with the voltage to such an extent that satisfactory compensation could not be obtained. While in general a single current transformer would be satisfactory, it would be better to eliminate the possibility of unbalanced currents by using two current transformers cross-connected, one in series with each leg of the phase across which the primary of the regulator is excited. If it is desired to compensate for both ohmic and reactive drop, a line drop compensator should be connected in the circuit, as shown in Fig. 12. With this connection the line drop compensator is set to compensate for ohmic and inductive drop to the load center and the voltage will automatically be maintained at the desired value irrespective of changes in load or power-factor.

Case II. Where lighting is connected on only two phases of a three-phase system, and motors are connected to the same feeders, it is best to use two regulators and three current transformers, one transformer in each leg, connected as in Fig. 13. If the current transformer in the middle leg were not installed, proper compensation could not be secured, owing to both phase displacement and any unbalancing of current in the three phases.

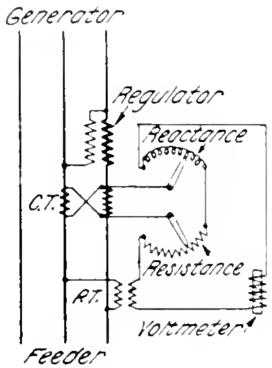


Fig. 12

Case III. Where lighting and power are connected to all three phases of a three-phase feeder, three single-phase regulators may be employed. It is then possible to adjust each phase independently of the others and establish a constant voltage at the load center of each. . It is best to use three regulators where there are chances of unbalancing, which is very apt to happen when lighting and power are combined. If a three-phase regulator were used, it is no doubt better to use two current transformers cross-connected, so as to get an average of unbalanced current. The connections of the three single-phase regulators should be made as in Fig. 14.

Case IV. Three-phase, four-wire feeders are in general use, the fourth wire being grounded. For such systems it is usual to employ three single-phase regulators having their secondaries connected in series with a phase wire and their primaries excited from phase wire to neutral. The best of regulation can be obtained by using this method, as it is practically equivalent to three independent single-phase feeders.

Two-Phase Feeders

Two-phase systems may be three or four-wire. If lighting is connected on both phases, the system may be regarded as two single-phase feeders and single-phase regulators used on each phase. In some cases the motor load is two-phase, while the lighting load is connected across the outside legs, the system being three-wire. One regulator can be made to control the lighting voltage if a slight distortion of the other voltages is not objectionable. If the voltage distortion

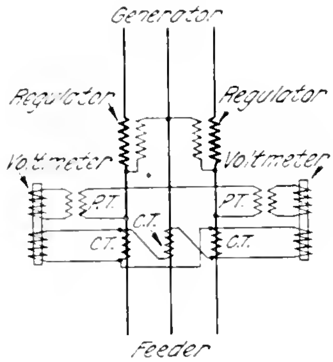


Fig. 13

is objectionable, two regulators had best be used, thus giving equal voltage between the neutral and each outside leg.

Special Methods of Regulation

Many departures from the above schemes exist and there are many ways in which regulators can be adapted to suit special conditions. Interconnected transmission systems find regulators useful in maintaining

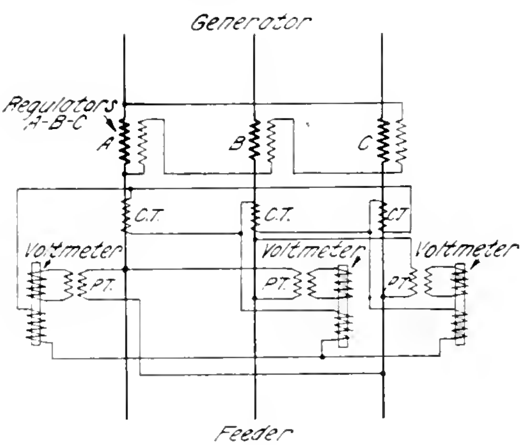


Fig. 14

constant voltage on the busbars of the substations, such an arrangement making a very flexible system and providing a means of keeping the substation bus at the same voltage as that of the generator station.

One example of the tying-in of two stations by means of feeder regulators is afforded by the connection of the Oakland station of the Great Western Power Company with the Fulsom station of San Francisco, through a three-phase submarine cable laid across San Francisco Bay. The conditions of operation were as follows:

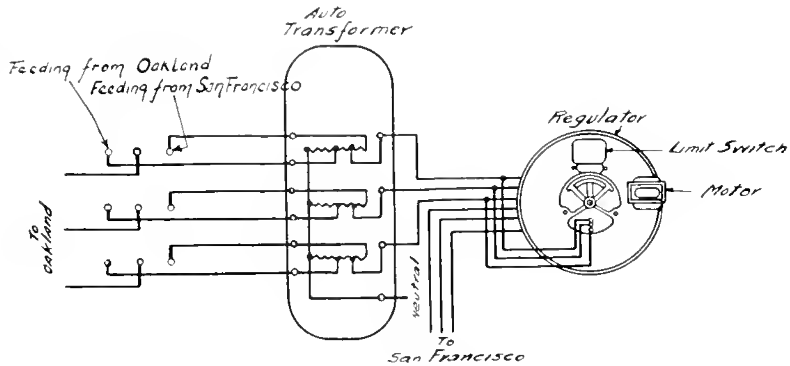


Fig. 15

Under normal operation power was delivered from the Oakland station at 9500 volts, 300 amperes, to the Fulsom station. The voltage at the Fulsom station under operating conditions was from 12,000 to 10,500 volts, while the voltage at the Oakland station was 12,000 volts, the drop in the Bay cable being approximately 2500 volts. Under emergency conditions it was desired to deliver power from San Francisco to Oakland, and as the bus voltages of the two stations differed considerably, the following scheme was adopted for effecting both combinations.

A three-phase induction regulator and a double wound auto-transformer were placed in the Fulsom station, San Francisco, the connections of the combination being shown in Fig. 15, and the connections of the automatic regulator in Fig. 16. The voltage delivered to the auto-transformer was 9500, this transformer boosting it to 10750 volts. The voltage at the regulator was therefore required to be boosted by the regulator before the lines could be tied to the busbars of the Fulsom station. Ordinarily, the outgoing voltage from the regulator was 11,500, this being the normal operating voltage of the Fulsom station. The regulator was set to automatically maintain the desired voltage at San Francisco.

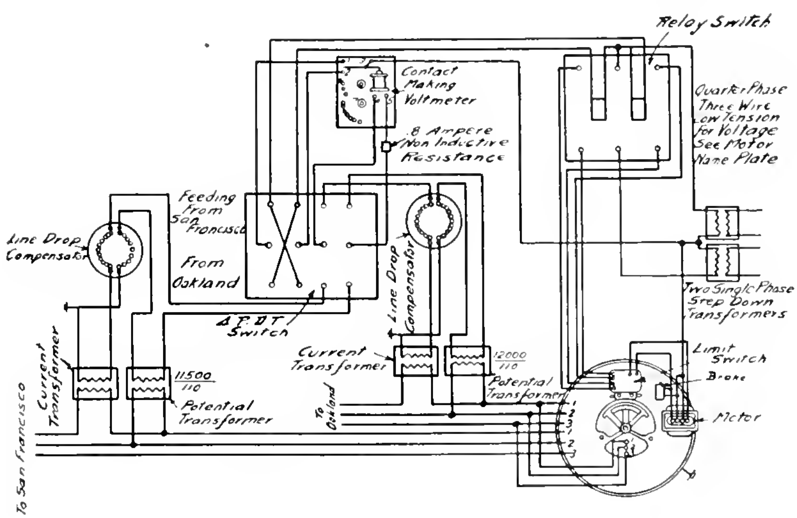


Fig. 16

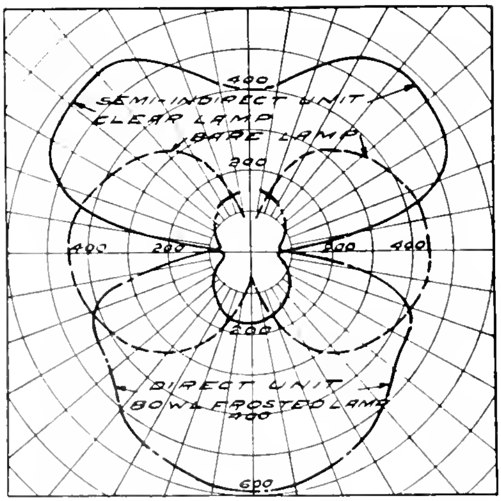
In case the source of power at Oakland should fail for any reason, the direction of current would be reversed and power would enter the regulator at 10,500 volts, because the Fulsom station takes power from the City Electric Co. lines, there being a material drop in the lines between the generator station and Fulsom substation. When this condition takes place the connections to the contact-making voltmeter are reversed by means of a four-pole double-throw switch shown in Fig. 16; and at the same time the other section of the auto-transformer is connected, so that 12,000 volts will be maintained on the bus at Oakland. Current at 10,500 volts is delivered to the regulator, where it is boosted by 1500 volts to 12,000, and the compensator adds 1200 volts; so that 13,200 volts is impressed on the submarine cable at San Francisco and proper voltage delivered at Oakland. The submarine cable then acts as a feeder from San Francisco, inasmuch as all sources of power at Oakland are inoperative.

A CONVERTIBLE MAZDA LIGHTING UNIT

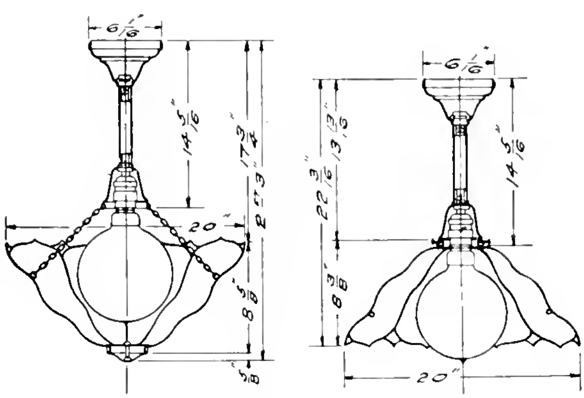
The convertible tungsten unit illustrated on these pages represents a new factor in the lighting field. The curves show that it has the widest angle of distribution and is the most efficient of any semi-indirect lighting unit so far devised. When converted to a direct lighting fixture it is also unsurpassed in efficiency and characteristics for a large light distributer. The small unit is for 150 and 250-watt Mazda lamps, and the large for 400 and 500-watt Mazda lamps. The new units possess the advantage particularly important in store lighting, of toning the light at relative maximum whiteness. This is due to the quality of the glass, the production of which is the result of over three years work. The shades are made in leaded glass sections put together with an extra heavy metal binding. The flat effect

Semi-indirect Monolux Unit, 500 Watt Lamp

Direct Monolux Unit, 500 Watt Lamp



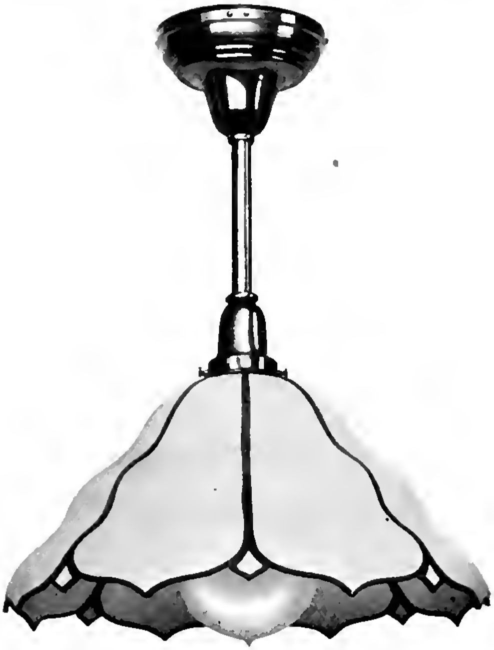
Photometric Curves for 500 Watt Units, giving average apparent candle-power in a vertical plane



Dimension Sketches of 500 Watt Units
Direct and Semi-indirect

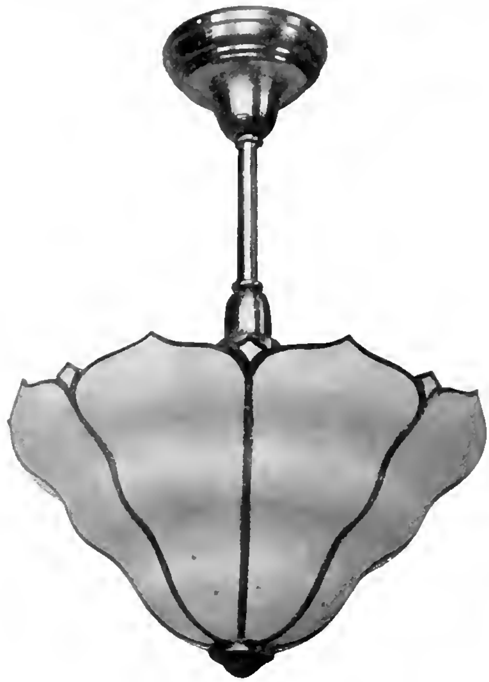
so noticeable in totally indirect lighting is eliminated and the line of demarcation which usually appears on the walls is overcome by gradation.

These convertible units are wired in two parts and can be quickly assembled, or converted from semi-indirect to direct, by disconnecting the chains



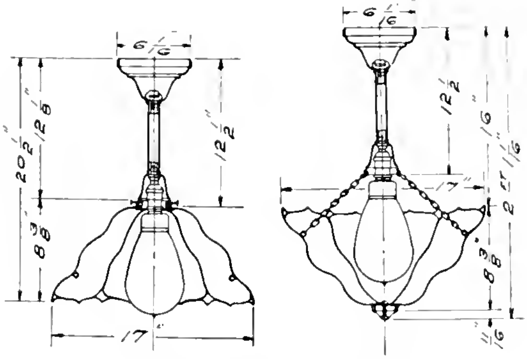
250 Watt Unit, Direct

and removing the shade cap. The change can be made in about five minutes. The advantage of this interchangeable feature is noticeable in cases where a consumer would like to try semi-indirect lighting, but is prevented from doing so by the fear that if it does not come up to his expectations he cannot revert to direct lighting without considerable expense. It frequently happens that in large office buildings some tenants prefer a semi-indirect system, while others are accustomed to and favor the direct lighting. With the convertible unit the tenant can change the lighting to accommodate his preference,

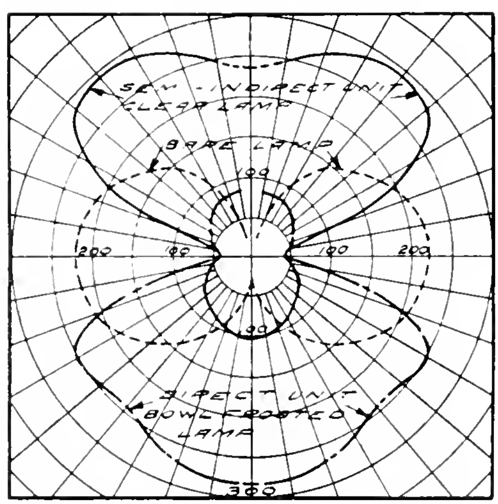


250 Watt Unit, Semi-indirect

without demanding a radical change in fixtures and without the ultimate result of introducing mixed units into the building. When used as direct units the lamps should be half-frosted. When used semi-indirect either half-frosted or clear lamps may be employed although the latter is preferable.



Dimension Sketches of 250 Watt Units
Direct and Semi-indirect



Photometric Curves for 250 Watt Units, giving average apparent candle-power in a vertical plane

ADVANCED COURSE IN ELECTRICAL ENGINEERING

Part IV

By Ernst J. Berg

Professor of Electrical Engineering, University of Illinois

Two Coils of Perfect Mutual Inductance Connected to Sources of Constant e.m.f. E and E_1

Let r,r_1 and L,L_1 be the resistances and inductances respectively,, and assume that the circuits are closed at the same instant. Assume first that the coils are connected in the same direction, that is, in such a way that the permanent current in both coils will produce magnetic fields of the same polarity. It is evident that in this case the impressed e.m.f. has to overcome not only the resistance and inductance drop due to the current in the coil, but also the e.m.f. which by transformer action is induced in one coil by the change of current in the other.

Consider one coil alone, for instance the second coil: The counter e.m.f. of this coil is $-L_1\frac{di_1}{dt}$. If it has N_1 turns, the voltage per turn is $-\frac{L_1}{N_1}\frac{di_1}{dt}$. Since it has been assumed that there is no leakage field between the two coils, it is evident that this same voltage per turn is induced in the first coil by the current in the second. Thus the "transformer" e.m.f. in the first coil having N turns is $-\frac{N}{N_1}L_1\frac{di_1}{dt}$, and similarly the transformer e.m.f. in the second coil by the current in the first is

$$-\frac{N_1}{N}L\frac{di}{dt}.$$

But

$$\frac{N}{N_1}=\sqrt{\frac{L}{L_1}};$$

therefore the e.m.f. in the first coil caused by the mutual flux is

$$-\sqrt{\frac{L}{L_1}}L_1\frac{di_1}{dt}=-\sqrt{LL_1}\frac{di_1}{dt}.$$

Thus it is seen how, when the mutual inductance usually denoted by M is perfect, $M=\sqrt{LL_1}$. In reality M is always smaller than $\sqrt{LL_1}$. Remembering that the general equation deals with e.m.f's consumed by resistance, inductance and mutual inductance, we have:

$$E=ir+L\frac{di}{dt}+M\frac{di_1}{dt} \qquad (53)$$

and

$$E_1=i_1r_1+L_1\frac{di_1}{dt}+M\frac{di}{dt} \qquad (54)$$

Equation 55 is obtained by multiplying 53 by L_1 and 54 by $-M$ and adding the equations so obtained.
It is:

$$L_1E-ME_1=L_1\,ir+LL_1\frac{di}{dt}$$
$$-Mi_1r-M^2\frac{di}{dt} \qquad (55)$$

Since with perfect mutual inductance

$$M^2=LL_1 \qquad (56)$$

$$i_1=\frac{L_1\,ir-L_1E+ME_1}{Mr_1} \qquad (57)$$

$$\therefore \frac{di_1}{dt}=\frac{L_1r}{Mr_1}\frac{di}{dt}.$$

Substituting this in equation 53:

$$E=ir+L\frac{di}{dt}+L_1\frac{r}{r_1}\frac{di}{dt}$$
$$=ir+\frac{L_1r_1+L_1r}{r_1}\frac{di}{dt} \qquad (58)$$

or

$$\frac{di}{dt}+\frac{rr_1}{Lr_1+L_1r}i=\frac{Er_1}{Lr_1+L_1r}.$$

Referring to equation 4,

$$i=\frac{E}{r}+C\epsilon^{-\frac{rr_1}{Lr_1+L_1r}t} \qquad (59)$$

To determine the integration constant C, it would be a mistake to assume that the current i is zero when $t=0$. All that is known is that the combined coil cannot be surrounded instantaneously by a flux—it takes some time to produce or alter a magnetic field, because energy is involved. It is possible that currents will flow the very first instant, currents which produce m.m.f's of equal magnitude but in opposite direction. One particular case of this would be where the currents were zero, but this is not a likely solution.

What is known, then, is that no flux will exist the first instant. Thus the m.m.f's must be equal and opposite, and since the cross section of the magnetic flux and the direction of the turns is assumed the same in both coils, it follows that for

$$t=o,\ iN=-i_1N_1$$

or

$$i_1=-\frac{N}{N_1}i=-i\sqrt{\frac{L}{L_1}} \qquad (60)$$

Substituting this value in equation 57:

$$-i\sqrt{\frac{L}{L_1}}=\frac{L_1ir-L_1E+ME_1}{Mr_1},$$

or

$$i=\frac{L_1E-ME_1}{Lr_1+L_1r} \qquad (61)$$

for $t=o$.

$$\frac{L_1E-ME_1}{Lr_1+L_1r}=\frac{E}{r}+C$$

$$\therefore C=-\frac{ME_1r+LEr_1}{r(Lr_1+L_1r)}$$

$$\therefore i=\frac{E}{r}-\frac{ME_1r+LEr_1}{r(Lr_1+L_1r)}\epsilon^{-\frac{rr_1}{Lr_1+L_1r}t} \qquad (62)$$

Similarly i_1 is found to be

$$i_1=\frac{E_1}{r_1}-\frac{MEr_1+L_1E_1r}{r_1(Lr_1+L_1r)}\epsilon^{-\frac{rr_1}{Lr_1+L_1r}t} \qquad (63)$$

Problem No. 7.

Prove by complete calculation that if the second coil is reversed the following are the equations of the currents

$$i=\frac{E}{r}-\frac{LEr_1-ME_1r}{r(Lr_1+L_1r)}\epsilon^{-\frac{rr_1}{Lr_1+L_1r}t} \qquad (64)$$

$$i_1=\frac{E_1}{r_1}-\frac{L_1E_1r-MEr_1}{r_1(Lr_1+L_1r)}\epsilon^{-\frac{rr_1}{Lr_1+L_1r}t} \qquad (65)$$

In the case that the two coils are excited from the same direct current busbars when $E=E_1$ the equations become:

For coils wound in the same direction:

$$i=\frac{E}{r}\left[1-\frac{Lr_1+Mr}{Lr_1+L_1r}\epsilon^{-\frac{rr_1}{Lr_1+L_1r}t}\right] \qquad (66)$$

$$i_1=\frac{E}{r_1}\left[1-\frac{L_1r+Mr_1}{Lr_1+L_1r}\epsilon^{-\frac{rr_1}{Lr_1+L_1r}t}\right] \qquad (67)$$

For coils wound in opposite direction:

$$i=\frac{E}{r}\left[1-\frac{Lr_1-Mr}{Lr_1+L_1r}\epsilon^{-\frac{rr_1}{Lr_1+L_1r}t}\right] \qquad (68)$$

$$i_1=\frac{E}{r_1}\left[1-\frac{L_1r-Mr_1}{Lr_1+L_1r}\epsilon^{-\frac{rr_1}{Lr_1+L_1r}t}\right] \qquad (69)$$

In Fig. 16 are given four curves showing the currents in two such coils of perfect mutual inductance, having the following constants:

$r\ =0.10$
$r_1=0.50$
$L\ =\ 2.5$
$L_1=10$
$E\ =E_1=10$ volts

It is assumed that they are connected in parallel to the same source of direct current, of a constant potential of 10 volts. The full drawn curves correspond to the condition in which the turns are in the same direction; the dotted curves to that in which the turns are in opposite directions. It is well to verify these curves by calculation. It is of interest to note from the full drawn curves that, while the two coils are connected to the same source of constant potential, during the first few seconds the currents actually flow in opposite direction. The *second* coil having twice as many turns as the *first*, and therefore a smaller final value of current, has a current of negative value at the first instant of one-half the magnitude of the current in the first coil. Eventually the currents become positive and are proportional inversely as the ohmic resistances.

It is of interest to deduce the equations of the currents in the two coils when the first is connected to a source of constant potential, and the second is short circuited upon itself, as shown diagrammatically in Fig. 17.

Prove that with the coils wound in the same direction:

$$i=\frac{E}{r}\left[1-\frac{Lr_1}{Lr_1+L_1r}\epsilon^{-\frac{rr_1}{Lr_1+L_1r}t}\right] \qquad (70)$$

$$i_1=-\frac{MEr}{r_1(Lr_1+L_1r)}\epsilon^{-\frac{rr_1}{Lr_1+L_1r}t} \qquad (71)$$

In Fig. 18, which gives the values of the currents, it is of interest to note that the current in the second coil, under this condition, remains negative and approaches the value zero. The initial values of the currents are twice as great as before. Thus the impedance is greatly reduced, as would be expected by the presence of the short circuited winding.

Prove that the heat dissipated in the short circuited coil is

$W = 5560$ joules.

Heretofore have been considered two coils having perfect mutual inductance, a case that is of theoretical interest only. When the mutual inductance $M < LL_1$, the problems become more complex and need for their solution linear differential equations of the second order. The general expression of such differential equations is

$$\frac{d^2y}{dx^2} + c\frac{dy}{dx} + ay = b \qquad (72)$$

where a, b and c are not functions of y but may or may not be functions of x.

In the problem referred to and indeed in almost all problems of importance, a, b and c are constants and are not functions of x. The solution then is:

$$y = \frac{b}{a} + A_1\epsilon^{m_1x} + A_2\epsilon^{m_2x} \qquad (73)$$

where A_1 and A_2 are integration constants and m_1 and m_2 the roots of the auxiliary equation:

$$m^2 + cm + a = o$$

$$\therefore m = -\frac{c}{2} \pm \sqrt{\frac{c^2}{4} - a} \qquad (74)$$

The roots might be real or complex, or the two roots might be equal:

1st $\quad \frac{c^2}{4} - a$ is positive

then

$$m_1 = -\left(\frac{c}{2} - \sqrt{\frac{c^2}{4} - a}\right) \qquad (75)$$

$$m_2 = -\left(\frac{c}{2} + \sqrt{\frac{c^2}{4} - a}\right) \qquad (76)$$

$$\therefore y = \frac{b}{a} + \epsilon^{-\frac{cx}{2}}$$

$$\left(A_1\epsilon^{-x\sqrt{\frac{c^2}{4}-a}} + A_2\epsilon^{+x\sqrt{\frac{c^2}{4}-a}}\right) \qquad (77)$$

2nd $\quad \frac{c^2}{4} - a$ is negative

then

$$m_1 = -\left(\frac{c}{2} - j\sqrt{a - \frac{c^2}{4}}\right) \qquad (78)$$

$$m_2 = -\left(\frac{c}{2} + j\sqrt{a - \frac{c^2}{4}}\right) \qquad (79)$$

$$\therefore y = \frac{b}{a} + \epsilon^{-\frac{cx}{2}}$$

$$\left[A_1\epsilon^{-jx\sqrt{a-\frac{c^2}{4}}} + A_2\epsilon^{+jx\sqrt{a-\frac{c^2}{4}}}\right]$$

which, by expanding sine and cosine functions and the exponential function ϵ^{jx}, can readily be proven to be equal to

$$y = \frac{b}{a} + A_1\epsilon^{-\frac{cx}{2}} sin\left(x\sqrt{a - \frac{c^2}{4}} + B\right) \qquad (80)$$

3rd $\quad \frac{c^2}{4} = a$

Then,

$$y = \frac{b}{a} + \left(A_1 + B_1x\right)\epsilon^{-\frac{cx}{2}} \qquad (81)$$

This last solution is not evident from the previous two, and therefore a short explanation is advisable. It is evident that when the square root becomes zero, $m_1 = m_2$. Thus one integration constant only is obtained, which shows that the solution is not general.

To get the general solution, assume that one of the roots is a very little larger than the other, that is,

$m_2 = m_1 + h$, where h is very small.

Then,

$$y = \frac{b}{a} + A_1\epsilon^{m_1x} + A_2\epsilon^{(m_1+h)x}$$

$$= \frac{b}{a} + A_1\epsilon^{m_1x} + A_2\epsilon^{m_1x}\epsilon^{hx}$$

$$= \frac{b}{a} + \epsilon^{m_1x}\left[A_1 + A_2\epsilon^{hx}\right]$$

but

$$\epsilon^{hx} = 1 + hx + \frac{h^2x^2}{L^2} + \;.\;.\;.\;.\;.$$

Since h is very small,

$$\epsilon^{hx} = 1 + hx$$

$$\therefore y = \frac{b}{a} + \epsilon^{m_1x}\left[A_1 + A_2 + A_2hx\right]$$

$$= \epsilon^{m_1x}\left(K + K_1x\right) + \frac{b}{a}.$$

(To be Continued)

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Dr. Ernst J. Berg

Dr. Berg is Professor of Electrical Engineering in the University of Illinois, and has for many years been a frequent contributor to the GENERAL ELECTRIC REVIEW. We are fortunate in having secured from him his series of papers on "An Advanced Course in Electrical Engineering," the publication of which was commenced in the March, 1912, number, and will extend probably through twelve issues in all. These papers are in the nature of an abstract of the lectures which Dr. Berg is delivering to the students of his graduate class. In addition to this month's instalment we are publishing on page 575 a further article by Dr. Berg on the "Potential Control of Alternating Current Systems using Synchronous Motors with Automatic Voltage Regulators."

GENERAL ELECTRIC REVIEW

FURTHER STUDY OF CORONA IN 1912

With such a powerful array of papers as was presented before the recent Boston Convention of the A.I.E.E., it was inevitable that limits of time should prevent the adequate discussion of all these contributions. A great many people have been deploring this; but at least we possess, in the volumes of the proceedings for the last few months, a wonderful collection of engineering papers ranging freely over nearly every phase of electrical engineering. If the discussion per paper had been increased, the number of papers would have been decreased in the same ratio; and since there can be no question as to the quality of the material presented, we should at least be thankful that we have in concrete form the views of so many of the leading engineers of the day.

On the whole it was fortunate that the discussion of high tension transmission matters had to bear no serious curtailment; since the three papers by Messrs. Harding, Whitehead and Peek were among the most important presented. Most of the interest centered around a point brought out in Mr. Peek's paper, which had first come to the author's notice in a lengthy stroboscopic study of corona. This is the interesting fact that the corona on positive and negative conductors of equal size is not the same. Of all the conclusions reached as the result of the mass of tests upon which the paper was based, probably the most important is this conclusion that the corona loss is apparently accompanied by conduction from the positive to the negative conductor, commencing always from the positive, first from one line and then from the other, once during every half-cycle. Dr. Steinmetz expressed the view that this condition tends to produce a unidirectional charge of the whole line relatively to earth; and, if this is so, it should be possible to raise the critical corona voltage by applying a unidirectional voltage of electrification of opposite polarity from line to earth.

This then opens up a further wide field for investigation. The subject is still of the greatest importance; and, in spite of the difficult work which has been performed in the last two or three years by Mr. Peek and others, virtually little is known of the real nature of corona. This knowledge is needed in further extending transmission development; and since the investigators in this field who possess at once sufficient knowledge of the subject and adequate appliances for prosecuting their studies are few, the publication of their data and conclusions will be watched with the closest interest by electrical engineers, and are sure to represent very important contributions to current electrical literature.

The next group of papers on this matter is not likely to be forthcoming until next summer's convention; but, amongst the general body of electrical men, there is certainly a demand for more lucid explanation of what is already known, and a general clearing up of several points of discussion. It may be remembered that Mr. Peek last year followed his Institute paper with a shorter essay in the November REVIEW, and we are hopeful that we shall shortly be able to give his views on the corona situation in 1912. This article will be based upon the results which he has himself obtained on the Schenectady model transmission line; and, apart from this, we are making efforts to secure a second article, which shall give a *resumé* of the Boston discussion, extract the essentials, and show in brief what is the full significance of the year's work. There are but few engineers capable of undertaking the task; but we expect to secure such a paper for publication in our December issue.

STEINMETZ AND HIS DISCOVERY OF THE HYSTERESIS LAW

By Douglas S. Martin

Extract from page 550: "Great and important as is the work which Dr. Steinmetz accomplished in later years and may still accomplish, there is a point of view from which it may be said that his chief claim to greatness rests upon the establishment of this fundamental law of magnetism, a law, which, it is true, was announced empirically and as yet rests only upon an empirical foundation, but which may at some time in the future be found to possess a real physical significance."

I

Little has ever been written of Steinmetz in a biographical way. Himself a prolific author, he has as yet failed to write about himself; and the average member of the electrical profession, while willing to accept a statement from Steinmetz as carrying almost a divine authority, knows little of the man and his career. Having regard to the time he has lived in Schenectady, he is known intimately to comparatively few men there. In the wider field of the Institute membership he is well-known by sight; and his contributions to the discussions, delivered always with an air of complete authority and with an entire absence of self-consciousness, have impressed (and even endeared him to) hundreds of others who may never have come into personal touch with him. Outside of these there are probably several thousands of students and designers who know him from his books; and there are still countless others who, careless of detail, think of him vaguely as the All-Wise man of the electrical profession.

This is certainly a wide circle of acquaintance; and it may be presumed that some papers setting out the salient facts of his life, his outstanding achievements, and his personal characteristics would be eagerly welcomed by as wide a circle of readers. At present no such task will be attempted; but, in order at least to pave the way for some such biography at a later date, it is logical, and should be of interest to many, to record something of Steinmetz's earlier work in this country during the time when, twenty years ago, he was laying the basis of a reputation which is enjoyed to-day by no other member of the profession. With the growth of this reputation it has become increasingly apparent that the science of applied electricity would have been a heavy loser had that slight inclination towards matters electrical been omitted from Steinmetz's composition. For he is as much mathematician as engineer, and as much physicist as mathematician; and he might so easily have decided to leave electricity alone. It is only by reflecting upon what he has since achieved, and the regard in which he is held by electrical men, whether they know him or not, that we can be sufficiently thankful for the chance which landed him, twenty-four years old, on these shores on the first of June, 1889; and the chance (it was little more) which led him into Eickemeyer's factory two weeks later.

II

His ship, *La Champagne*, docked one Saturday afternoon and put her cabin passengers ashore; while the hundreds in the steerage, among whom were Steinmetz and his friend Asmussen, were held on board like cattle till the next Monday—the "blue laws" still ruling New York—when they were passed ashore for inspection at Castle Garden, now the Aquarium, and the forerunner of the present Ellis Island. Steinmetz's earliest experiences of American hospitality were not happy. He could speak but little English; so little, in fact, that, when asked by an official whether he knew the language, he could only reply, "A few." His friend came to his rescue, not only with reinforcements for this uneven dialogue, but later when the matter of means of support was reached. As Dr. Steinmetz has related with considerable amusement, he neither possessed the ten dollars necessary for a safe landing, nor, in the opinion of the gathering officials, did he seem capable, to judge from his appearance, of earning such a sum if they let him land. The hour found the man forthcoming; and the friend, as we have said, was ready with the needful funds. The details were satisfactorily adjusted, and two weeks later Steinmetz presented his letter of introduction to Rudolf Eickemeyer at Yonkers. The element of chance probably was at work here, as there were other nebulous plans then in his head; but it may also be assumed that he was led to Eickemeyer in the belief that here would at least be work and opportunity for a man with some knowledge of electrical matters. Actually his knowledge was somewhat limited, at least so far as practice was concerned. He had never handled—hardly ever seen—even a direct current motor; and, although he had published in Switzerland an able paper on the design of transformers, the sight of one of them ("converters" as they were then called) had never been vouchsafed to him. Eickemeyer, who could judge his man, engaged him as assistant draftsman at twelve dollars a week.

We must here recall something of the man into whose service Steinmetz now entered, and the nature of the work in which he engaged; since, apart from the extent to which the electrical industry as a whole is indebted to him for pioneer work in the design of alternating current machines, Steinmetz himself owes much to the inspiration which he drew from close contact with the older man in his researches on magnetic materials. Well as Eickemeyer's name is known amongst electrical engineers, his work in this field was in reality no more than incidental to the main work of his life. Hat-making may sound an unromantic calling; but in the middle of last century, when the crude and wasteful methods of hand production represented a condition which was crying for a man who could produce automatic apparatus, the hat business as a vocation was full of attraction for a man with imagination and the ability to invent. Eickemeyer possessed both; and they enabled him to revolutionize the then prevailing practice in the hat-making industry both in America and abroad. During the intervening years many other mechanical matters had engaged his attention; and during the civil war the manufacture of revolvers and other fire-arms was maintained as a regular part of the Yonkers business.

Fig. 1. Neperhan Street, Yonkers, N. Y. The Westchester Storage Company (on right) now occupy the three floors of what was twenty years ago the Eickemeyer factory building. To the left of this (second floor), between the storage premises and the Newsdealer's, can be seen the outside of the room in which Dr. Steinmetz carried out his magnetic researches in 1891, 1892 and 1893.

*"He had always followed in a general way the various advances in the sciences, taking great interest in electricity; and when the Bell telephone was brought out, having more time and means at his disposal than he had previously enjoyed, he took up electricity as a study for his leisure rather than with a view

* Extract from an article in the *Electrical Engineer* for December 17, 1890, a biographical sketch of Rudolf Eickemeyer.

to applying it in a practical way. Experimenting with various forms of telephones, he became familiar with the peculiarities of different forms of electromagnets; and from their use in telephones to the construction of dynamos was but a step. The celebrated ironclad dynamos and motors known as the "Eickemeyer" were the first attempt on his part to put to practical use the results of electrical studies and investigations extending over a space of nearly ten years. They have proved very satisfactory........The Eickemeyer motors have also been applied to electric railway work, and found highly efficient......The question of the best material to be used in the construction of dynamos caused Eickemeyer to set to work to get some instrument which would enable him to determine readily the relative values, magnetically, of various qualities of iron and steel; and the result was a magnetic bridge, by means of which the magnetic value of the material can be told as readily as a loaf of bread is weighed on the scales of a bakery. The instrument has proved a complete magnetic laboratory in itself, and by its use Mr. Eickemeyer has been able to determine many questions in the construction of electric devices, which, without it, would have been difficult and expensive experiments."

We make this extract to show that at this time there was therefore considerable variety in the work going on in the Eickemeyer building, hat-making machinery, traction motors, elevator motors, and special electrical testing, including these experiments with the magnetometer, all going to make up the day's work. The draftsman held himself in readiness at all times to apply himself to the solution of problems in any one of these various directions. For eight or nine months Steinmetz worked in the drafting room, and it was probably about March of 1890 that he began to specialize on magnetic testing. For the purpose of carrying out this work on a larger scale and in a more thorough manner, Eickemeyer then leased a room adjoining his existing factory and in which the testing equipment became installed. In Fig. 1 the outside of this additional room can be seen. On the right are the 3 floors of the old Eickemeyer factory, now occupied by the Westchester Storage Company. The laboratory is on the second floor immediately

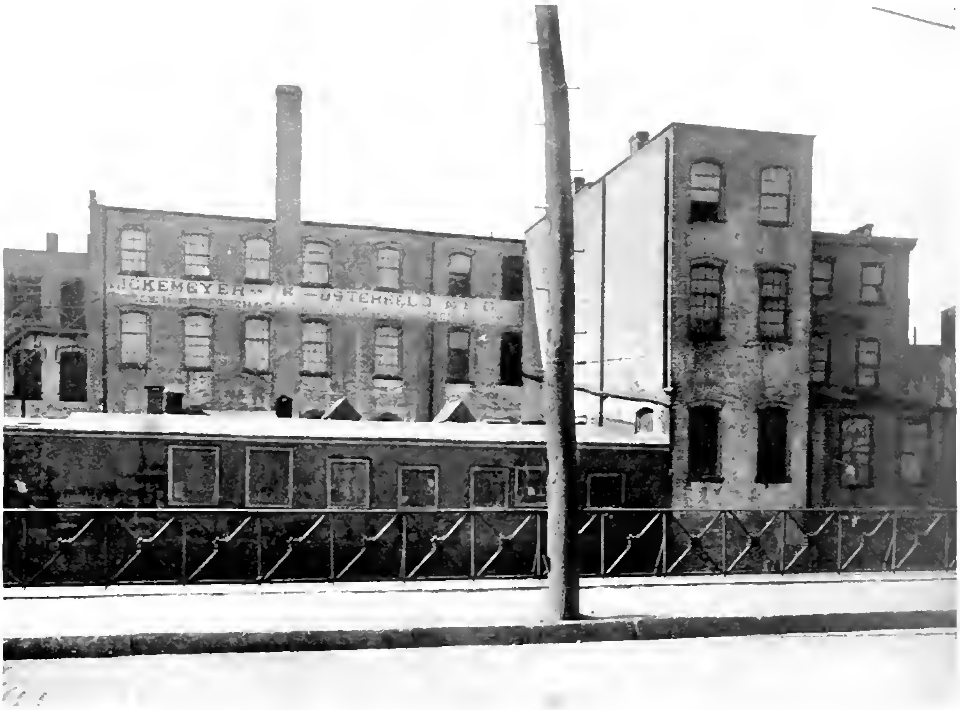


Fig. 2. Rear view of Eickemeyer and Osterheld factory building as it appears to-day. The back of the laboratory building is seen on the extreme right.

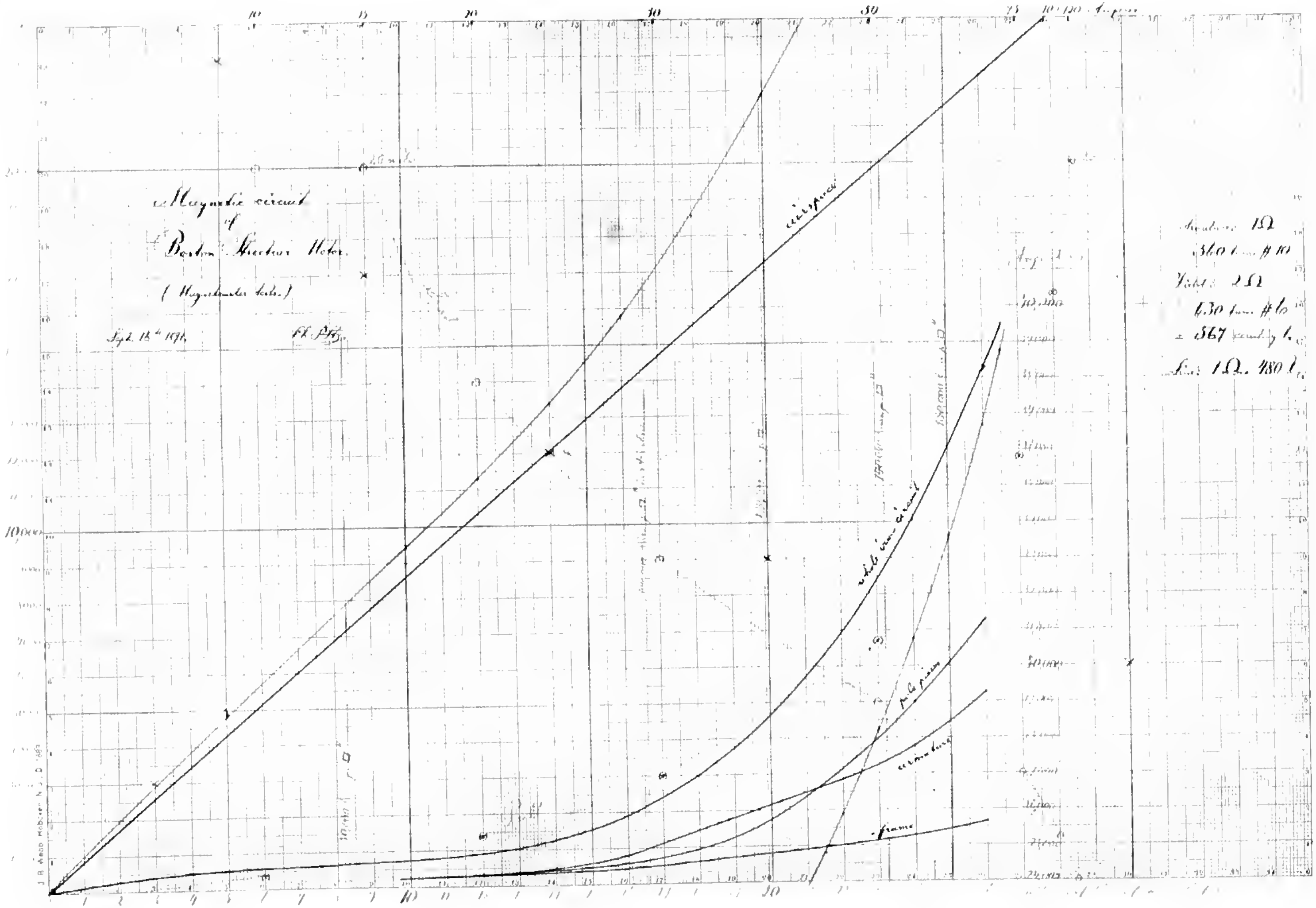
to the left, between the storage building and the Newsdealer's. Below it is a machinist's shop (Skinner & Connolly), still under the same management as twenty years ago, and apparently little changed. Fig. 2 shows a rear view of these buildings. Although the Eickemeyer Company was bought up at the end of 1892 the name "Eickemeyer and Osterheld" is still standing on the rear walls, as can be seen in this photograph. The laboratory building in this illustration is to be seen on the extreme right. The laboratory itself is about 20 feet wide by 30 feet long, and at the present time shows little signs of its use twenty years ago as a magnetic research room. On a recent visit to Yonkers the only piece of equipment which Dr. Steinmetz could trace as having held its place unchanged since his time was a very rusty wash-hand-stand in a corner of the room by the window. The laboratory (as it then was) is located on Neperhan Street, Yonkers, and the passenger to New York can easily see the building today as his train passes through Yonkers station on the New York Central line.

Steinmetz was placed in charge of the new laboratory. His assistant, a man skilled in the hat machinery business, was liable to be called out at a moment's notice to investigate and remedy troubles in the machines used in hat-making. Work in the remainder of the plant proceeded as before. Eickemeyer himself was the driving power in the factory; and it would appear that, during times when ill-health kept him to his house, little work was done there. His arrival at the place was always the signal for the very closest attention to the work in hand. The office staff first went through the mill. Eickemeyer was a disciplinarian. There was a right way and a wrong way for everything. It was usually found that the office staff had unwisely chosen the wrong way. The factory came next. This took longer, but here again most things usually were wrong. Finally came the testing laboratory and the man in charge. The relations were quite different. Eickemeyer would sit down and talk with Steinmetz by the hour. When we remember that, whatever their actual experience in the field of applied electricity, here were two of the most capable minds which that science has yet known, it may be judged that these were illuminating conversations; and the present-day engineer would be prepared to give much for a record of them, if such had been preserved. These laboratory consultations were conducted with probably no more formality than was observed when the men met outside the factory. Steinmetz and Eickemeyer were a great deal together, and both had this matter of the magnetic qualities of iron greatly at heart. The subject, it may readily be imagined, was therefore constantly under discussion; and the speculation, occasioned by some result which may have been found during the week's testing, was allowed full scope in the meeting on the following Sunday afternoon, which Steinmetz soon fell into the way of habitually spending at the big Eickemeyer house on the hill. He was living meanwhile with Edward Müller, his predecessor in the drafting room, and at this time the senior draftsman to the factory.

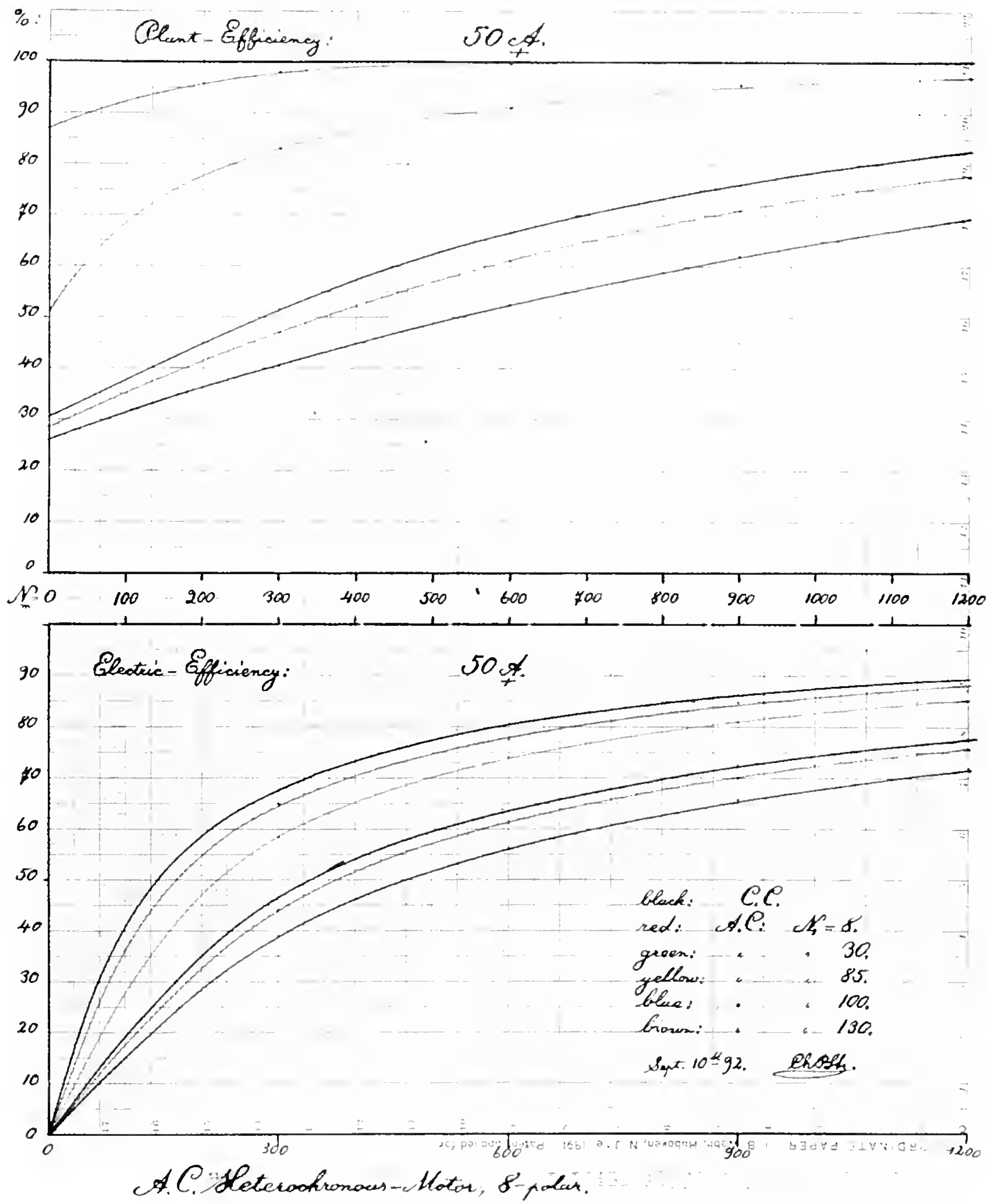
III

It was about this time that the want of a more thorough understanding of the magnetic properties of iron was felt by alternating current designers very acutely. They all of course had access to the published tables of Ewing, but these left off at the very point where a designer of a commercial machine might have found them useful. Thus, we may find a table showing the relation between the density *B* and the ergs lost per cycle in a piano steel wire, or calculated from this, the horsepower loss per ton at 100 cycles per second; all of which showed that there were iron losses which had to be allowed for, but failed to give the designer hard facts on the subdivision of such loss into eddy current and hysteresis for a known standard, and the variation in lost watts which he must expect from changing his material, his frequency or his density. Nowadays the station engineer who requires a new generator specifies the rating which he needs, and the manufacturer supplies a machine exactly to give that rating, predicting its performance within very small limits. Twenty-five years ago things were different; and while the magnetic circuit, so far as it related to direct current machines, was clearly understood and had been treated in a book by Gisbert Kapp published in 1886, the design of many lines of alternating current machines which subsequently became standard were based virtually upon a cut-and-try procedure.

Steinmetz and Eickemeyer were now (late summer, 1890) engaged on the design of the single-phase commutator motor with compen-



The above is a reproduction of some early curves plotted by Dr. Steinmetz in September, 1891. Probably the Institute paper was at this time in preparation. The curves relate to the magnetic circuit of a street-car series motor which had been built at the Eickemeyer factory for Boston. The curves, it will be seen, are calculated for various parts of the magnetic circuit, using the formula in which the exponent of B, the density, had recently been derived by Steinmetz. The curves also include the calculated speed and torque characteristics.



The above is a reproduction of efficiency curves of an 8-pole single-phase motor, plotted by Dr. Steinmetz in September, 1892. This, it will be noted, is about the time of the second half of his Institute paper. The curves plotted represent one of the earliest instances of deriving the characteristics of an alternating current motor by the segregation-of-losses method. The iron loss used in these calculations was derived from a density-loss curve, calculated from the formula in which the newly-derived exponent of *B* was introduced. The expression "plant efficiency" is the early name for what is now called "power-factor."

sated armature winding (Eickemeyer's best-known contribution to the electric storehouse). Both men realized the limitations placed upon them by this "groping in the dark." Steinmetz took all of Ewing's results which he could lay hands on and subjected them to a very critical examination. He probably suspected that he would find an exponent connecting B with the watts lost, and discover "that law of nature which gives the dependence of the hysteresis upon the magnetization.*. . . In trying to find at least a clue to this law I subjected a very complete set of Ewing's observations on the hysteretic energy made on a soft iron wire, consisting of ten tests from a magnetization of 1974 lines of magnetic force per square centimeter up to 15560 lines per square centimeter, and to analytical treatment by the method of least squares, in order to ascertain whether the losses due to hysteresis are proportional at all to any power of the magnetization, and which power this is. The results of this calculation seemed to me interesting enough to publish, in so far as all these observations fit very closely the calculated curve within the errors of observation; and the exponent of the power was so very nearly 1.6 that I could substitute 1.6 for it and combine those observations of Ewing's in the formula

$$H = .002 \times B^{1.6}$$

where H is the loss due to hysteresis in ergs per cu. cent. ($= 10^{-7}$ watt seconds) per cycle, and B is the maximum magnetization (number of lines of magnetic force per square centimeter). . . ." Great and important as is the work which Dr. Steinmetz accomplished in later years and may st ll accomplish, there is a point of view from wh'ch it may be said that his chief claim to greatness rests upon the establishment of this fundamental law of magnetism, a law, which, it is true, was announced empirically and as yet rests only upon an empirical foundation, but which may at some time in the future be found to possess a real physical s'gnificance.

This investigation took Steinmetz through the summer and fall of 1890; and by the time his article appeared he was already at work on hysteresis tests in the Yonkers laboratory, much more complete than any which had been made up to that time, carried out on any and every sample of iron which could be obtained, and employing what seems to us the crudest power plant and testing outfit. They were nevertheless to be massed into the paper before the Institute which was to establish his growing reputation upon a permanent and unassailable basis. This paper was divided into two parts, the first being presented on the 19th of January, 1892, 13 months after the appearance of Steinmetz's first article in the *Electrical Engineer*, and the second on the 27th of September of the same year. The first paper occupies some 48 pages of the Institute *Proceedings*, while the second with its appendixes runs to no fewer than 130; in addition to which the author contributes a lengthy written supplement to the discussion.

"Let us, in a few words, try to outline some of the facts which we learn here for the first time.† About two years ago Mr. Steinmetz first drew attention to the fact, then unnoticed, that when you magnetize a piece of iron between a certain terminal negative value and a corresponding terminal positive value—say, 5000 C.G.S. lines per sq. cm. in one direction and 5000 in the other direction—the area of the enclosed Ewing loop or the hysteretic energy which has been given to the iron was a certain definite function of the maximum magnetization, namely, it varied as $B^{\frac{8}{5}}$, where B was the maximum value. That in itself was a discovery, but it was found to agree with results which had already been obtained. Ewing's own curves supplied that law. But no one would have supposed at first sight, that if you took a piece of iron and magnetized it from 5000 lines positive to zero and back, or from 5000 lines positive to 2000 lines positive and back, you would still have the same law within that limited range. Mr. Steinmetz has shown us that it does follow even in that case. The loop itself is not the same; but the new loop, under those conditions, still retains between these values the law of the $\frac{8}{5}$*th* power."

The papers are on file in the *Proceedings*, and no attempt will be made to summarize them here. In them may be found detailed particulars as to the method of making the tests, the apparatus employed, and the results and conclusions obtained.

President Frank Sprague, in introducing Steinmetz to the Institute for the presentation of the second part of his hysteresis paper

* See *Electrical Engineer* December 17, 1890, page 677. "Note on the Law of Hysteresis," by C. P. Steinmetz.

† Discussion September 27, 1892, by Dr. A. E. Kennelly. At the present time not the least valuable of Dr. Steinmetz's contributions to Institute business is his readiness to rise in his place after an intricate theoretical paper has been presented, and, in a few clean-cut phrases, to put before his audience the substance and the practical bearing of many pages of theory. In the present instance we find Dr. Kennelly summing up in a few words the essential facts of these two papers of Steinmetz—a valuable service, since few engineers at that time had had sufficient practical experience in handling magnetic materials to enable them to arrive quickly at the substance of a 200-page paper on the subject.

(September, 1892) adverts to the reputation which the author had already obtained in this line of research. "His work in the past has been most important in its character, and this paper will fully support the reputation he has already earned." We have seen that by this time Steinmetz had been less than three years in the United States, and that his published pronouncements on hysteretic phenomena had been restricted to a short article in the *Electrical Engineer* and a single paper before the Institute. An explanation for this sudden burst into fame, however, is provided in the fact that any engineer engaged in the design of electrical machines found his principal difficulties in the magnetic circuit, had practically no data upon which to work, and was more than ready to lend an ear to any expression of serious opinion. It is certain that during this year of 1901, in which the Yonkers experiments were being carried out, many of Eickemeyer's friends, who were then leaders in the electrical field, visited the laboratory as a matter of personal interest; in addition to which a considerable amount of private testing work on various samples of iron was made for outside manufacturers. The results which are given in the Institute paper therefore probably represent only a very small portion of the mass of tests which were carried out during this fruitful period. Of those which are recorded there the first relates to hysteresis tests on the iron circuit of a Westinghouse converter (transformer); a second relates to a magnetic circuit built up of well-insulated layers of very thin sheet iron; a third to a sample of cast steel, annealed and hardened; and others to soft machine steel, cast iron, and some specimens of magnetic iron ore. An accurate idea, however, of the scope of these researches can only be obtained from a careful perusal of the two papers referred to, published in Vol. IX of the A. I. E. E. *Proceedings*.

IV

How was the paper received? Did the audience realize that this was real pioneer work, and represented probably the weightiest contribution to electrical engineering in the line of original research which had been made for many years? To judge from the discussion which followed the paper, it would seem that it was just a little over the heads of most of the electrical men of the day. Those who could understand accorded it whole-hearted applause. We make the following extracts:—

Editorial from the *Electrical Engineer* of January 27, 1892, Vol. XIII. "The American Institute of Electrical Engineers has been the medium for bringing out not a few papers of scientific interest and practical importance; but we believe that none of more absorbing interest and practical utility has been presented to the Institute than that of Mr. Charles P. Steinmetz last week on the Law of Hysteresis."

Editorial from the *Electrical Engineer* of October 19, 1892. "In his previous work Mr. Steinmetz had already given a glimpse of the direction in which he was working.... The importance of his latest work is still further enhanced by the reduction and explanation of all the various phenomena of the magnetic circuit by the aid of only three constants, viz. α the coefficient of magnetic hardness; σ the coefficient of magnetic saturation; and η the coefficient of magnetic hysteresis. He thus finally brings the magnetic circuit within the reach of analytical treatment, in the same way that the electrical circuit has been mastered by Ohm's law.... He holds out to us the hope of our obtaining a full understanding of the phenomenon of magnetism in the near future."

Dr. A. E. Kennelly in discussion on Steinmetz's paper of September 27, 1892. "I think it will be unnecessary for me to express the general and very high opinion in which we hold the paper to which we have just listened. It is a classic to us, and I think it will be a classic to a great many more than ourselves. The Institute may well congratulate itself upon this paper having been read before it."

Mr. William Stanley in discussion of Steinmetz's paper of September 27, 1892. "It seems to me that Mr. Steinmetz has done for the magnetic circuit very much what Ohm did for the electric circuit. He has defined the law relating loss of energy to flux. To the constructing engineer working with the alternating current appliances of to-day the paper affords more assistance than anything we have ever listened to."

Dr. Charles E. Emery in discussion of Steinmetz's paper of September 27, 1892. "This paper has evidently required an enormous amount of earnest work. It is a very notable example of successful experimental investigation, for which, as well as the clear and complete manner in which the subject has been examined and presented, the author is to be indeed congratulated."

TRANSFORMER CONNECTIONS FOR THREE-PHASE TO TWO-PHASE TRANSFORMATION

By Louis F. Blume

Transformer Engineering Department, General Electric Company

This article makes an analysis of various schemes in use for transforming electrical energy from three-phase to two-phase circuits. The author divides the thirteen schemes into five main groups, according to the potential relation existing between the two-phase windings. A table is given in which the schemes are compared on a basis of internal power-factor for unity power-factor load; and the connections of each scheme, with voltage and normal current for each winding are shown diagrammatically. The discussion considers the relative merits and demerits of the different styles of connection as regards internal power-factor, voltage symmetry, etc.; while a number of diagrams are shown from which it is explained how the various schemes may be compared on the basis of the interlacing required to secure good regulation.—Editor.

Before the invention of the three-phase to two-phase transformer, two distinct electrical systems were being developed for the distribution of polyphase power. In Europe, about 1890, the three-phase induction motor was being introduced, and at the same time the two-phase induction motor was being exploited in the United States. Considerable competition grew up between advocates of the two systems, because it was believed at that time that the one excluded the other, and that a company once adopting the two-phase system would be prevented from using any machinery or apparatus built for the three-phase system. When, however, it was demonstrated how simply power could be transformed from one system to the other, with very little loss in energy, the controversy dropped almost in a day. A number of schemes for three-phase to two-phase transformation have been devised, and it is the purpose of this paper to analyze several of these schemes and to compare their relative advantages. In the analyses of connections for this transformation the effects of losses, leakage reactance and magnetizing current on the voltages and currents are neglected. The following generalizations then apply:—

1—Transformation from three-phase to two-phase or the reverse cannot affect the power-factor of the system. In other words, the power-factor on the two-phase side is equal to the power-factor on the three-phase side.

2—The average power-factor within the windings (internal power-factor) of three-phase to two-phase transformers is generally less than, and cannot be greater, than the power-factor of the load.

In the accompanying table is given the internal power-factor, based on unity power-factor load, for the two-phase side and three-phase side, as well as the average for various schemes of transformation. Accompanying this is a set of diagrams which show the actual connections for each scheme, together with the voltage and normal current for each winding. These are worked out on the assumption of a transformation of balanced power equal to $2EI$ from a three-phase line voltage E to a two-phase line voltage E, at unity power-factor. The three-phase line current in each

No.	Style of Winding		Flux Relation	% Power-Factor		
	2-Ph. Side	3-Ph. Side		2-Ph. Side	3-Ph. Side	Average
1	Independent	T	2ϕ	100	92.8 (86.6, 100)	96.4
2	L	Special	"	97.5	97.5	97.5
3	Independent	Δ	3ϕ	92.8 (86.6,100)	92.8 (86.6, 100)	92.8
4	"	Δ	"	89.5	96.6	93.0
5	"	Δ or Y	"	80.8 (75, 86.6)	100	90.0
6	"	"	"	77.3	100	88.6
7	Symm.	"	"	62.4	100	81.2
8	"	"	"	100	100	100
9	T	"	"	86.6	100	93.3
10	T	"	"	91.4	100	95.7
11	L	"	"	82.6	100	91.3
12	Asymm.	"	"	82.3	100	91.1
13	"	"	"	92.2	100	96.1

case is equal to $2EI$ divided by $1.73E$, or $1.155I$.

The various schemes can be grouped according to the potential relation between the windings on the two-phase side:

1—Independent, in which the two phases are not electrically connected. Such a transformer can be connected to any kind of a two-phase load. *Schemes 1 to 6* (except 2).

2—Symmetrical, in which the middle points of each phase are at the same potential. *Schemes 7 and 8.*

3—*T*, in which the end of the winding in one phase is connected to the middle point of the other phase. *Schemes 9 and 10.*

4—*L*, in which the two phases are connected in series. *Schemes 2 and 11.*

5—Asymmetrical. Any other arrangement of windings not included in the above. *Schemes 12 and 13.*

In all excepting the first group the potential relation between the phases of the two-phase load must be the same as that existing between the two-phase transformer windings, or else the phases of the load must be electrically distinct. It is evident, therefore, that Groups 1 and 2 are the only ones which can be used in connection with synchronous converters. For three-wire two-phase systems Groups 1 and 4 only can be used; and Groups 3 and 5 can only be applied to loads in which the phases are not interconnected.

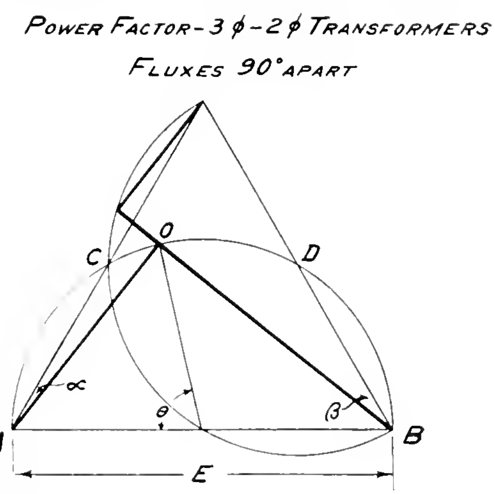


Fig. 1

Another line of division can also be made on the basis of flux relations, resulting in one type in which the fluxes are 90 deg. apart (2-phase) and another in which the fluxes are 120 deg. apart (3-phase). The first type requires two single-phase transformers or one two-phase transformer consisting of a three-legged core, two legs being used to contain the windings and the third having 41.4 per cent. greater cross-section. If an

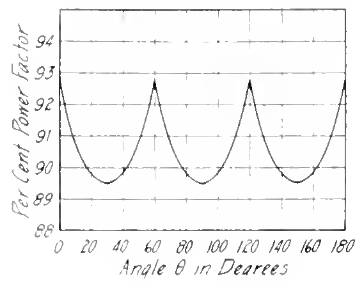


Fig. 2. Power-factor of Three-phase to Two-phase Transformers, Fluxes 90° Apart

ordinary three-phase core is used, consisting of three legs in which the core sections are equal, the flux density in one leg will necessarily be 41.4 per cent. greater than in the other two. For the second type, making use of three-phase fluxes, either three single-phase transformers or one three-phase transformer can be used. An ordinary three-phase core is perfectly adapted for such transformation.

Two-phase Fluxes

The most familiar example of the first type is shown diagrammatically in Scheme 1 (Fig. 5). It consists of two single-phase

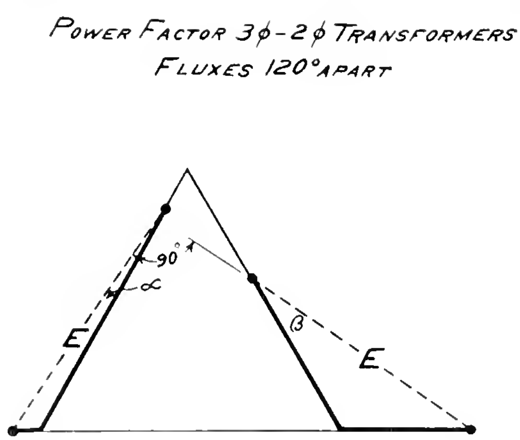


Fig. 3

transformers, one known as the main, the primary of which is provided with a 50 per cent. tap for connecting to the primary of the other transformer (teaser), the number of turns in which is 86.6 per cent. of the total turns of the main. The secondary windings are alike. Since the three-phase current is equal to $1.155I$, the volt-ampere rating of each portion of the three-phase side will be measured by the voltage induced in that

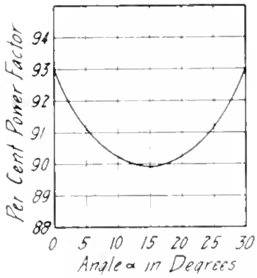


Fig. 4. Power-factor of Three-phase to Two-phase Transformers Fluxes 120° Apart

portion. The total volt-ampere rating will then be the arithmetical sum of the values for each portion. The volt-amperes for the main transformer is $1.155EI$, and for the teaser $0.866 \times 1.155EI = EI$, making a total of $2.155EI$. The actual load delivered is $2EI$, and the power-factor on the three-phase side will therefore be equal to 92.8 per cent. Since the two-phase windings operate at unity power-factor, the average for both sides gives 96.4 per cent.

The general case for two-phase fluxes is given in Figure 1 from which can be written

$$\alpha + \beta = 30 \text{ deg.};$$

and also for the voltages induced in the two windings:

$$E \cos \alpha,$$
$$E \cos \beta$$

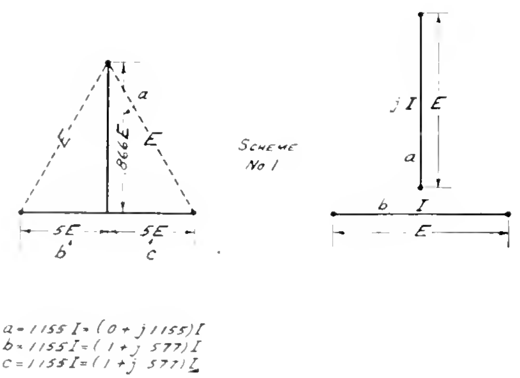


Fig. 5

The total volt-ampere rating, therefore, is $1.155EI(\cos \alpha + \cos \beta)$; giving for a non-inductive load of $2EI$, the expression for internal power-factor in the primary winding as follows:

$$p = \frac{2EI}{1.15\,EI\,(\cos\alpha + \cos\beta)}.$$

Therefore

$$p = \frac{1.73}{\cos\alpha + \cos\beta}.$$

For Scheme 1, $\alpha = 0$ and $\beta = 30$ deg. Substituting this in the above equation gives an internal power-factor of 92.8 per cent.

This equation, as plotted in Fig. 2, gives the power-factor for any position of the point O on the semi-circle AOB, in terms of the angle subtended by the arc OA. It is evident from this plot that the maximum power-factor of 92.8 per cent. is obtained at the four points A, C, D and B, at which points the connection becomes the ordinary one given in Scheme 1. At intermediate points the power-factor is less, the minimum value of 89.5 per cent. being obtained at the positions midway between the points AC, CD and DB.

Three-phase Fluxes

The simplest cases for three-phase fluxes are given in Schemes 3 and 4 (Figs. 7 and 8), and these are again particular cases of the more general one, given in Fig. 3, from which can be written

$$\alpha + \beta = 30°$$

and the volt-amperes in the windings

$$EI(\cos\alpha - 0.577\,\sin\alpha + 1.155\,\sin\alpha)$$
$$EI(\cos\beta - 0.577\,\sin\beta + 1.155\,\sin\beta)$$

The total volt-amperes are therefore

$$EI(\cos\alpha + 0.577\,\sin\alpha + \cos\beta + 0.577\,\sin\beta).$$

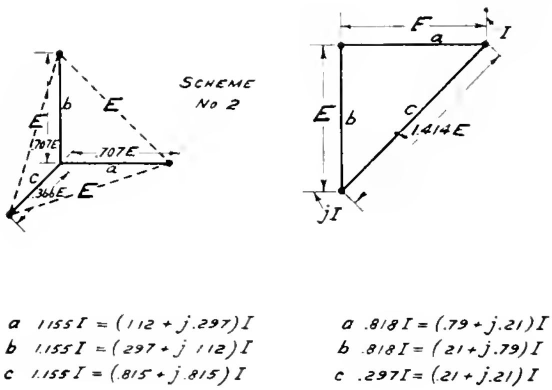


Fig. 6

Dividing the power delivered ($2EI$) by this expression and simplifying the results, we have, for the average power-factor on the two-phase side,

$$p = \frac{2}{2.155\ \cos\alpha + 0.577\ \sin\alpha}$$

This equation is plotted in Fig. 4, which shows the maximum power-factor for $\alpha = 0$ deg. (Scheme 3); and when $D = 15$ deg.

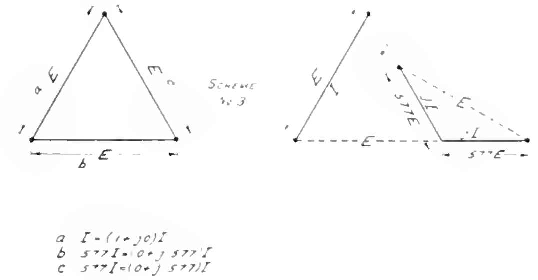


Fig. 7

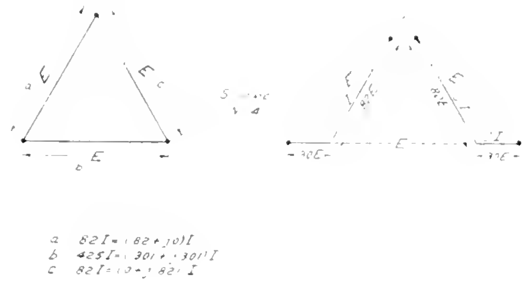


Fig. 8

(Scheme 4) the minimum power-factor is obtained. Because the currents in the windings on the three-phase side are not equal they must be connected delta. If they are connected Y, a distortion of the neutral results when the transformers are loaded. The three-phase windings can only be connected Y when the currents flowing in them are equal and 120 deg. apart in phase. This can be accomplished by modifying Schemes 3 and 4, obtaining Schemes 5 and 6 respectively (Figs. 9 and 10). It should be noted, however, that this is done at the expense of considerably reducing the average internal power-factor (see table).

In all the methods so far given the two-phase windings are electrically distinct.

The first of these, Scheme 7, Fig. 11, makes use of a delta-connected winding on a three-phase core, from which the two-phase voltages are obtained by taking off the proper taps. The voltages selected are those which will give a symmetrical two-phase system; and the currents are divided in such a way that balanced and equal currents will be obtained in the windings on the three-phase side, thus enabling them to be connected either in Y or delta.

Any number of asymmetrical two-phase voltages can be obtained from delta-connected windings by providing suitable taps.

A considerable modification of delta-connected two-phase windings is given in Scheme 8 (Fig. 12). This connection consists of three windings, one for each phase. Two of the phases are identical, each consisting of two coils, wound for 0.577 times the two-phase line voltage and having a current capacity of 0.577 times the two-phase line current. The third phase consists of three

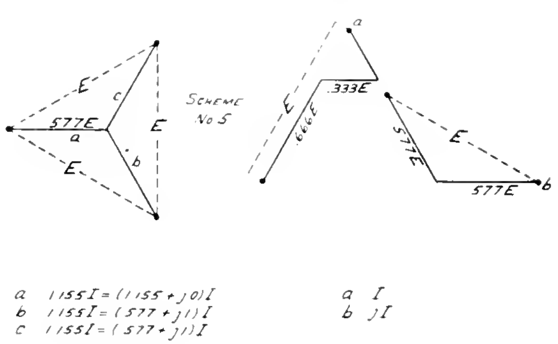


Fig. 9

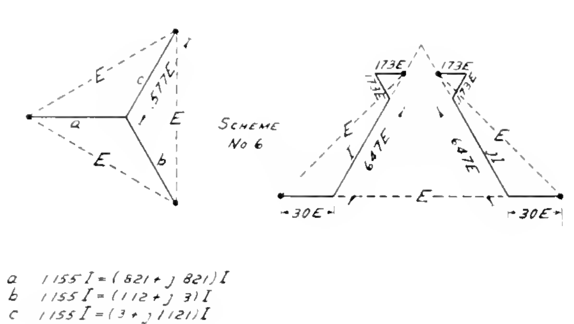
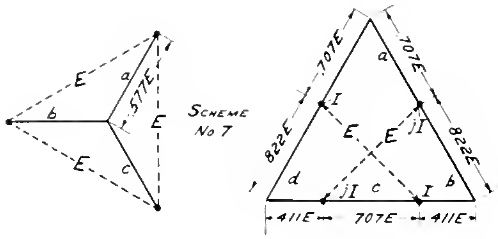


Fig. 10

There are, in addition, a number of miscellaneous schemes in which the windings on the two-phase side are electrically interconnected in one way or another.

coils, one being wound for 0.577 line voltage and the other two being identical and wound for 0.212 line voltage. The respective current capacities are 0.421, 1, 1, *times* the line current. The most excellent feature of this scheme is that unity power-factor is obtained. For operating a three-wire two-phase circuit, an excellent connection is given in Scheme 2. This consists of a three-legged core, the middle



a 1155I = (30 + j1121)I
b 1155I = (82 + j.82)I
c 1.155I = (112 + j 30)I

a 61I = (423 + j423)I
b .71I = (423 + j.577)I
c 82I = (.577 + j 577)I
d .71I = (577 + j 423)I

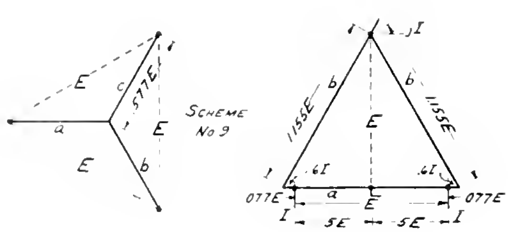
Fig. 11

leg having a cross-section 1.41 times as great as that of the outside legs. It is interesting to note that, although this scheme uses three-phase fluxes, they are unbalanced, two of them being 90 deg. apart. The winding, *c*, on the two-phase side has an equal number of turns, but a different current capacity, from windings *a* and *b*.

All the remaining schemes possess an objectionable feature in that the two-phase windings are inter-connected so as to give voltages which are not symmetrical.

Methods of Analysis

The complete analysis for any given scheme can be very readily made by any one without

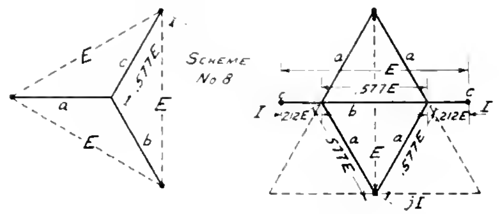


a 1155I = (1155 + j0)I
b 1155I = (577 + j1)I
c 1155I = (577 + j1)I

a 834 = (67 + j.5)I
b .6I = (.33I + j.5)I

Fig. 13

the use of vector diagrams by the following method. Assume a load on one phase of the two-phase side and zero load on the other phase. Work out the resulting currents on the two-phase and three-phase sides, by the application of the rule that the sum of the ampere-turns in the transformer must equal zero. Repeat this for the other phase. The resultant current for each winding is then equal to the square root of the sum of the squares of the components for that winding.



a 1155I = (1155 + j0)I
b 1155I = (.577 + j1)I
c 1155I = (577 + j1)I

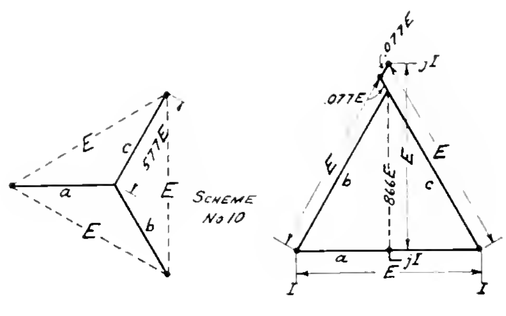
a 577I = (.288 + j.5)I
b .42 I = (42 + j0)I
c I = (1 + j0)I

Fig. 12

In the analysis given with the diagram of connections for each scheme, the loads on the two-phase side are assumed to be I and jI respectively, and the currents due to these loads are given in parentheses for each part of the winding. The resultants of these components, also given in each figure, are the normal currents in the windings.

Interlacing

A study of these analyses will enable one to compare the various schemes from the standpoint of the interlacing required to



a 1.155 I = (1155 + j0)I
b 1.155I = (577 + j1)I
c 1.155I = (.577 + j1)I

a .834I = (.67 + j.5)I
b .6I = (.33 + j.5)I
c .6I = (.33 + j.5)I

Fig. 14

secure good regulation. Whenever there are currents flowing in the primary side of a transformer without equivalent ampere-turns on the secondary side, or *vice versa*, the magnetic effect of the currents flowing on the one side, in itself, must be equal to zero. The coils in which these currents flow must therefore be interlaced to secure good regulation. For example, in Scheme 1, 0.577 *I* is flowing in half the primary main in one direction and in the other half in the opposite direction. These currents magnetically annul each other, there being no equivalent currents in the secondary side. As far as these currents are concerned the two coils act as a primary and secondary of a transformer, and on that account the reactance between these two coils must be made small.

This is illustrated in Figs. 18 to 23, which show the effect of reactance on the voltage relations in T-connected transformers. Non-inductive load is assumed and the effect of resistance is neglected. In Figs. 18, 19 and 20 the two-phase side is primary. Fig. 18 shows that for perfect interlacing between the two halves of the main, the per cent. reactance in the teaser must be equal to the per cent. reactance in the main if distortion on the secondary side is to be avoided. Fig. 19 shows that any reactance between the two halves of the primary main can be compensated for by reducing the reactance in the teaser by an equivalent amount. Fig. 20 shows the distortion produced by bad interlacing.

In Figs. 21, 22 and 23, the three-phase side is made primary and the two-phase side secondary. These show that the characteristics within the transformer, which will produce no distortion for two to three-phase transformation will likewise produce no distortion for three to two-phase transformation.

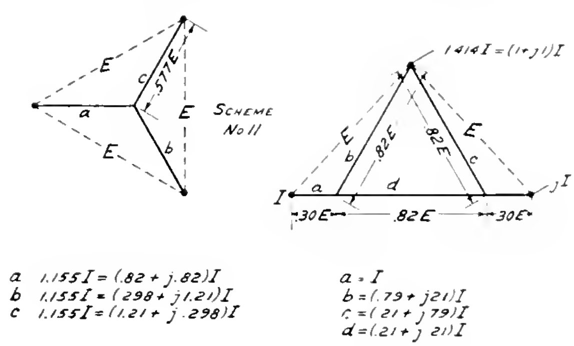


Fig. 15

In all these figures the primary applied voltages are represented by dotted lines, the secondary no-load voltage by full lines and the secondary full load voltage by heavy lines. Referring to Fig. 18, in which the two-phase side is considered primary, and the effect of reactance drop for the case of perfect interlacing is shown, the line *ab* is the reactance volts in the teaser, and the line

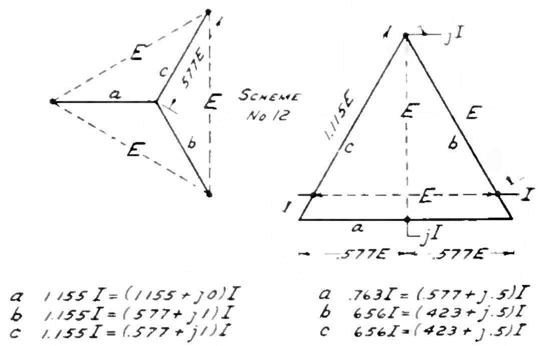


Fig. 16

cd the reactance volts in the main. The triangles *oab* and *fcd* are the regulation diagrams for the teaser and main respectively, the line *ab* being the reactance drop in the teaser due to the teaser current, and the line *cd* being the reactance drop in the main due to the main current. There being perfect interlacing between the two halves of the main, there is no reactance drop due to the teaser current flowing in the main. From Fig. 18 it is evident that in this case to secure no distortion, or, in terms of the figure, to maintain the triangle representing the secondary voltage equilateral, the volts drop in the teaser must be equal to 87 per cent. of the volts drop in the main. This, however,

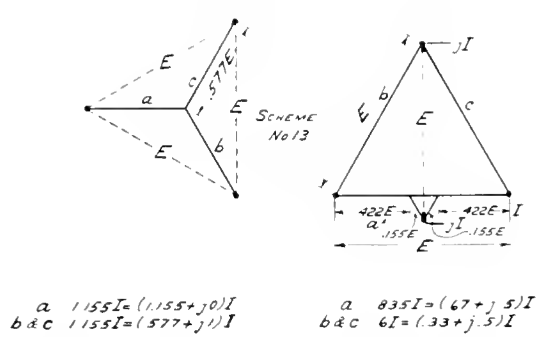


Fig. 17

does not hold when the two halves of the main winding are not perfectly interlaced, i.e., when there is an appreciable reactance drop between the two halves of the main winding on the three-phase side. The features of this are shown in Fig. 19. The line *cd* again represents the reactance volts due to the main current flowing in the main. The teaser current produces the reactance volts

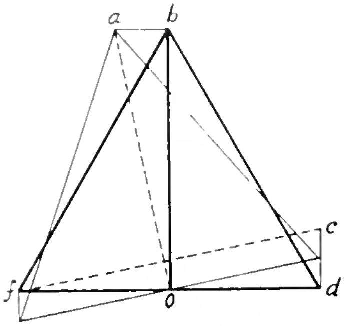


Fig. 18. Reactance Drop in T Connected Transformers, 2-Phase Primary. Perfect interlacing and equal per cent reactance in main and teazer.

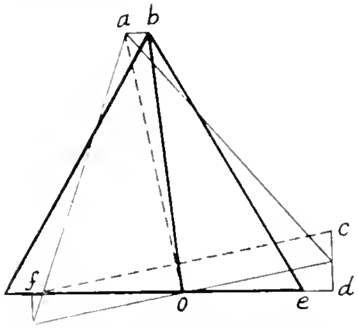


Fig. 19. Reactance Drop in T Connected Transformers, 2-Phase Primary. Imperfect interlacing but no distortion.

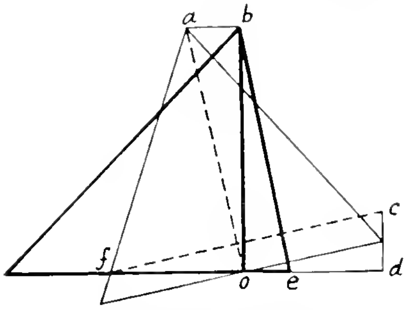


Fig. 20. Reactance Drop in T Connected Transformers, 2-Phase Primary. Improper interlacing producing bad distortion.

drop in the teaser represented by the line *ab*, and in addition a drop in the main on account of imperfect interlacing, represented by the line *de*. Lines *ab* and *de* are in phase with each other because they are drops due to the same current. This drop does not affect the value of the main voltage, but shifts it with respect to the teaser voltage. It is evident from Fig. 19 that distortion of the secondary terminal voltage can be prevented by reducing the reactance drop in the teaser, by an amount equal to the reactance drop in the main due to the teaser current. By

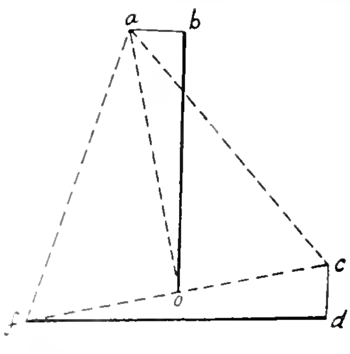


Fig. 21. Reactance Drop in T Connected Transformers, 3-Phase Primary. Perfect interlacing and equal per cent. reactance in main and teazer.

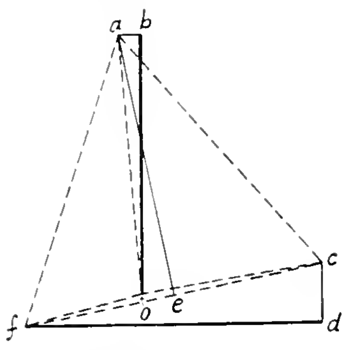


Fig. 22. Reactance Drop in T Connected Transformers, 3-Phase Primary. Imperfect interlacing but no distortion.

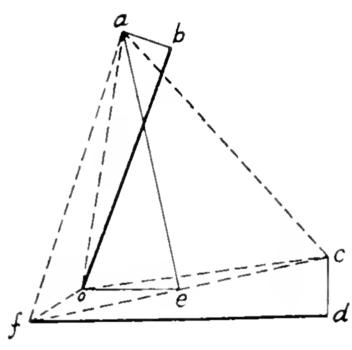


Fig. 23. Reactance Drop in T Connected Transformers, 3-Phase Primary. Imperfect interlacing producing bad distortion.

this means the secondary line voltage is balanced, although the potential of the middle point *O* is shifted. Fig. 20 is a similar diagram which shows the distortion produced when the reactance due to bad interlacing is too large to be compensated for.

Figs. 21, 22 and 23 are the vector diagrams when the three-phase side is considered primary. The same cases are taken as when the two-phase side was considered primary and the same notation is employed. These figures show that the results are the same whether the two-phase or the three-phase side is considered primary.

These results can be stated mathematically, thus: T-connected transformers, in order to operate with no distortion on the secondary side when balanced load is delivered, require the following relation of reactances:

$$(\text{Per cent. } IX)_M = (\text{per cent. } IX)_T + (\text{per cent. } IX)_C$$ in which

$(\text{Per cent. } IX)_T$ = Per cent. reactance drop in teaser operating on 86.6 per cent. tap, expressed in per cent. of teaser voltage.

$(\text{Per cent. } IX)_M$ = Per cent. reactance drop in main due to main current (86.6 per cent. of three-phase line current).

$(\text{Per cent. } IX)_C$ = Per cent. shift of the potential of the middle point 0 on account of the reactance between the two halves of the main due to the teaser current flowing in the main, and expressed in percent. of teaser voltage. This drop is numerically equal to 1.155 times the per cent. drop which would be produced in a two-to-one auto-transformer consisting of the three-phase side of the main, in each part of which a current equal to ½ the teaser current is flowing.

Similarly, for resistance drops:

$$(\text{Per cent. } IR)_M = (\text{per cent. } IR)_T + (\text{per cent. } IR)_C,$$

and therefore for Impedance Drops,

$$(\text{Per cent. } IZ)_M = (\text{per cent. } IZ)_T + (\text{per cent. } IZ)_C.$$

LOAD CHARACTERISTICS OF CENTRIFUGAL PUMPS

By Maxwell W. Day

Assistant Engineer, Power and Mining Department, General Electric Company

This article illustrates the necessity for care in the selection of a centrifugal pump for various services. The head against which it must work must be accurately known, since a small difference in head or speed produces a considerable difference in the quantity delivered—greater or less, depending on the shape of the quantity head characteristic, flat or steep. The published curves with accompanying text serve mainly to draw attention to the much more pronounced variation in power and volume, produced by a variation in head or speed, with a pump with a flat characteristic than with a steep one. In the selection of the former therefore the necessity for great accuracy as regards head and speed is particularly apparent. As to regulation, control of the volume can always be better performed by speed control than by throttling, although the preference is not so marked in the case of a pump with flat characteristic as with steep.—Editor.

The peculiar characteristics of centrifugal pumps call for special care in their selection and in the selection of the motor drive and method of control.

The features of centrifugal pump operation are, in some respects, the opposite of those of reciprocating pumps. With constant speed an increase of the resistance against which the reciprocating pump operates increases the pressure and, therefore, the load on the driver, while with the centrifugal pump an increase of resistance reduces the load. If it be desired to reduce the volume of a reciprocating pump, without changing the speed, some of the water must be allowed to escape through a bleeding, or by-pass, valve; but with the centrifugal pump the volume is reduced by throttling the discharge. A reduction of the head for a reciprocating pump does not affect the volume (except very slightly due to leakage), but reduces the power required. A reduction of head with the centrifugal pump increases the volume delivered and the power required. The amount of increase of volume depends upon the characteristic of the pump.

In starting up a reciprocating pump with a low-torque motor the water may be delivered through a by-pass into the suction until the motor is up to speed, when the by-pass is gradually closed and the water delivered into the system. In starting a centrifugal pump the discharge may be entirely closed until the motor is up to speed. The amount of power for running a centrifugal pump with closed discharge may vary from one-third to one-half of the rated horse power.

Fig. 1, "A," gives the characteristics of a fire pump with a capacity of 1000 gal. per min. against a pressure of 100 lb. per sq. in. and the curve shows the equivalent head in feet. On this pump the maximum head is obtained with about 40 per cent. of the rated volume, and falls off rapidly beyond 1200 gals. The efficiency at different loads, as well as the brake horse power required, are shown on the curve. The horse power required with the discharge closed is about 42 and at 1000 gal. 94.

In selecting a centrifugal pump, the desired head against which it is to work should be accurately known, unless the motor is provided with some speed control; since a small difference in the static head will produce considerable difference in the quantity delivered, and a slight variation in speed will produce a considerable variation in the quantity delivered, especially with a pump which has a flat characteristic, i.e., a flat quantity-head curve, or q-h. curve. Fig. 1, "B," shows the quantity-head and power

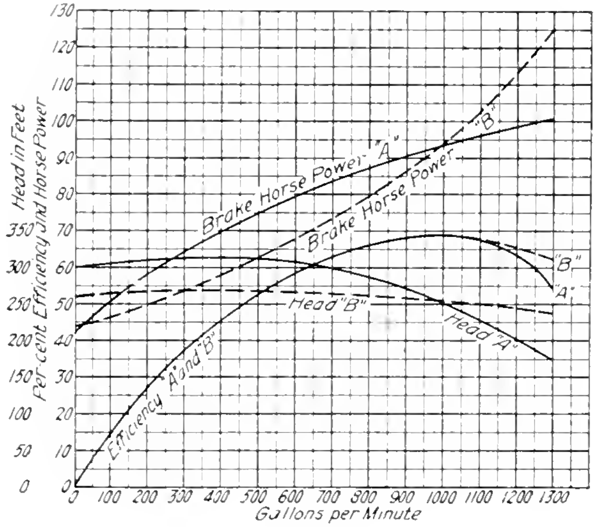


Fig. 1

curves of another pump, with a flat characteristic. The maximum pressure is only 4.0 per cent. higher than the pressure at rated volume, while on the "A" curve it is over 22 per cent. higher. The flat characteristic produces a large change of volume for a small change of speed or a small change of static head, while the steep characteristic produces a much smaller change of volume for the same change in speed or static head.

Fig. 2 shows some additional characteristics of both pumps calculated for different static heads. In order to show this on a large scale the lower part of the curve below 200 ft. static head is omitted. The normal static head is assumed to be 230 ft., and the additional head for friction and velocity of the water in the pipe is assumed to be 25 ft. for 1000 gal. This will vary largely in different installations according to the size and length of the pipe. The q-h. curves of the pumps at normal speed show the different pressures and the corresponding volumes which they are capable of producing.

The q-h. curve of the system shows the amount of head required for various volumes to overcome the static head of 230 ft. and the additional friction head. These curves cross at 1000 gal. and 255 ft. head. This means that when either pump is running at normal speed, it will deliver a total pressure of 255 ft., which is just sufficient to deliver 1000 gal. through the system. If, however, the static head were only 200 ft., the characteristics of the system become as shown in the dotted curve at the bottom. This crosses the "A" pump curve at 1110 gal., and 231 ft. total head, showing that a reduction of static head of 30 ft. increases the volume from 1000 to 1110 gal. or 11 per cent. If, however, the static head is increased by 30 to 260 ft., the new q-h. curve of the system crosses the "A" pump curve at about 278 ft. and 865 gal., a decrease of 13.5 per cent. By referring to Fig. 1 it is seen that, at the low head, where pump "A" is delivering 1110 gal., the horse power is 96.7 or an increase of about 3.1 per cent. over the normal value; and at the higher head, where

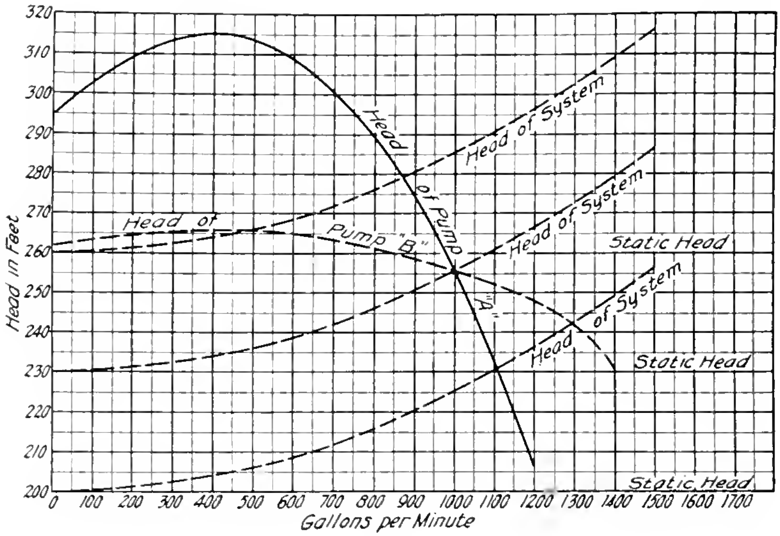


Fig. 2

the delivery is 865 gal., the horse power is 89.7 or a decrease of about 4.4 per cent. of the normal value. These figures show the variation of volume and power caused by pumping into a tank which is gradually filled; as the tank fills up the static head increases and the volume and power are reduced.

Again looking at Fig. 2, the effects of the same conditions on pump "B" may be seen. The normal point coincides with that of pump "A." However, at the static head of 200 ft. the characteristic of pump "B" crosses that of the system at 1295 gal. and 242 ft.; showing that a reduction of 30 ft. in static head increases the volume from 1000 to 1295 gal. for pump "B," in contrast to 1110 gal. for pump "A." For 260 ft. static head, an increase of 30 ft., the new q-h. curve of the system crosses the "B" pump curve at 475 gal. 265 ft. Fig. 1 shows that, at the low head, pump "B" requires 125 h.p. or an increase of 33.2 per cent. over the normal, and at the higher head the horse power is 74 or a decrease of 21.1 per cent. This clearly indicates the very much more pronounced increase or decrease of volume and horse power when the static head is decreased or increased, with a pump having a flat characteristic, than with one having a steep characteristic.

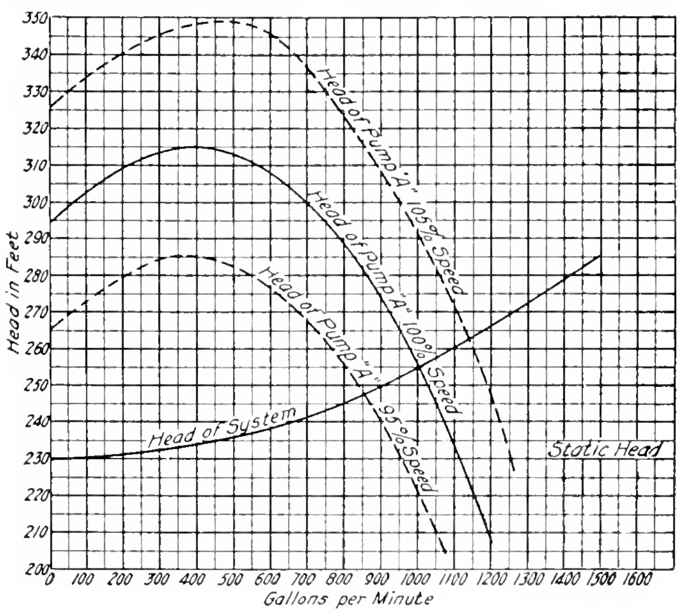


Fig. 3

In Fig. 3, relating to the "A" pump, the upper q-h. curve corresponds to an increase of speed of 5 per cent. and the lower one to a decrease of 5 per cent. With 230 ft. static head and an increase of 5 per cent. in speed the two curves cross at 1135 gal. 262.5 ft., showing that an increase of 5 per cent. in speed produces an increase of 13.5 per cent. in volume. For a decrease of 5 per cent. in speed the curves cross at 855 gal. and 247.5 ft. head, giving a decrease of 14.5 per cent. in volume. With an increase in speed the pressure at the greater volume is increased 3 per cent.; so that the horse power required is about 117 per cent., or the increase is slightly more than in proportion to the cube of the speed.

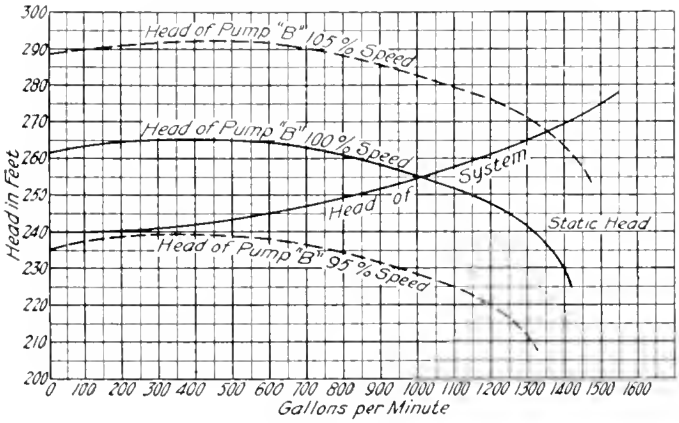


Fig. 4

In laying out the q-h. curves of the pump the pressure is taken in proportion to the square of the speed, and the volume in proportion to the speed. It is frequently stated that the pressure of a centrifugal pump is proportional to the square of the speed, but this does not hold true except in case the volume is increased at the same time in proportion to the speed. Whether this will take place depends upon the resistance of the system. On centrifugal fans, which have no static head, this relation holds true; but with a centrifugal pump working against a certain static head, which is frequently a very large proportion of the total head, the relation of speed, pressure and volume actually produced does not follow this law.

Fig. 4 shows similar data for the "B" pump. Assuming a static head of 230 ft. and a friction loss at rated load of 25 ft. the normal speed q-h. curve of the "B" pump crosses the q-h. curve of the system at 1000 gal. and 255 ft. If the speed be increased 5 per cent. the curves cross at 1290 gal. and 272 ft., or an increase of 29 per cent. in volume for 5 per cent. in speed. For a 5 per cent. decrease of speed the curves cross at 590 gal. and 238 ft., showing a decrease of 41 per cent. in volume for 5 per cent. decrease in speed.

The approximate horse power required at different speeds may be obtained as follows: first, the volume or gallons delivered at the reduced or increased speed is divided by that speed expressed in per cent. of the normal; second, the horse power required to obtain this new volume at normal speed is found from the normal curve in Fig. 1; and, third, this value of horse power is multiplied by the cube of the new speed expressed in per cent. of the normal. The result is the horse power required at the new speed. This gives for the "A" pump 111.2 h.p. at 105 per cent. speed or an increase of 18.6 per cent.; at 95 per cent. speed the horse power is 78 or a decrease of 16.9 per cent. For the "B" pump the horse power at 105 per cent. speed is 135.5 or an increase of 44.4 per cent.; at 95 per cent. speed the horse power is 59.4 or a decrease of 36.6 per cent. These figures illustrate the greater change in power with a change in speed, for a pump of flat characteristic than for one of steep characteristic.

On Fig. 5 the characteristic curves of pump "B" at normal, 105 per cent. and 95 per cent. speed are repeated. In this case, however, the piping, whose loss is represented as 25 ft. in Fig. 4, is assumed to be increased in diameter or decreased in length, so that the friction loss is but 15 ft. This will allow a static head of 240 ft. to be used to work the pump at its normal rating. On this basis, an increase of speed of 5 per cent. would increase the volume to 1355 gal. or 35.5 per cent. and a decrease of speed of 5 per cent. would reduce the pressure below the static head of 240 ft. and the pump would deliver no water. This shows that a pump with flat characteristic will give a great change in volume due to a slight change in speed, or a slight change in static head. In this case the increase or decrease of power is much greater than in proportion to the cube of the speed. For general purposes a pump with a steep characteristic does not need to be selected with as great an accuracy of head or speed as one with a flat characteristic.

A pump with a steep characteristic is particularly desirable for some kinds of drainage service, such as dry docks where the static head varies from nothing at the beginning of the pumping, to 30 or 40 ft., at the end of the pumping. Pumps have been especially designed for this purpose which take nearly the same horse power over a large range of head because the pressure falls off very greatly with low heads and large volumes.

Regulation

When it is desired to decrease the volume delivered it can be done either by throttling or by reducing the speed. In the case of pump "A," shown in Fig. 3, it will be noted, that with the normal horse power of 93.8, at the normal volume and pressure of 1000 gal. and 255 ft. respectively, if the volume be throttled to 855 gal. or 85.5 per cent., the pressure rises to 280 ft. or 109.9 per cent., while the pressure required for the system is only 247.5 ft. or 97.2 per cent.; making a loss of pressure due to throttling of 32.5 ft. or 12.7 per cent. According to the horse power curve of Fig. 1, the power required when throttled to 855 gal. is 89.5 h.p. or

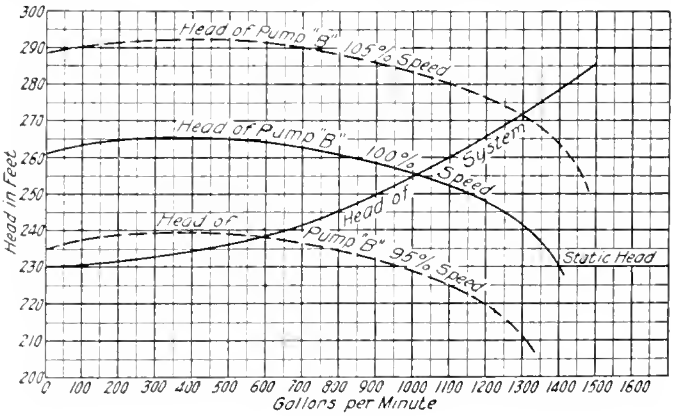


Fig. 5

95.3 per cent. of the full load rated horse power. Now it has been seen previously, that, if the speed is reduced to 95 per cent., the pump will deliver 855 gal. at 247.5 ft., the pressure required by the system. Hence if the speed is thus reduced instead of throttling at normal speed, the loss of head due to throttling will be eliminated. Moreover, the horse power required at 95 per cent. speed, according to previous calculation, is only 78 or 83.1 per cent., showing a saving of 11.5 horse power or 12.2 per cent. over the throttling method.

In the case of pump "B" shown in Fig. 4, it will be seen that, with the normal horse power of 93.8 at the normal volume and pressure the same as pump "A," if the volume be throttled to 590 gal. or 59 per cent., the pressure rises to 264.5 ft. or 103.7 per cent., while the pressure required for the system is only 238 ft. or 93.4 per cent.; making a loss of pressure due to throttling of 26.5 ft. or 10.4 per cent. According to the horse power curve of Fig. 1, the power required when throttled to 590 gal. is 67.6 h.p., or 72.0 per cent. of the full load rated horse power.

It has been shown that the "B" pump, when its speed is reduced 5 per cent., will deliver 590 gal. at 238 ft., the pressure required by the system. Hence, if the speed be thus reduced, instead of throttling at normal speed, the loss of head due to throttling will be eliminated. Further, the horse power required at 95 per cent. speed, taken from earlier figures, is 59.4 or 63.3 per cent., showing a saving of 8.2 h.p. or 8.7 per cent. over the throttling method.

Comparing the two pumps on the basis of throttling, the above figures show for the "B" pump, the one with the flat characteristic, a waste of only 8.7 per cent. in power for a throttling to 59 per cent. of normal capacity; while for pump "A," the one with the steep characteristic, the waste is 12.2 per cent. for a throttling to only 85.5 per cent. capacity. This shows the considerable advantage of variable speed motors to obtain variable volume, especially with the pump of comparatively steep characteristic. Also, if throttling must be done, it is plain that there is a decided advantage in having a pump of flat characteristic.

Where the pump speed is reduced by resistance in the armature circuit a sacrifice of efficiency is made. In the case of the "A" pump, reducing the speed to 95 per cent. by armature resistance reduces the efficiency approximately in that proportion, so that to obtain 83.1 per cent. output we would need $\frac{83.1}{0.95}$ or 87.5, per cent. of the rated horse power input, i.e., throttling requires about 95.3 per cent.; reduced speed by armature control 87.5 per cent.; reduced speed by field control 83.1 per cent. of the full rated horse power.

The horse power of pump "B", when running at full speed and delivering 59 per cent. volume, throttled, we have seen to be 72.0 per cent.; when running at the proper reduced speed without throttling, 95 per cent. of normal speed, the horse power is 63.4 per cent., and, if armature control be used, the input is approximately $\frac{63.4}{0.95}$ or 66.8 per cent.; i.e., throttling requires about 72 per cent.; reduced speed by armature control 67 per cent.; and reduced speed by field control 63.5 per cent. of the full rated horse power.

In the same way it can be shown that, with an external system having a comparatively flat characteristic, such as shown on Fig. 5, regulation by throttling can be done more economically than with an external system of steeper characteristic, such as shown on Fig. 4.

In conclusion, while a flat characteristic can be used with throttling to better advantage than a steep characteristic, still speed control is preferable in either case. The relatively high horse power consumption at reduced volume when throttled is not due entirely to the increase of pressure; but partially to the poorer efficiency of the pump at reduced volume and full speed.

REVIEW OF GRAPHICAL AND ANALYTICAL METHODS FOR PREDETERMINING OPERATING CHARACTERISTICS OF INDUCTION MOTORS

PART II

By Prof. C. R. Moore

School of Electrical Engineering, Purdue University

The first part of this paper, which was published in last month's Review, was confined to a consideration of the rotating field and a comparison of the induction motor with the static transformer. Prof. Moore proceeds this month to describe in detail the various methods in use for predicting a motor's performance. Under "analytical methods" are described the Steinmetz and the Franklin-and-Esty methods. The author then deals with the principles underlying the use of graphical methods, and illustrates the application of these principles to the solution of induction motor problems. Under this section the Heyland, the Specht, and the Arnold diagrams are drawn out and explained; from which it is made clear how to arrive at the linear quantities representing the various characteristics. For notation the reader is referred to Part I.—Editor.

The tests and preliminary calculations necessary for the application of the following methods may be briefly summed up as follows: Data covering voltage, amperes, and watts input are taken while the motor is running light and also with the rotor locked. From these tests, values of power-factor and short circuit current (at full rated voltage impressed) may be calculated. Measurements of stator resistance per phase must also be made.

The rotor resistance is usually worked out in terms of stator values, so that ratio of transformation need be considered. This may be obtained from design data, or from a slip test as follows:

$$R_s = \frac{E \times slip}{I_p}$$

This value is usually increased by a small percentage to allow for the eddy current effect in the rotor bars. It is a matter of common experience that this value of resistance becomes larger as the slip increases. The test should be made at as near full load as possible. If the motor is of the wound rotor type, the secondary resistance may be measured directly.

The reactance X_t may be calculated from the short circuit test and divided between rotor and stator as desired. Values of conductance and susceptance (or resistance and reactance) of the exciting circuit may be calculated directly from the open circuit or no load test.

Analytical Methods

Incident to the application of analytical methods it is convenient to prepare a table of values in which certain assumed values, usually of slip, are inserted and others calculated. The circuits upon which analytical methods are based are shown in Fig. 5 and Fig. 6. Approximate circuits, such as shown in Fig. 7, are seldom used when results are to be calculated, as the formulæ applicable thereto are but little simpler than those applying to a more exact circuit, and the results obtained less exact.

Steinmetz Method. (See Steinmetz's "Theoretical Elements of Electrical Engineering," page 266.) In this method, the circuit shown in Fig. 5 is made use of; the relation $E = e + R_p I_h + X\ I_m$ giving a close approximation to the true value of the counter e.m.f. e of the primary when the machine is running light. Also $g = \frac{I_h}{e}$ and $b = \frac{I_m}{e}$. The primary and secondary reactances are assumed to be equal, that is $X_p = X_s$.

Tabulating the various quantities as developed in the text above referred to, we have:

1 % Slip. (Various values assumed.)

2 $s^2 X_s^2$

3 $R_s^2 + s^2 X_s^2$

4 $a_1 = \frac{s R_s}{R_s^2 + s^2 X_s^2}$

5 $a_2 = \frac{s^2 X_s}{R_s^2 + s^2 X_s^2}$

6 $b_1 = a_1 + g$

7 $b_2 = a_2 + b$

8 $\sqrt{b_1^2 + b_2^2}$

9 $c_1 = 1 + R_p b_1 + X_p b_2$

10 $c_2 = R_f b_2 - X_f b_1$

11 $\sqrt{c_1^2 + c_2^2}$

12 $e_s = \dfrac{E}{\sqrt{c_1^2 + c_2^2}} = counter\ e.m.f.\ at\ slip\ s$

13 $I_f = e_s \sqrt{b_1^2 + b_2^2}$

14 $b_1 c_1 + b_2 c_2$

15 $T = e_s^2 a_1$

16 $P = T\ (1 - s)$

17 $Output = P - F$

18 $P_0 = e_s^2\ (b_1 c_1 + b_2 c_2) = watts\ input$

19 $EI_f = apparent\ input$

20 $Efficiency = \dfrac{P - F}{P_0}$

21 $Power\text{-}factor = \dfrac{P_0}{EI_f}$

22 $H.P.\ (output)$

23 % $Load$

Franklin and Esty Method. (See Franklin and Esty's "Elements of Electrical Engineering," page 290.) This scheme makes use of the circuit shown in Fig. 6, although the authors in the work mentioned above prefer to consider the exciting circuit as being made up of resistance and reactance in series. The table here shown is a development of the problem as stated in the above text.

In this method the entire reactance of the machine is placed in the primary circuit, as shown in Fig. 6. The reader is referred to footnote at bottom of page 289 of the above text for a statement in defense of this approximation.

Tabulation of the formulæ resulting from the above development follows.

1 % Slip. (Various values assumed)

2 $a = sEr_1$

3 $b = sEx_1$

4 $c = R_s\ (r_1 + R_f) + s\ (r_1 R_f - x_1 X_t)$

5 $d = R_s\ (x_1 + X_t) + s\ (r_1 X_t + x_1 R_f)$

6 $c^2 + d^2$

7 $q = ER_s$

8 $I_f = \sqrt{\dfrac{(q + a)^2 + b^2}{c^2 + d^2}}$

9 $I_{ws} = \dfrac{c\ (q + a) + bd}{c^2 + d^2}$

10 $Power\text{-}factor = \dfrac{I_{ws}}{I_f}$

11 $Input = EI_{ws}$

12 $I_s = \sqrt{\dfrac{a^2 + b^2}{c^2 + d^2}}$

13 $P = I_s^2 R_s \left(\dfrac{1 - s}{s} \right)$

14 $Output = P - F$

15 $Efficiency = \dfrac{P - F}{EI_{ws}}$

16 $Torque = \left(\dfrac{1}{1 - s} \right) P$

17 $H.P.\ (output)$

18 % $Load$

Theory of Graphical Methods

Scheme (a) In Fig. 13, consider that a voltage E_s has been applied to a part of a circuit containing resistance and reactance, and that current I_s, lagging $\theta°$ behind the impressed voltage, flows therein. The reactance voltage and ohmic drop are at right angles to each other, and the voltage drop due to resistance is in phase with the current. We can therefore lay off the XI_s and RI_s drops as shown, since their vector sum always equals the impressed voltage. If now either X or R_s be regarded as variable, the locus of the vertex of the triangle is a semi-circle, as shown. For our purpose here, the resistance R_s will be taken as the variable, and X and E_s as constants.

As R_s varies, the current I_s also varies; but its value remains proportional to XI_s,

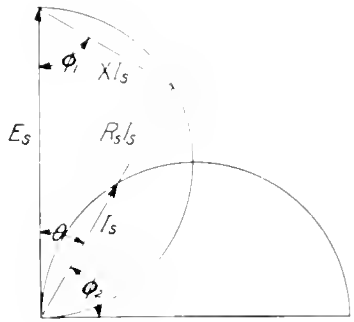


Fig. 13. Fundamental Circle Diagram

since X is constant. Also the angles ϕ_1 and ϕ_2 remain equal for all values of R_s, so that the locus of the current values is a semi-circle whose diameter equals $\frac{E_s}{X}$. This relationship forms the basis of all ordinary circle diagrams and has been applied by many writers to induction motor and transformer problems.

Scheme (b) The principle of inversion seems not to have found application in this country. In many cases it may be conveniently applied to the solution of alternating current problems, so that it seems advisable to review a few of the fundamentals concerning it.

In Fig. 14 consider right triangle *osb*, taking the leg $os = a$ as constant and the leg $sb = y_1$ as variable. The hypotenuse *ob* will also be a variable. For all values of y_1 lay off (from 0) on the hypotenuse *ob* the value $\frac{1}{ob} = oc$.

The locus of the points c is a circle, as shown.

Proof. Take the x and y axes as shown and consider x and y as the coordinates of the point c.

$$\text{Then } x^2+y^2=\overline{oc}^2=\frac{1}{\overline{ob}^2}=\frac{1}{a^2+y_1^2}=\frac{1}{a^2+a^2tan^2\theta}$$

$=\frac{cos^2\theta}{a^2}$, or $oc=\frac{1}{a}cos\,\theta$, which is the equation of a circle.

If, therefore, y_1 be regarded as a variable resistance and a as a constant reactance, the circle represents to some suitable scale the reciprocal of the impedance, or the admittance of the two. Scalar values of $\overline{oc}$, as measured from the diagram, when multiplied by the impressed voltage give values of current.

Most practical problems, however, involve (as in the case of the induction motor) series-parallel combinations of resistance and reactance, so that to get the total effect the scheme must be carried farther. That is, after a first circle of admittance has been drawn, other admittances may be added to it so that the inversion of a circle must be known also.

In Fig. 15 consider circle $a_1\,s\,c$ having its center in the x axis, as shown. The equation of this circle is $(x-a)^2+y^2=r^2$. Choose any point a having coordinates x, y, and draw os. Lay off on os from o, $ob_1=\frac{1}{os}$, the coordinates of point b_1 being x_1y_1. The locus of the

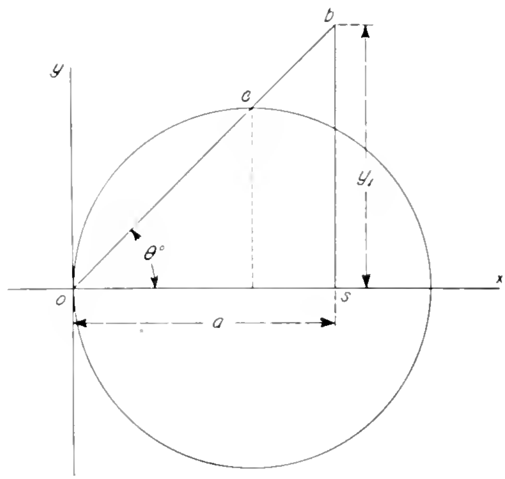


Fig. 14. Inversion (of Triangle)

point b_1, as s moves around the circle $a_1\,s\,c$, is a circle.

Proof. $(x-a)^2+y^2=r^2$

$$x^2+y^2=\overline{os}^2$$

from which $y^2=r^2-(x-a)^2=\overline{os}^2-x^2$

$$\text{Solving, } x=\frac{\overline{os}^2+a^2-r^2}{2a}=\frac{\frac{1}{x_1^2+y_1^2}+a^2-r^2}{2a}$$

$$=\frac{1+(a^2-r^2)\,(x_1^2+y_1^2)}{2a\,(x_1^2+y_1^2)}$$

Also, $\frac{y_1}{x_1}=\frac{y}{x}$ so that $y=\frac{xy_1}{x_1}$

$$\therefore\ y=\frac{1+(a^2-r^2)\,(x_1^2+y_1^2)}{2a\,(x_1^2+y_1^2)}\,\frac{y_1}{x_1}$$

$$x_1^2+y_1^2=\frac{1}{x^2+y^2}=$$

$$\frac{1}{\left[\frac{1+(a^2-r^2)(x_1^2+y_1^2)}{2a(x_1^2+y_1^2)}\right]^2\left(1+\frac{y_1^2}{x_1^2}\right)}$$

$$=\frac{2ax_1-1}{a^2-r^2}=\frac{2ax_1}{a^2-r^2}-\frac{a^2}{(a^2-r^2)^2}+\frac{r^2}{(a^2-r^2)^2}$$

Solving

$$\left(x_1-\frac{a}{a^2-r^2}\right)^2+y_1^2=\frac{r^2}{(a^2-r^2)^2}$$

This equation shows that the locus of b_1 is a circle having its center on the x axis at a distance equal to $\frac{a}{a^2-r^2}$ from the origin and a radius equal to $\frac{r}{a^2-r^2}$. Obviously a circle and its inverse have common tangents.

In order to illustrate the application of the above principles to the solution of induction motor problems, circuit A will be taken as an example. Beginning at the rotor side of the circuit, a right triangle is constructed having legs equal to the constant reactance X_s and any value of the variable resistance $\frac{R_s}{s}$ (see Fig. 16). os_1 represents the impedance of the rotor circuit at slip s, and os represents to some suitable scale the admittance. M is the inverse circle for the rotor circuit and represents the locus of all admittance values for any slip s (either positive or negative).

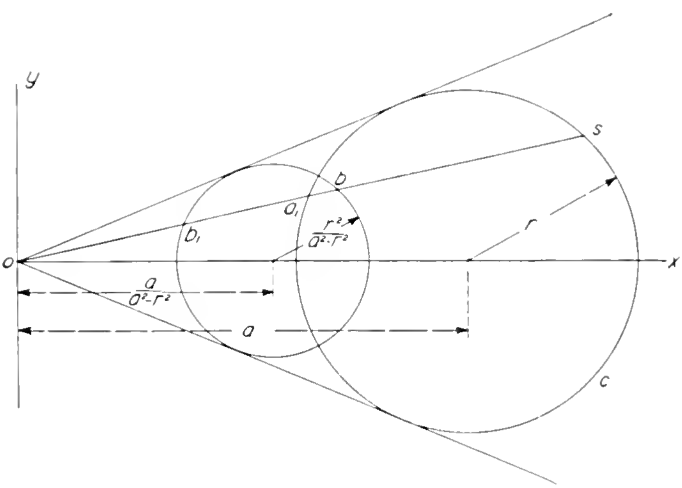


Fig. 15. Inversion (of a Circle)

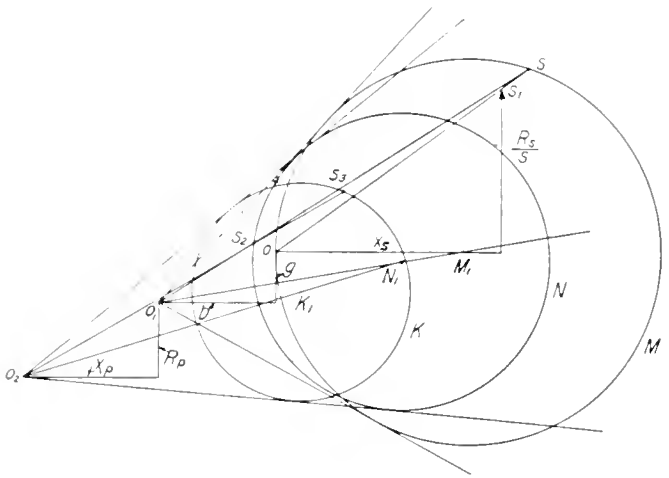


Fig. 16. Circle Diagram for Circuit A, Based upon Principle of Inversion

Having now the admittance of the rotor circuit for any slip s, the admittance of the exciting circuit may be added at o as shown (conductance and susceptance taken in proper direction), so that values of admittance for exciting circuit plus rotor circuit may be measured directly from o_1 to circle M. However, in order to include the resistance and reactance of the primary circuit, the inverse circle of M must be drawn, its position and diameter being determined by the scale chosen. This circle is represented by N, and values measured to it from o_1 are values of impedance. Thus o_1s_2 represents to some suitable scale the impedance of the exciting circuit plus the rotor circuit for slip s, and corresponds to the value of admittance shown by o_1s.

At o_1 we may now add the values of resistance and reactance in their proper direction, so that values measured from o_2 to circle N represent the total impedance of the motor circuit. Thus o_2s_2 represents total impedance for slip s. However, for practical work it is more convenient to work with admittance values so that the inverse circle of N is drawn, giving circle K. This circle then represents the total admittance of the motor circuit, and values measured from o_2 thereto, when multiplied by the voltage impressed, give the current values. This multiplication may be effected by changing the scale; therefore the diagram is very convenient. For the slip s, as shown, os_3 is the corresponding total admittance of the motor. This diagram has been put in more convenient form by Dr. Arnold, and the practical working diagram will be considered in a later paragraph.

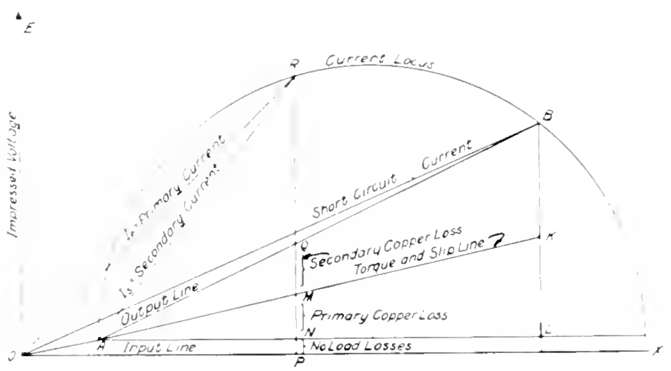


Fig. 17. Heyland Circle Diagram

Heyland Circle Diagram. (See Standard Handbook, page 543.) Heyland's circle diagram, shown in Fig. 17, is a graphical solution of circuit c, Fig. 7. In the construction of this diagram it is assumed that the magnetizing current is constant, the circular portion ($ARBX$) being the locus of current in a circuit (primary and secondary) having constant reactance ($X_p + X_s$) and variable resistance $\left(R_p + \frac{R_s}{s}\right)$. A line drawn from A to any point on the circle therefore represents the current passing through X_s and $\frac{R_s}{s}$, and is called secondary current. Strict interpretation of the diagram, together with a study of the circuit shown in Fig. 7, shows that this current also passes through R_p and X_p, and that the energy component of this current, when the rotor is locked, may be divided into two parts proportional to primary and secondary copper loss.

This division forms a basis for the measurement of primary and secondary copper losses for any load.

For any current value in the secondary, as AR, the output may be found by deducting from the energy component RN, the primary copper losses and secondary copper losses. The line AB may therefore be regarded as an output line. OR being the vector sum of AR and OA, represents the total current input, the power-factor being the cosine of the angle ROE. The torque measured in synchronous watts will be proportional to the line RM. The slip being equal to the per cent rotor loss, and this being practically all copper loss, is shown by the line QM. Since the efficiency equals $\frac{\text{output}}{\text{input}}$, this value is expressed by the ratio $RQ \div RP$. These measurements and calculations, repeated for several points on the circle between A and B, give the motor performance as based on circuit c, Fig. 7.

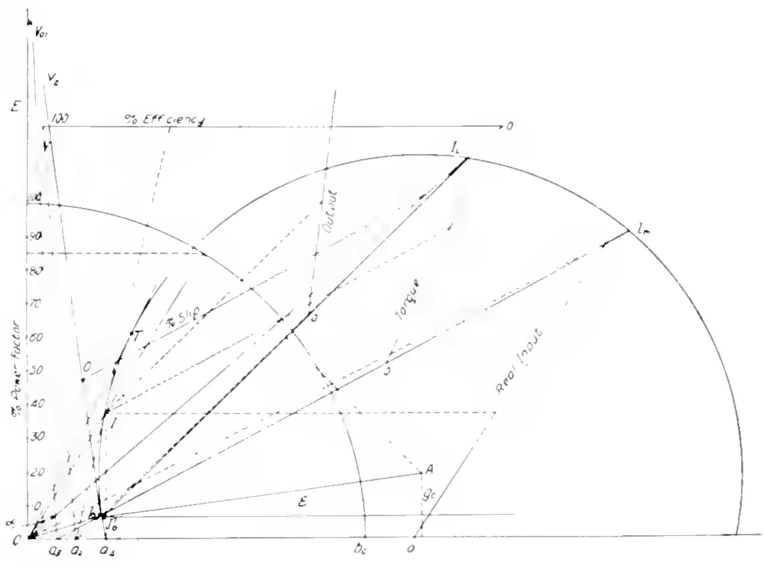


Fig. 18. Circle Diagram by Specht

Specht's Diagram. (See Electrical World, vol. XLV, page 388.) In Fig. 18 is shown a circle diagram due to Specht, which is constructed as follows: Lay off from the origin O the short circuit current (at full voltage) OI_L and the no-load current OI_0 at their proper angles and draw I_0I_L. The center of the current locus circle will obviously lie on a perpendicular line erected at the middle of I_0I_L.

The current vector OI_0^1 is the theoretical no-load current, the energy component of I_0^1 corresponding to the no-load input minus the primary copper loss. Draw parallel to the x axis a line through I_0^1 and lay off the angle ϵ as shown. The point of intersection of I_0^1A with the perpendicular erected at the mid point of I_0I_L marks the center of the current locus circle. The circle may now be drawn.

This angle ϵ may be determined as follows:

$tan\ \epsilon = \frac{OI_0^1 \times R_p}{E}$; $OI_0^1 = OI_0 = I_e$ (app.) If the theoretical no-load loss is the tested no-load input minus the friction, windage and primary copper loss could be obtained from the formula:

$$tan\ \epsilon = \frac{\overline{OI_0}^1}{E} \left[R_p + (X_p + X_s)\ cos\ \theta_0^1\right]$$

Since, however, this theoretical no-load point is difficult of determination, the term $\frac{OI_0^1}{E} (X_p + X_s)\ cos\ \theta_0^1$ is neglected to compensate for friction and windage losses.

For any current value between I_0 and I_L, as OI, the power-factor, input and output may be found graphically as follows: On the y axis a power-factor scale may be laid off as shown and a quadrant drawn. The intersection of the current vector (produced) with the projection of this quadrant on the y axis gives the power-factor. The input is proportional to the vertical distance measured from I to the x axis, since this quantity is equal to the product of the voltage and the component of the current in phase therewith. A scale showing real input directly may be constructed as shown. The output is proportional to the vertical distance measured from I to the line I_0I_L, since this quantity is equal to the product of the voltage and that portion of the current in phase therewith not consumed in the losses of the machine. A convenient scale may be constructed for output similar to that used for input.

I_m is a point at which the rotor resistance (effective) is zero. The power-factor for this condition may be computed from the formula,

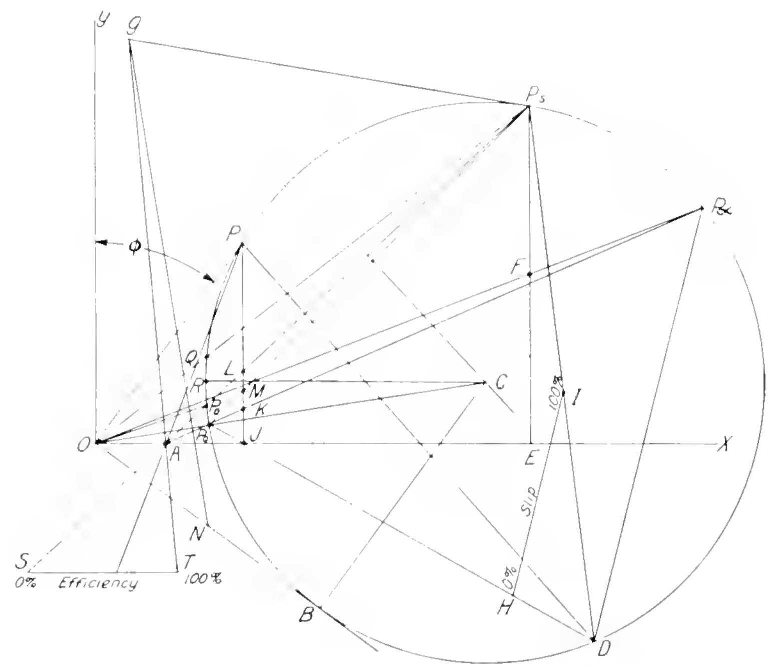


Fig. 19. Arnold Method

$$cos\ \theta_m = \frac{R_p}{\sqrt{R_p^2 + (X_p + X_s)^2}}$$

which determines I_m. Draw $I_m I_0$ and continue same until it intersects the x axis at a_3. The base line for total primary losses $a_3 V_{01}$ may now be drawn, making the angle a with the x axis. This angle may be found as follows:

$$tan\ a = \frac{Eb_c - x_p T^2}{R_p T^2 - Eg_c - 2d\ (b_c R_p - g_c X_p)}$$

where d = distance of a_3 from O in amperes
b_c = abscissa of A "
g_c = ordinate of A "
T = length of tangent OT "

Draw tangent $I_0^1 V_2$ and continue it until it intersects the x axis at a_4. This line is termed the base line of secondary copper loss. Prolong $I_L I_0$ until it intersects the x axis at a_2 and draw $a_2 V$, dividing the distance between $a_3 V_{01}$ and $a_4 V_2$ in the ratio $\frac{a_3 a_2}{a_2 a_4}$.

A line parallel to the x axis, determined by $I_0 I_L$ and $a_2 V$, constitutes a scale of efficiency, as shown. A line parallel to $I_0^1 I_m$, determined by $a_4 V_2$ and $I_0^1 I_L$, forms a scale of slip, as shown.

Arnold Graphical Method. Prof. Arnold has developed a graphical method representing the graphical solution of circuit A, Fig. 5. This may be outlined as follows.

Choose two axes OX and OY (Fig. 19) intersecting at O and forming a right angle. Lay off the short circuit current (at full load voltage) to some scale, as shown by OP_s, also lay off OP_0 representing the exciting current in value and phase position. Draw line $P_s P_0$ intersecting x axis at A. Erect a perpendicular to x axis and find mid point R. Draw RC parallel to x axis. The point of intersection, C, of this line with the perpendicular erected at the middle of $P_0 P_s$ is the center of the circle to be used as the current locus.

Draw tangents OB and $P_s G$. Bisect OB at N and draw NG perpendicular to OC. Draw GA. Any line drawn parallel to x axis and determined by lines $P_s S$ and GT (as ST) laid off in 100 parts constitutes a scale of efficiency.

Draw $P_s E$ perpendicular to OX and bisect it at F. Draw $OFP\alpha$ and $AP\alpha$ cutting the circle at $P\alpha$ and P_a respectively. The distance from P_0 to a line through P_a (parallel to OX) is a measure of the friction loss. Take any point on circle, as D, and draw $P_s D$ and $P\alpha D$; also $P_a D$. Any line, as HI, determined by the lines $P_s D$ and $P_a D$, drawn parallel to $P\alpha D$, if laid off into 100 parts constitutes a scale of slip.

To use this diagram, choose any point P between P_a and P_s. The line OP is proportional to total current. Cosine ϕ (as shown) represents the power-factor. PL is proportional to net output; PM to output plus frictional loss; PK to torque in synchronous watts; and PJ to total input.

In choosing scale for output, torque, etc., in this diagram, it should be borne in mind that the quantities are taken per phase and that the quantities measured are really values of current and must be multiplied by the proper wattage and number of phases to get real values.

Values of efficiency and slip may be read on their respective scales by drawing lines from P through A and from P to D.

(To be Continued)

THE DEVELOPMENT OF OIL CIRCUIT-BREAKERS

By E. B. Merriam

Assistant Engineer, Switchboard Department, General Electric Company

This article provides an interesting object-lesson in evolution, where the process has been forced by necessity. As a general rule the development of the generating machine has slightly antedated the development of its controlling switch; and, since the former is always useless, or at least dangerous, without the latter, the men in charge of oil-switch design have had to travel quickly in order to keep pace with the rapid strides which have been made in machine design and in increased outputs. More than once the limit has apparently been reached; but further demands have quickly followed, and the designer has been forced to prosecute fresh researches, in order that the required oil-break apparatus may be forthcoming.—Editor.

The demands of modern economic conditions have called for the concentrated production of electrical energy in large central stations. The control of this energy has presented many new problems in the design of protective devices, chief among which has been that of the automatic interrupter of abnormally loaded electrical circuits.

For many years oil circuit-breakers and fuses were used with good effect on direct current systems. When used on heavy power alternating current circuits connected to transmission systems, however, these devices set up line disturbances difficult to suppress. The large flaring arcs were also objectionable through their liability to involve adjacent apparatus, and on account of the great amount of room necessary for their proper isolation. Tests were made to find a suitable circuit-interrupting device for use on large-capacity systems. The various schemes tried included an air-break switch; a gravel switch; a switch in which an insulating shutter was thrown across the gap in order to shut out the arc; a lightning arrester switch, in which the principle of the non-arcing multigap arrester was employed; a tube switch, in which a plunger in descending drew an arc into a tube with an opening at the top, the pressure developed in the tube blowing the arc out through this opening; a switch in which a blast of air was blown across the contacts, thus lengthening out and rupturing the arc; and switches having an upward or downward break in a suitable oil. Of these various devices, the most efficacious was found to be that in which the circuit was opened in oil.

The investigators, having found that an oil-break circuit interrupter was the most suitable, next turned their attention to finding out the most suitable type of oil circuit-breaker. With this end in view, they experimented with knife-blades in oil, with drums similar to railway controllers, and with rods having a vertical or horizontal movement. This led to the development of a lever switch immersed in oil, which, for several years, remained the most efficient type of oil-break switch. As capacities increased, however, the limits of this switch were soon reached; and, as a result of the previous tests, there was developed a switch having a double

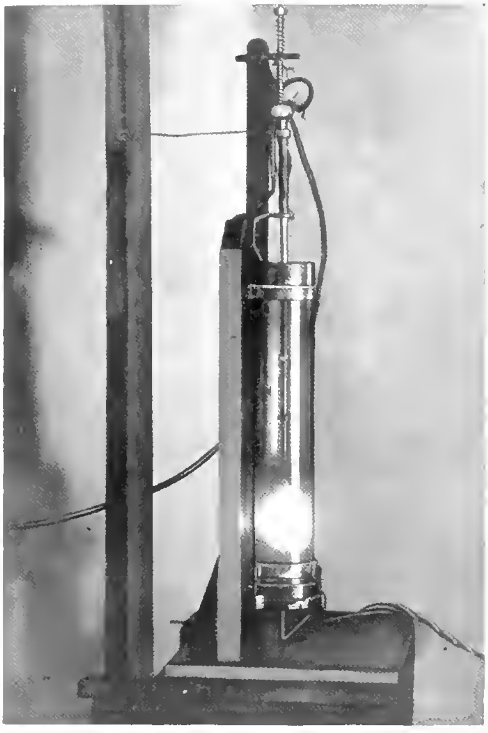


Fig. 1. Miniature Oil-break Switch, Used to Study the Action of a Transient Electric Arc Under Oil

downward break in oil. The stationary contacts of this switch were spring fingers, and the moving element was a bridging contact which connected the stationary ones when the switch was closed. This device had advantages in that the contacts cleaned themselves each time the switch was operated; that there were a minimum number of points to be insulated from ground; and that the stationary contacts, when the switch was open, were always insulated from each other by a clean layer of oil, since, as they were located near the top of the oil-vessel, most of the moisture and dirt in the oil gravitated to the bottom. The main advantage of this switch, however, was that it was possible to remove the oil vessel for inspection of the contacts and renewal of oil without disturbing any other portion of the switch, particularly the connections. This switch as initially developed was in service on circuits up to 6600 volts and is still effective.[1] The time soon came when transmission voltages began to pass this point and rendered necessary the development of switches for use at higher voltages on larger systems.

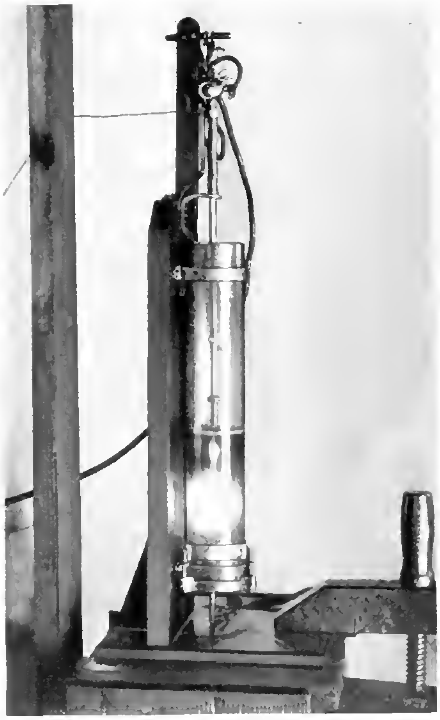


Fig. 2. Miniature Oil-break Switch Used for Experimental Study of Arc-squelching Schemes

Fig. 3. Transient Electric Arc in Air, Showing the Necessity of Oil-break Switch When Large Amounts of Power are to be Opened

A radical departure was early made in the design of the oil circuit-breaker. For controlling the larger capacity circuits which were first encountered investigations were made on a double upward vertical-break switch, in which each break was made in a separate compartment. The first commercial device consisted of cylindrical oil vessels, rather short for their diameter, in which the rods moved vertically upward, and in which the oil-chamber was practically sealed from the outside air. Owing to the air-tight nature of the oil-vessel operating difficulties were experienced; and the next step was to open the oil-chamber to air, placing suitable oil-diverters in the top of the oil-vessel so as to deflect any oil which might be thrown out due to the opening of the switch and the formation of an arc. With increased generating capacities it was found that this switch at times ejected a quantity of oil; and it was next necessary to provide a suitable air space in the top of the oil-vessels to act as a buffer. Besides this, an increased vent space was found necessary so that the air on top of the oil could be readily renewed, thus preventing the formation of explosive mixtures.

The maintained increase in generating capacities soon overtook the developments in oil circuit-breakers, and necessitated an additional investigation to increase the capacity of the device. As a result there was developed a baffle plate for the vertical upward-break type of circuit-breaker. The function of this device was to keep the oil in the neighborhood of the stationary contacts, for whenever an electrical circuit carrying considerable energy is opened in oil gases are generated. These expand and rise, and tend to force the oil out of the containing vessel. They also form with air explosive mixtures, and either explode, or burn for a considerable length of time when ignited. It is seen, therefore, that oil circuit-breakers must be provided with strong oil-containing vessels in order that they may withstand the high initial stresses which are often present under certain conditions, and also that suitable provision be made for retaining the oil.

This type of switch remained standard for large-capacity systems for a number of years. The advent of the steam turbine-generator, with its greatly diminished internal reactance and correspondingly increased short-circuit current, increased the short-circuit current of systems beyond the capacity of this circuit-breaker. To meet the new condition further investigations were made; and suitable oil-diverting devices were introduced into the oil-vessels, which practically doubled the capacity of the oil-circuit breaker. This, together with structural changes in the design of the oil-vessel, made the highly developed large capacity oil circuit-breaker of to-day for use on moderate voltage systems. The present indications are that the oil circuit-breaker will not be developed very much further along the lines at present being followed; but that, for the control of very much greater capacities than at present found, some new lines of improvement will be necessary. At present it is proposed to take care of these greater capacities by sub-dividing the generating units into groups of less than 50,000 kw. It is not possible to apply it to all systems owing to the diversity of the loads which they carry, together with their method of distributing power. Another proposal is the introduction of current limiting reactances, not only into the generator circuits but also into the feeder circuits.

Fig. 5. Oil-break Switch for Out-of-door Installations

Fig. 4. Oil-break Switches Under Test Conditions Made to Represent Actual Operation

In the above outline, mention was made of the increase in the capacities of systems, reference being made principally to those of moderate voltage. At the same time the pressure of transmission lines has been gradually increased; until a point was some time ago reached beyond which the developed circuit-breakers were unsuited for the control

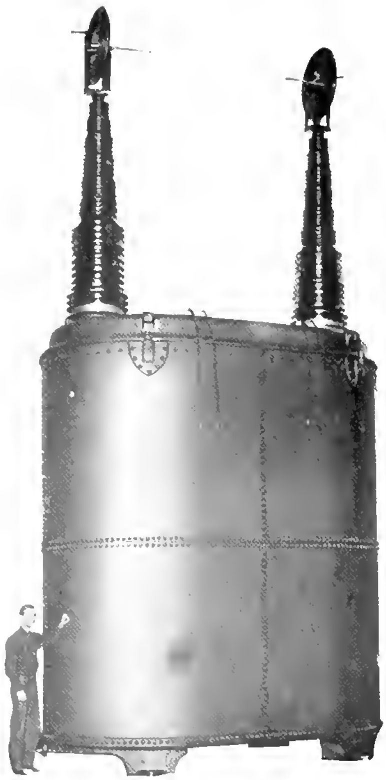


Fig. 6. 750,000 Volt Testing Transformer for Investigating Insulation for High-voltage Oil-break Switches

of circuits of higher voltage. To meet the need for a circuit-breaker for use on high voltage systems, a research was made for developing proper methods of insulating the terminals of oil circuit-breakers. Early investigations in connection with a 40,000-volt installation disclosed the fact that, for this pressure, wet-process porcelain made a suitable bushing; although it was found that simply increasing the dimensions of a porcelain bushing would not take care of the higher voltages soon to be encountered. The problem involved in designing a bushing is different from, and more difficult than, that of designing an insulator. It has been found that, owing to the electrical constants of these materials, no great benefit is derived from increasing the thickness of insulation, owing principally to the uneven distribution of the electric potential. The result has been the development of two radically different types of bushings for insulating the leads of oil circuit-breakers. One of these is the so-called condenser lead originating in Germany, and the other the filled lead, a product of this country. These two bushings represent the results of a great deal of research in attempting to overcome the obstacles imposed by the very high voltages now used on long distance transmission lines. A somewhat striking photograph is reproduced on the cover of this publication, showing the upper half of an oil-break switch bushing being tested at 400,000 volts.

Another feature of high voltage circuit-breakers which is now apparent is their huge size, and the great amount of oil necessitated by the requirements of insulation. It should be noted that oil circuit-breakers for use on circuits of moderate voltage have their over-all dimensions usually fixed by the energy of the circuit which they control. Those for high voltage, however, have their size fixed principally by the insulation value of the mediums used in the construction of the device and the factor of safety required. At present it has been found advisable to use principally air and some insulating liquid such as petroleum oil for the insulation between ground and bare contacts of the circuit-breaker.

It is thus seen that modern oil circuit-breakers are the result of extensive research, undertaken in order to meet the demand for apparatus which will efficiently and safely control the output of large electrical stations.

POTENTIAL CONTROL OF ALTERNATING CURRENT SYSTEMS BY SYNCHRONOUS MOTORS WITH AUTOMATIC VOLTAGE REGULATORS

By Ernst J. Berg

Professor of Electrical Engineering, University of Illinois

From time to time there have appeared in the Review contributions on the synchronous condenser and its effect on power-factor, as well as descriptions of typical installations with brief statements of the results obtained. The increasing demand for improved economies in transmission lines and distribution systems has awakened such interest in this machine that we feel that it may not be unseasonable to present to our readers a series of articles dealing with the synchronous condenser as a means for the improvement of power-factor and the maintenance of constant voltage, as well as detailed descriptions of such installations as may be of genuine interest to the engineering fraternity. Our first article, which appears in this issue, is a paper by Dr. E. J. Berg, reprinted with some modifications from the September, 1907, issue of the General Electric Review. In it are derived certain simple formulæ useful in synchronous condenser calculations and in the investigation of the results to be expected from its use; while the accompanying tables demonstrate the great advantages to be gained from the installation of such a machine. We hope to print the second article of the series in an early issue.—Editor.

To obtain independent potential control of different feeders in a distribution system, some kind of regulator must be used. Frequently such control is obtained by the use of a transformer provided with a number of taps which are connected to a dial switch. The potential is then varied, either automatically or by hand, by connecting the lines to different sections of the transformer. Another and more satisfactory way is that of using a synchronous motor in connection with an automatic voltage regulator. This arrangement operates to maintain constant potential in the receiving circuit by virtue of the following well-known characteristics of the synchronous motor.

For any given load on a synchronous motor the armature current is at a minimum for a certain critical value of the field excitation. At this point the motor constitutes a load of unity power-factor, the current taken by the motor being neither lagging nor leading. For weaker field excitations the current taken by the motor is lagging, and for stronger field excitations the current taken is leading. Therefore controlling the excitation of the synchronous motor provides a means of varying the power-factor of the local receiving circuit of which the synchronous motor forms a part.

General Discussion

Before attempting to explain the rather complex electrical phenomena involved in this method of control, it may be desirable to recapitulate some of the fundamental principles involved in any electric power transmission proposition.

The general equation giving the relation between emf's currents and line constants is:

$$E=e+IZ \tag{1}$$

where

E = voltage per phase at generator

e = voltage per phase at receiving circuit

I = total current in each line conductor $=i+ji_1-ji_2$

j, i, i_1, and i_2 being respectively $\sqrt{-1}$, energy current, and wattless currents, i_1 being lagging when positive and i_2 being leading when positive.

Z = impedance per phase $=r-jx$, r and x being respectively the resistance per phase and the reactance per phase, including, of course, transformers and reactive coils as well as line. Assume that the generator voltage is kept constant, and the ratio $\frac{E}{e}=k$

Substituting for I and Z in (1):

$$\begin{aligned}E&=e+(i+ji_1-ji_2)\ (r-jx)\\&=e+ir+i_1x-i_2x-j\ (ix-i_1r+i_2r)\end{aligned}$$

Inasmuch as the imaginary term in this expression is small compared with the real term, we may neglect it and write

$$E=e+ir+i_1x-i_2x \tag{2}$$

$$\text{and } i_2=\frac{e\ (1-k)+ir+i_1x}{x}$$

The voltage of the generating station is most conveniently kept constant at all loads. The function of the synchronous motor, connected at each receiving center with the regulator for controlling the field excitation, is to maintain the receiving circuit at constant voltage, the value of which will be determined by the calculations. Since $k=\frac{E}{e}$ in any particular branch system, the problem is to keep this ratio constant at all loads. It results from this condition that at light load or no load on the receiving circuit a lagging current has to be taken by the synchronous motor to establish an artificial drop, when otherwise there should be none; and at full load a leading current should be taken to help to overcome the drop due to the load proper.

Substituting $k=\frac{E}{e}$, and the full load values $i=C$, $i_1=C_1$ and $i_2=C_2$ in (2), and solving for C_2:

$$C_2=\frac{e\ (1-k)+Cr+C_1x}{x} \qquad (3)$$

and

$$k=\frac{e+Cr+C_1x-C_2x}{e} \qquad (4)$$

These equations thus give a means of determining the amount of wattless current C_2 necessary to maintain the ratio k between generator voltage and receiving voltage, over a transmission of constants r and x, at full load on the receiving circuit proper, that is with a load of C amperes energy current and C_1 amperes lagging current.

To use the synchronous motor to best advantage it should give full leading current at full load, and full lagging current at no load, on the receiving circuit proper. Thus, at no load, substituting $C=0$, $C_1=0$, and $C_2=-C_2$ for lagging current, in (4), we get

$$k=\frac{e+C_2x}{e}$$

Substituting this value of k in (3) and solving for C_2:

$$C_2=\frac{Cr+C_1x}{2x} \qquad (5)$$

Again, substituting this value of C_2 in (4):

$$k=1+\frac{Cr+C_1x}{2e} \qquad (6)$$

Since C_2 is the leading or lagging current taken by the synchronous motor, these two equations (5) and (6) give us the rating of the synchronous motor and the ratio of voltages at all loads between generator and receiving end of line.

To find the synchronous motor current for any fractional load of the receiving system proper, substitute in (2) the value k, as obtained in (6), and solve for i_2, obtaining:

$$i_2=\frac{ir+i_1x}{x}-\frac{Cr+C_1x}{2\,e\,x} \qquad (7)$$

which is therefore a general equation giving the synchronous motor currents for any loads i and i^1, in the receiving circuit when C and C_1 represent the full load values.

At half load (7) becomes

$$i_2=0$$

that is, the synchronous motor runs without wattless current. At less than half load i_2 is negative, that is lagging, and at more than half load i_2 is positive, that is leading.

The total line current is $I=i+ji_1-ji_2$

or

$$I=i+j\ (i_1-i_2)$$
$$=\sqrt{i^2+(i_1-i_2)^2}$$

The line loss is therefore

$$[i^2+\ (i_1-i_2)^2]r;$$

and the per cent. line loss of the loss if no compensation were used is

$$100\ \frac{i^2+(i_1-i_2)^2}{i^2+i_1^2}=$$

$$100\left(1\ -\ \frac{2i_1-i_2^2}{i^2+i_1^2}\right) \qquad (8)$$

There is obviously no reduction in line loss if $i_2=2i_1$, but there is gain if $i_2\ <\ 2i_1$. It is also obvious, from (7), that the greater the reactance x the smaller is the synchronous motor current i_2.

As a rule the line and transformer reactance is not sufficient to enable the most economical synchronous motor to be used, but additional reactance has to be installed. There is, however, a practical limit to the amount of reactance that can be used; but it is safe to say that unless the line and transformer reactance amounts to 15 per cent, reactive coils should be installed so as to bring the total reactance to between 15 and 20 per cent.

Application of Automatic Voltage Regulator

This regulator to work satisfactorily should not be called upon to take care of a range of field excitation of more than 100 per cent. Therefore, to utilize the synchronous motor to its full capacity it should have such characteristics that with a change of field excitation of 100 per cent the current changes from full load lagging to full leading. Such synchronous motors must have a close regulation, i.e., should give at least three times full load current when short-circuited with normal field.

Motors which have a short-circuiting current of from 1.6 to 2 times full load current are therefore not suited for control, except at a reduced rating. These motors, with 100 per cent variation of field excitation, can only be used as compensators to 53 per cent and 67 per cent of their rated outputs, respectively.

It is often desirable to make use of the compensating synchronous motor for power purposes, especially since the synchronous motor lends itself to this double function with very slight increase of heating.

The theoretical relation between mechanical output and output as compensator is as sine to cosine, as given in Table I or vice versa:

TABLE I

PER CENT. OF RATING ENERGY OUTPUT	PER CENT. RATING FOR PHASE CONTROL
100	0
95	31
90	43
80	59
71	71
50	87

As an illustration, assuming that the calculations indicated a synchronous motor, as compensator, of 310 kw. capacity, and that a synchronous motor of 1000 kw. running at a maximum load of 950 kw., was already installed, the use of the motor for both phase control and power purposes would result in only normal heating.

Numerical Instance

1000 kw., 60-cycle, three-phase power is delivered at 10,000 volts over a line 19.2 miles long made of No. 0 B. & S. wires 18 in. apart. The power-factor of the load is 89.5 per cent.

$$C = \frac{\text{watts delivered}}{\text{delivered voltage} \times \sqrt{3}}$$

$$= \frac{1{,}000{,}000}{10{,}000\sqrt{3}} = 57.8$$

$$C_1 = \sqrt{\left(\frac{C}{\text{Power-factor}}\right)^2 - C^2}$$

$$= \sqrt{\left(\frac{57.8}{.895}\right)^2 - 57.8^2} = 28.9$$

The resistance and reactance are obtained from equations given in the discussion of line constants, as:

$r = 10$ ohms

$x = 11.5$ ohms.

Substituting these values in (5):

$$C_2 = \frac{Cr + C_1x}{2x}$$

$$= \frac{(57.8)\ (10) + (28.9)\ (11.5)}{2\ (11.5)}$$

$$= 39.5 \text{ amp.}$$

Substituting in (6):

$$k = 1 + \frac{Cr + C_1x}{2e} = 1.079$$

Thus since the full load energy current is 57.8 amp., the synchronous motor must have a capacity equal to 68 per cent of the energy output, and the generator voltage should be kept 7.9 per cent higher than the voltage at the receiving end.

The reduction in line loss by the use of the compensating motor is obtained by substituting these values in (8), as:

$$100\left(1-\frac{2(28.9)+(39.5-(39.5)\ (39.5)}{57.8^2+28.9^2}\right)$$

$$=83.$$

i.e., 83 per cent of what it would have been if no compensation were used. Or, putting it in another way, the line copper could be decreased 17 per cent for the same loss.

Calculated Tables

The following tables facilitate determinations of the various constants involved in these problems, and refer to unit energy delivered at the receiving station. Various percentages of resistance and reactance are considered. Resistances of 5, 10 and 15 per cent mean that 5, 10 and 15 per cent of the voltage per phase at the receiving end is consumed in the transmission resistance when full load current is passing. Reactances of 10, 20 and 30 per cent mean reactances of such value that if full load current is passing the drop will be 10, 20 and 30 per cent respectively.

The tables are worked out for various power-factors of the load, and give the ratio of generator voltage to voltage at the receiving end of the line. The size of the synchronous motor is given as the ratio of synchronous motor rating to energy output of load, and the relative line losses are given with and without the use of the motor.

The values in Table II are computed for a total reactance of 10 per cent, made up of line reactance proper and any other reactance in series with the line. Table III is computed for a total reactance of 20 per cent, and Table IV for a reactance of 30 per cent.

The following example will serve to illustrate the use of the tables. Assume a line of 10 ohms resistance and such reactance that with energy current flowing there is 10 per cent drop in voltage (referring to the receiving end), and 20 per cent total reactance, consisting of 10 per cent in line reactance and 10 per cent in special reactive coils. The power-factor of the load is 89.5 per cent.

Referring to the table: The synchronous motor should have a capacity equal to 50 per cent of the actual load; the generator voltage should be kept 10 per cent higher than the voltage at the receiving end; and the line loss will be 10 per cent, instead of the 12.5 per cent which it would be if no compensating synchronous motor were used.

TABLE II

Compensation for Line Drop by Synchronous Motor

Per Cent Line Drop	Per Cent Power-factor	Energy Load at Receiving End	Volts at Generating End	Volts at Receiving End	Capacity of Synchronous Motor*	Per Cent Line Loss Without Compensation	Per Cent Line Loss With Compensation
Res., 5 React., 10	100	Full	1.025	1.00	25.	5.	5.3
		3/4			12.5	2.8	2.89
		1/2			0.	1.25	1.25
		1/4			12.5	0.31	0.39
		0			25	0.	0.31
	89.5	Full	1.05	1.00	50.	6.25	5.
		3/4			25.	3.55	2.89
		1/2			0.	1.56	1.56
		1/4			25.	0.39	0.39
		0			50.	0.	1.25
	70.7	Full	1.075	1.00	75.	10.	5.3
		3/4			37.5	5.63	3.51
		1/2			0.	2.5	2.5
		1/4			37.5	0.62	0.39
		0			75	0	2.8
	50	Full	1.1115	1.00	111.5	20.	6.9
		3/4			56.	11.26	5.56
		1/2			0.	5.	5.
		1/4			56.	1.25	0.39
		0			111.5	0.	6.2
Res., 10 React., 10	100	Full	1.05	1.00	50.	10.	12.5
		3/4			25.	5.63	6.25
		1/2			0.	2.5	2.5
		1/4			25.	0.62	1.25
		0			50.	0.	2.5
	89.5	Full	1.075	1.00	75.	12.5	10.6
		3/4			37.5	7.04	5.63
		1/2			0.	3.13	3.13
		1/4			37.5	0.78	1.25
		0			75.	0.	5.6
	70.7	Full	1.10	1.00	100.	20.	10.
		3/4			50.	11.26	6.25
		1/2			0.	5.	5.
		1/4			50.	1.25	1.25
		0			100.	0.	10.
	50	Full	1.1365	1.00	136.5	40.	11.33
		3/4			68.3	22.52	9.41
		1/2			0.	10.	10.
		1/4			68.3	2.5	1.25
		0			136.5	0.	18.6
Res., 15 React., 10	100	Full	1.075	1.00	75.	15.	23.4
		3/4			37.5	8.45	10.56
		1/2			0.	3.75	3.75
		1/4			37.5	0.94	3.05
		0			75.	0.	8.4
	89.5	Full	1.10	1.00	100.	18.7	18.75
		3/4			50.	10.55	8.68
		1/2			0.	4.68	4.68
		1/4			50.	1.17	3.05
		0			100.	0.	15.
	70.7	Full	1.125	1.00	125.	30.	15.9
		3/4			62.5	16.9	8.68
		1/2			0.	7.5	7.5
		1/4			62.5	1.87	3.05
		0			125.	0.	23.4
	50	Full	1.162	1.00	161.5	60.	16.7
		3/4			80.8	33.8	12.06
		1/2			0.	14.6	14.6
		1/4			80.8	3.75	3.05
		0			161.5	0.	39.2

TABLE III

Compensation for Line Drop by Synchronous Motor

Per Cent Line Drop	Per Cent Power-factor	Energy Load at Receiving End	Volts at Generating End	Volts at Receiving End	Capacity of Synchronous Motor*	Per Cent Line Loss Without Compensation	Per Cent Line Loss With Compensation
Res., 5 React., 20	100	Full	1.025	1.00	12.5	5.	5.08
		3/4			6.3	2.8	2.84
		1/2			0.	1.25	1.25
		1/4			6.3	0.31	0.33
		0			12.5	0.	0.08
	89.5	Full	1.075	1.00	37.5	6.3	5.08
		3/4			18.7	3.55	3.
		1/2			0.	1.56	1.56
		1/4			18.7	0.39	0.33
		0			37.5	0.	0.71
	70.7	Full	1.125	1.00	62.5	10.	5.7
		3/4			31.3	5.63	3.8
		1/2			0.	2.5	2.5
		1/4			31.3	0.62	0.33
		0			62.5	0.	1.95
	50	Full	1.198	1.00	99.	20.	7.7
		3/4			49.5	11.26	6.
		1/2			0.	5.	5.
		1/4			49.5	1.25	0.33
		0			99.	0.	4.9
Res., 10 React., 20	100	Full	1.05	1.00	25.	10.	10.6
		3/4			12.5	5.63	5.78
		1/2			0.	2.5	2.5
		1/4			12.5	0.62	0.78
		0			25.	0.	0.63
	89.5	Full	1.10	1.00	50.	12.5	10.
		3/4			25.	7.04	5.78
		1/2			0.	3.125	3.125
		1/4			25.	0.78	0.78
		0			50.	0.	2.5
	70.7	Full	1.15	1.00	75.	20.	10.6
		3/4			37.5	11.26	7.04
		1/2			0.	5.	5.
		1/4			37.5	1.25	0.78
		0			75.	0.	7.5
	50	Full	1.223	1.00	111.5	40.	13.8
		3/4			56.	22.5	11.1
		1/2			0.	10.	10.
		1/4			56.	2.5	0.78
		0			111.5	0	12.47
Res., 15 React., 20	100	Full	1.075	1.00	37.5	15.	17.1
		3/4			18.8	8.45	9.
		1/2			0.	3.75	3.75
		1/4			18.8	0.94	1.47
		0			37.5	0.	2.16
	89.5	Full	1.125	1.00	62.5	18.7	15.2
		3/4			31.3	10.55	8.5
		1/2			0.	4.68	4.68
		1/4			31.3	1.17	1.47
		0			62.5	0.	5.8
	70.7	Full	1.175	1.00	87.5	30.	15.2
		3/4			43.8	16.9	10.
		1/2			0.	7.5	7.5
		1/4			43.8	1.87	1.47
		0			87.5	0.	11.47
	50	Full	1.248	1.00	124.	60	18.6
		3/4			62	33.8	15.4
		1/2			0	15.	15.
		1/4			62.	3.75	1.47
		0			124	0	23.1

TABLE IV

Compensation for Line Drop by Synchronous Motor

Per Cent Line Drop	Per Cent Power-factor	Energy Load at Receiving End	Volts at Generating End	Volts at Receiving End	Capacity of Synchronous Motor*	Per Cent Line Loss Without Compensation	Per Cent Line Loss With Compensation
Res., 5 React., 30	100	Full	1.025	1.00	8.3	5.	5.03
		3/4			4.15	2.87	2.82
		1/2			0.	1.25	1.25
		1/4			4.15	0.31	0.32
		0			8.3	0.	0.04
	89.5	Full	1.10	1.00	33.3	6.25	5.14
		3/4			16.7	3.55	3.03
		1/2			0.	1.56	1.56
		1/4			16.7	0.39	0.32
		0			33.3	0.	0.56
	70.7	Full	1.175	1.00	58.3	10.	5.86
		3/4			29.2	5.63	3.86
		1/2			0.	2.5	2.5
		1/4			29.2	0.62	0.32
		0			58.8	0.	1.71
	50	Full	1.283	1.00	94.6	20.	8.07
		3/4			47.3	11.26	6.21
		1/2			0.	5.	5.
		1/4			47.3	1.25	0.32
		0			94.6	0.	4.46
Res., 10 React., 30	100	Full	1.05	1.00	16.66	10.	10.28
		3/4			8.3	5.63	5.7
		1/2			0.	2.5	2.5
		1/4			8.3	0.62	0.69
		0			16.66	0.	0.28
	89.5	Full	1.125	1.00	41.6	12.5	10.05
		3/4			20.8	7.04	5.91
		1/2			0.	3.13	3.13
		1/4			20.8	0.78	0.69
		0			41.6	0.	1.73
	70.7	Full	1.20	1.00	66.6	20.	11.11
		3/4			33.3	11.26	7.36
		1/2			0.	5.	5.
		1/4			33.3	1.25	0.69
		0			66.6	0	0.44
	50	Full	1.309	1.00	10.3	40.	14.9
		3/4			51.5	22.56	11.73
		1/2			0.	10	10.
		1/4			51.5	2.5	0.69
		0			10.3	0.	10.6
Res., 15 React., 30	100	Full	1.075	1.00	25.	15.	15.9
		3/4			12.5	8.45	8.68
		1/2			0.	3.75	3.75
		1/4			12.5	0.94	1.17
		0			25.	0.	0.63
	89.5	Full	1.15	1.00	50.	18.7	15.
		3/4			25.	10.55	8.68
		1/2			0.	4.68	4.68
		1/4			25.	1.17	1.17
		0			50.	0.	2.5
	70.7	Full	1.225	1.00	75.	30.	15.9
		3/4			37.5	16.9	12.2
		1/2			0.	7.5	7.5
		1/4			37.5	1.87	1.17
		0			75.	0.	5.6
	50	Full	1.335	1.00	111.7	60.	20.6
		3/4			56.	33.8	16.6
		1/2			0.	15.	15.
		1/4			56.	3.75	1.17
		0			111.7	0.	12.5

*This gives synchronous motor capacity as a percentage of the energy output of the receiving circuit, assuming a synchronous motor that has a short-circuit current three times as large as a normal full load current.

ADVANCED COURSE IN ELECTRICAL ENGINEERING

PART V

BY ERNST J. BERG

Coils Having Resistance, Self Inductance and Imperfect Mutual Inductance

Fig. 19 represents two such coils wound in the same direction and connected to two sources of constant potential. Let the e.m.f. impressed on the first coil be E and that on the second coil E_1. Let their resistances and inductances be respectively r, r_1 and L, L_1 and let $M < LL_1$.

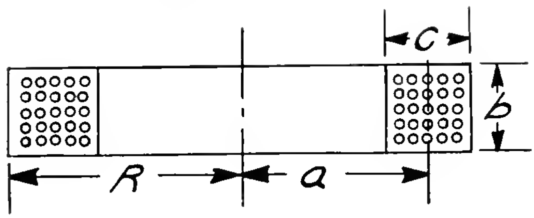


Fig. 14

It follows that

$$E = ri + L\frac{di}{dt} + M\frac{di_1}{dt} \qquad (82)$$

and

$$E_1 = i_1 r_1 + L_1\frac{di_1}{dt} + M\frac{di}{dt} \qquad (83)$$

Differentiate 83.

$$\therefore O = r_1\frac{di_1}{dt} + L_1\frac{d^2 i_1}{dt^2} + M\frac{d^2 i}{dt^2} \qquad (84)$$

From 82 is found

$$\frac{di_1}{dt} = \frac{1}{M}\left(E - ir - L\frac{di}{dt}\right) \qquad (85)$$

$$\therefore \frac{d^2 i_1}{dt^2} = -\frac{1}{M}\left(r\frac{di}{dt} + L\frac{d^2 i}{dt^2}\right) \qquad (86)$$

Substitute (85) and (86) in (84) and arrange the equation in reference to derivatives.

$$\therefore \frac{d^2 i}{dt^2}\left(LL_1 - M^2\right) + \frac{di}{dt}\left(L_1 r + L r_1\right) + irr_1 = Er_1 \qquad (87)$$

Or

$$\frac{d^2 i}{dt^2} + \left[\frac{L_1 r + L r_1}{LL_1 - M^2}\right]\frac{di}{dt} + \frac{rr_1 i}{LL_1 - M^2} = \frac{Er_1}{LL_1 - M^2} \qquad (88)$$

$$\therefore i = \frac{E}{r} + A_1\epsilon^{m_1 t} + A_2\epsilon^{m_2 t} \qquad (89)$$

Similarly

$$i_1 = \frac{E_1}{r_1} + B_1\epsilon^{m_1 t} + B_2\epsilon^{m_2 t} \qquad (90)$$

where m_1 and m_2 are the roots of equation.

$$m^2 + \frac{L_1 r + L r_1}{LL_1 - M^2}m + \frac{rr_1}{LL_1 - M^2} = 0 \qquad (91)$$

$$m = -\frac{(L_1 r + L r_1) \mp \sqrt{(L_1 r - L r_1)^2 + 4M^2 r r_1}}{2(LL_1 - M^2)} \qquad (92)$$

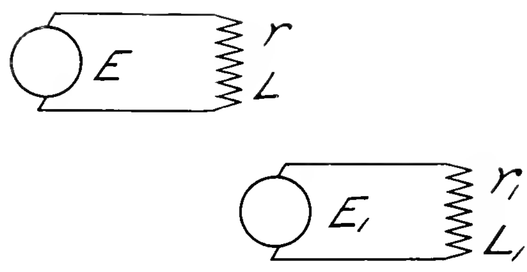
It is evident, from the factors under the square root sign, that in this case the two roots are real.

Thus the solution is

$$m_1 = -\frac{L_1 r + L r_1 - \sqrt{(L_1 r - L r_1)^2 + 4M^2 rr_1}}{2(LL_1 - M^2)} \qquad (93)$$

and

$$m_2 = -\frac{L_1 r + L r_1 + \sqrt{(L_1 r - L r_1)^2 + 4M^2 rr_1}}{2(LL_1 - M^2)} \qquad (94)$$



Figs. 15 and 19

The integration constants A_1, A_2 and B_1, B_2 are readily determined, since in this case (where the mutual inductance is not perfect) currents can not flow without producing some flux, and thus, since the establishment of flux requires time, the currents can not appear instantaneously.

Therefore at $t=0$, $i=i_1=0$.

Referring to (89) and denoting the final current $\left(\text{where } I=\frac{E}{r}\right)$ (95)

by

$$0=I+A_1+A_2, \text{ or } A_2=-(A_1+I)$$

$$\therefore L_1E-ME_1=L_1ir-Mi_1r_1+(LL_1-M^2)\frac{di}{dt}$$

$$\therefore i_1=\frac{1}{Mr_1}\left[L_1ir+ME_1-L_1E+\frac{di}{dt}(LL_1-M^2)\right] \qquad (100)$$

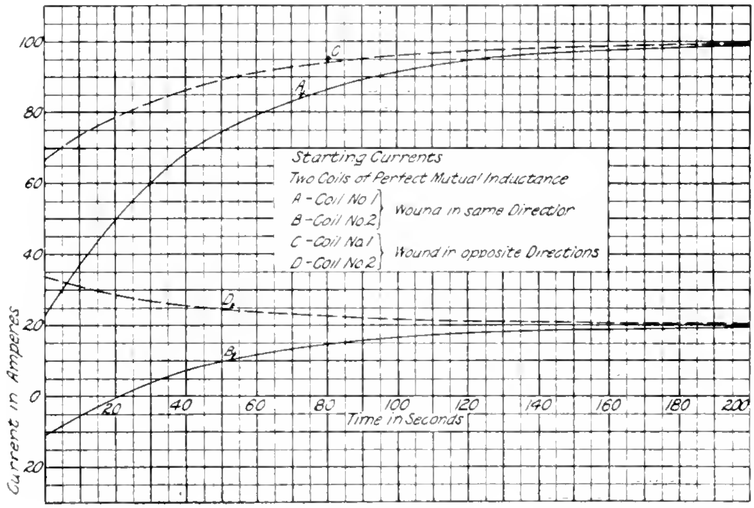


Fig. 16

we get

$$i=I+A_1\epsilon^{m_1t}-(A_1+I)\epsilon^{m_2t} \qquad (96)$$

and

$$i_1=I_1+B_1\epsilon^{m_1t}-(B_1+I_1)\epsilon^{m_2t} \qquad (97)$$

These equations still contain the two unknown quantities A_2 and B_2. To determine them, multiply (82) by L_1 and (83) by $-M$.

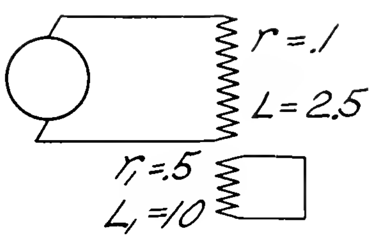


Fig. 17

$$L_1E=L_1ir+LL_1\frac{di}{dt}+L_1M\frac{di_1}{dt} \qquad (98)$$

$$-ME_1=-Mi_1r_1-ML_1\frac{di_1}{dt}-M_2\frac{di}{dt} \qquad (99)$$

The value of $\frac{di}{dt}$ is found by differentiating 96 and the value of i directly from equation (96). Substituting these values in (100) and remembering that for $t=0$, $i_1=0$, the integration constant A_1 is found to be:

$$A_1=\frac{L_1E-ME_1+m_2I(LL_1-M^2)}{(m_1-m_2)\ (LL_1-M^2)} \qquad (101)$$

$$\therefore A_2=-(A_1+I) \qquad (102)$$

Similarly

$$B_1=\frac{LE_1-ME+m_2I_1(LL_1-M^2)}{(m_1-m_2)\ (LL_1-M^2)} \qquad (103)$$

$$B_2=-(B_1+I_1) \qquad (104)$$

The equations of the currents are found by substituting these constants in equations (96) and (97). They are so long and cumbersome, however, that it seems unnecessary to insert them in this text.

Assume that the two coils are identical and wound in the same direction, and are connected across the same constant potential busbars. What are the equations of the currents? m_1 and m_2 are found from equations (93) and (94).

$$m_1 = -\frac{r}{L+M} \qquad (105)$$

$$m_2 = -\frac{r}{L-M} \qquad (106)$$

$A_1 = B_1$ is found from equation (101) by substituting these values.

$$A_1 = B_1 = -\frac{E}{r} = -I$$

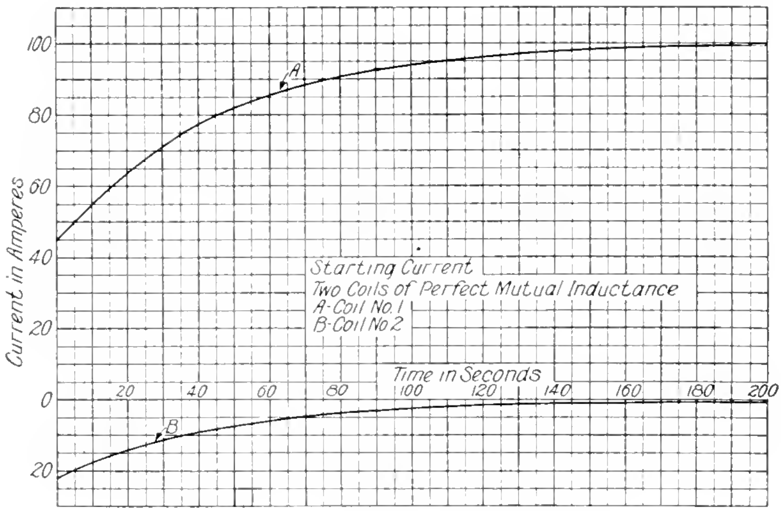


Fig. 18

thus

$$A_2 = B_2 = 0.$$

Referring to equation (96):

$$i = i_1 = \frac{E}{r}\left[1 - \epsilon^{-\frac{r}{L+M}t}\right] \qquad (107)$$

This shows that the mutual inductance acts as self inductance.

It is also evident that if the two coils are wound in opposite directions the circuit is almost non-inductive. It would be non-inductive if $M = L$; that is, with perfect mutual inductance. It is of particular interest to study the relations of the currents in two such identical windings inductively related when one is supplied with current from a source of constant potential and the other is short circuited.

It is well to deduce the equations from the two general expressions:

$$E = ir + L\frac{di}{dt} + M\frac{di_1}{dt}$$

and

$$0 = i_1 r_1 + L_1\frac{di_1}{dt} + M\frac{di}{dt}$$

However, it is evident that having once determined the general equations (96), (97), (101), (102), (103) and (104), it is possible to give the equations for the case in consideration by putting $E_1 = 0$;, that is,

$$I_1 = \frac{E_1}{r_1} = 0$$

$$i = I + A_1\epsilon^{m_1t} - (A_1 + I)\epsilon^{m_2t} \qquad (108)$$

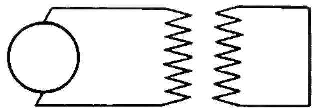


Fig. 20

and

$$i_1 = B_1\epsilon^{m_1t} - B_1\epsilon^{m_2t}$$

$$= B_1\,(\epsilon^{m_1t} - \epsilon^{m_2t}) \quad (109)$$

Referring to equation (101) and substituting equations (105) and (106)

$$A_1 = -\frac{I}{2}, \text{ and}$$

$$A_2 = -(I + A_1) = -\frac{I}{2}$$

$$\therefore\ i = I - \frac{I}{2}\left[\epsilon^{-\frac{r}{L+M}t} - \epsilon^{-\frac{r}{L-M}t}\right] \qquad (110)$$

Referring to equation (103) and making similar substitutions we get

$$B_1 = -\frac{I}{2}$$

$$\therefore\ i_1 = -\frac{I}{2}\left[\epsilon^{-\frac{r}{L+M}t} - \epsilon^{-\frac{r}{L-M}t}\right] \qquad (111)$$

It is evident that these equations do not lead themselves to the limiting condition

$M = L$, on account of the assumption made in determining the integration constants; viz., that leakage flux exists between the two coils. To get these values, equations (70) and (71) should be used.

placed at various distances apart so that the mutual inductance is $M = L$ in curve *a*, $M = 0.9\ L$ in curve *b*, $M = 0.7\ L$ in curve *C*, $M = 0.5\ L$ in curve *d*, and $M = 0.1\ L$ in curve *e*.

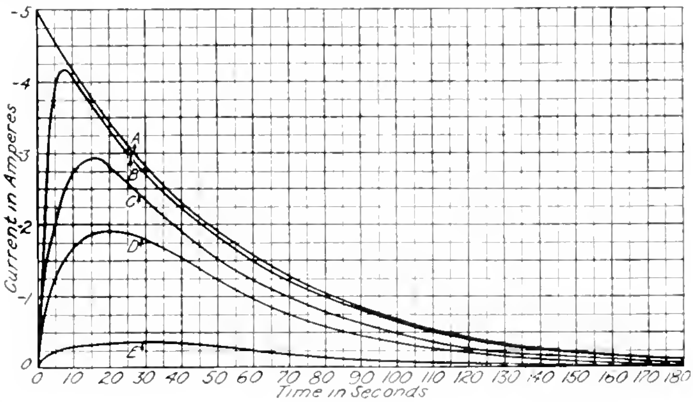


Fig. 21. Induced Currents. Two Coils of Self-inductance L, and Mutual Inductance M The Primary Connected Across D C. Mains, the Secondary Short-circuited

Curve A	$L_1 = L_2 = 2.5$ henrys	$R_1 = R_2 = 0.10$ ohms	$e = 1.0$ volt.	$L = M$
" B	" " "	" " "	" " "	$M = .9L$
" C	" " "	" " "	" " "	$M = .7L$
" D	" " "	" " "	" " "	$M = .5L$
" E	" " "	" " "	" " "	$M = .1L$

$$i_2 = \frac{e}{2R}\left(\epsilon^{-\frac{r}{L+M}t} - \epsilon^{-\frac{r}{L-M}t}\right)$$

In Fig. 21 are given some very interesting curves which show how the current in the short circuited winding depends upon the leakage flux between the windings. These curves represent the conditions of two identical coils having a resistance of 0.10 ohms and an inductance of 2.5 henrys,

One of the coils is connected to a source of constant potential, $e = 1$ volt, while the other is short circuited.

Prove that the time for the maximum value of the secondary current is:

$$t = \frac{L^2 - M^2}{2Mr}\ \epsilon\ log \frac{L+M}{L-M}.$$

(To be Continued)

ERRATUM

We regret that a rather serious error, which may have caused some confusion to many of our readers, appeared in the August Review in our publication of Professor Sydney W. Ashe's article on Acuity Tests. Two views were shown on page 507, reproduced from photographs taken on the same evening, in the same room, and with the same camera exposure, for an indirect and a direct lighting source. It was stated that Figure 4 represented the appearance of the room for the indirect lighting, and Figure 5 for the direct. The reverse is actually the case; and the upper picture, in which the shadows are considerably more sharply defined than in the lower, relates, of course, to the direct lighting method. For many reasons it would have been much simpler if we could have shown a reproduction of the complete negative in which the lighting source itself was visible. This scheme was hardly feasible, owing to the fact that the reduction which would have been necessary would have been such as to render it impossible, or at least very difficult, to distinguish any detail in the two views which were to be compared. The top part of the picture was therefore removed in each case; and we would repeat that the lighting unit in the case of the upper picture was a lamp carrying its diffuser in the usual burning position, and that the unit for the lower picture employed a lamp diffuser suspended in an inverted position with ordinary picture wire run through small holes punched near the rim.

NOTE ON THE EXPONENTIAL ϵ^{-x}

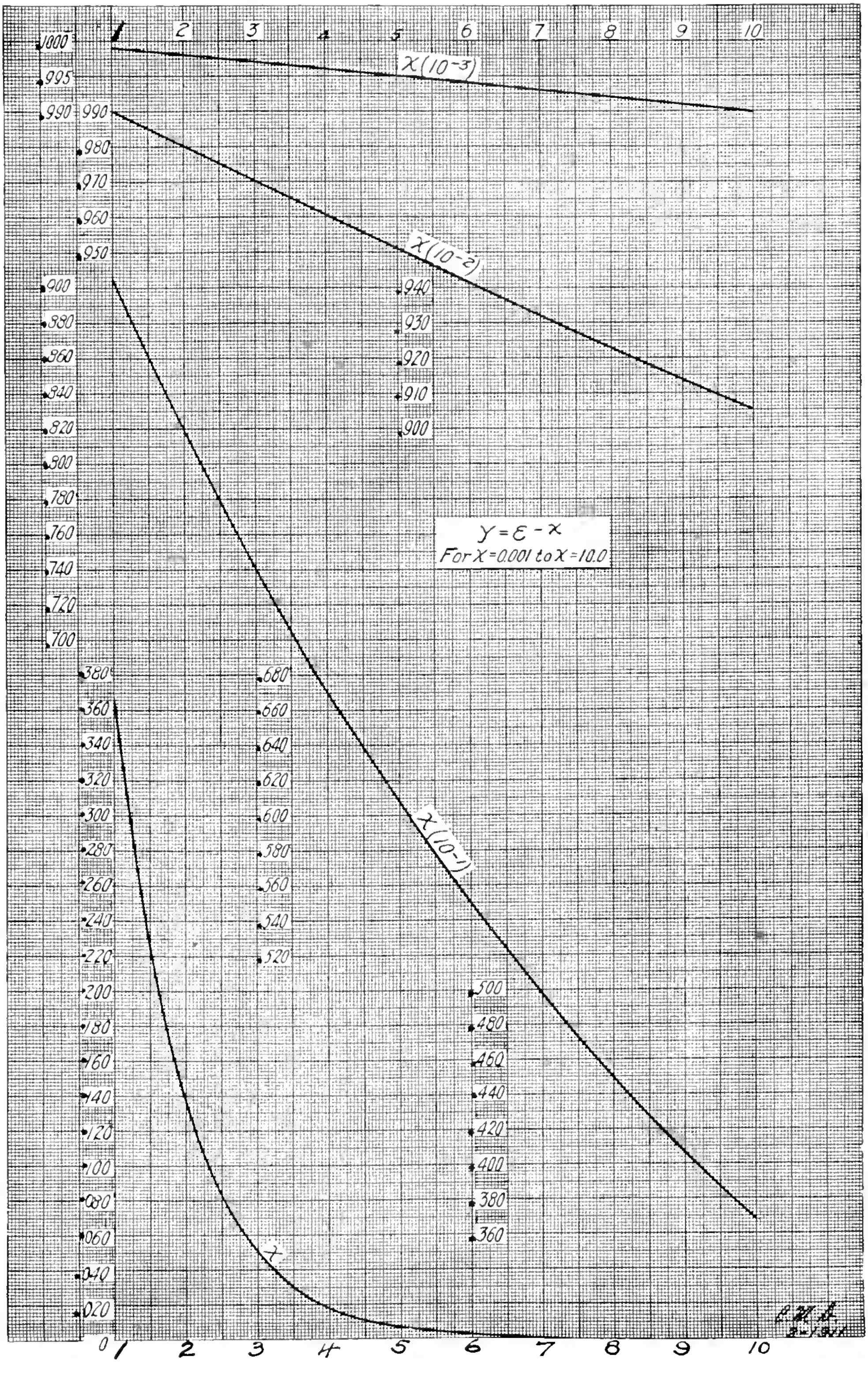
A study of Dr. Berg's lectures now appearing in the REVIEW shows that equations involving the exponential, ϵ^{-x}, are very frequent. The necessity for calculating many values of this expression has brought out a number of time and labor-saving devices, such as slide rules, tables and curves, giving results to three decimal places, which are sufficient for engineering calculations. The curve sheet on the opposite page was devised by the writer and has been found very convenient. It is offered here as supplementary to the curve Fig. 3, page 159, given in Dr. Berg's first article (March, 1912). The table, which has been arranged by Mr. G. R. Carter, gives the values of the exponential ϵ^{-x}, without any interpolation, to three places of decimals, for values of x from 0.00 to 2.39 with increments of 0.01, and from 0.00 to 7.90 with increments of 0.1. With very simple interpolation four places of decimals may be obtained from this table.

CASSIUS M. DAVIS.

$$y = \epsilon^{-x}$$

x	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	1.000	0.990	0.980	0.970	0.961	0.951	0.942	0.932	0.923	0.914
0.1	0.905 *	0.896	0.887	0.878	0.869	0.861	0.852	0.844	0.835	0.827
0.2	0.819	0.811	0.803	0.795 *	0.787	0.779	0.771	0.763	0.756	0.748
0.3	0.741	0.733	0.726	0.719	0.712	0.705 *	0.698	0.691	0.684	0.677
0.4	0.670	0.664	0.657	0.651	0.644	0.638	0.631	0.625	0.619	0.613
0.5	0.607	0.600	0.595 *	0.589	0.583	0.577	0.571	0.566	0.560	0.554
0.6	0.549	0.543	0.538	0.533	0.527	0.522	0.517	0.512	0.507	0.502
0.7	0.497	0.492	0.487	0.482	0.477	0.472	0.468	0.463	0.458	0.454
0.8	0.449	0.445 *	0.440	0.436	0.432	0.427	0.423	0.419	0.415 *	0.411
0.9	0.407	0.403	0.399	0.395 *	0.391	0.387	0.383	0.379	0.375	0.372
1.0	0.368	0.364	0.361	0.357	0.353	0.350 *	0.346	0.343	0.340	0.336
1.1	0.333	0.330	0.326	0.323	0.320	0.317	0.313	0.310	0.307	0.304
1.2	0.301	0.298	0.295	0.292	0.289	0.287	0.284	0.281	0.278	0.275
1.3	0.273	0.270	0.267	0.264	0.262	0.259	0.257	0.254	0.252	0.249
1.4	0.247	0.244	0.242	0.239	0.237	0.235 *	0.232	0.230	0.228	0.225
1.5	0.223	0.221	0.219	0.217	0.214	0.212	0.210	0.208	0.206	0.204
1.6	0.202	0.200	0.198	0.196	0.194	0.192	0.190	0.188	0.186	0.185 *
1.7	0.183	0.181	0.179	0.177	0.176	0.174	0.172	0.170	0.169	0.167
1.8	0.165	0.164	0.162	0.160	0.159	0.157	0.156	0.154	0.153	0.151
1.9	0.150 *	0.148	0.147	0.145	0.144	0.142	0.141	0.139	0.138	0.137
2.0	0.135	0.134	0.133	0.131	0.130	0.129	0.127	0.126	0.125 *	0.124
2.1	0.122	0.121	0.120	0.119	0.118	0.116	0.115	0.114	0.113	0.112
2.2	0.111	0.110	0.109	0.108	0.106	0.105	0.104	0.103	0.102	0.101
2.3	0.100	0.099	0.098	0.097	0.096	0.095	0.094	0.093	0.093	0.092

x	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0	1.000	0.905 *	0.819	0.741	0.670	0.607	0.549	0.497	0.449	0.407
1	0.368	0.333	0.301	0.273	0.247	0.223	0.202	0.183	0.165	0.150 *
2	0.135	0.122	0.111	0.100	0.091	0.082	0.074	0.067	0.061	0.055
3	0.050 *	0.045	0.041	0.037	0.033	0.030	0.027	0.025 *	0.022	0.020
4	0.018	0.017	0.015 *	0.014	0.012	0.011	0.010	0.009	0.008	0.007
5	0.007	0.006	0.006	0.005 *	0.005 *	0.004	0.004	0.003	0.003	0.003
6	0.002	0.002	0.002	0.002	0.002	0.002	0.001	0.001	0.001	0.001
7	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.000	0.000	0.000


$y = \varepsilon^{-x}$
For x = 0.001 to x = 10.0
$x(10^{-3})$
$x(10^{-2})$
$x(10^{-1})$
x

DIRECT CURRENT SYSTEMS OF DISTRIBUTION FOR LIGHTING SERVICE

By J. R. Werth

Lighting Dept., General Electric Company

The principles of direct current distribution as originally laid down by Edison are today still made use of with but little radical change. The author of this paper presents diagrams showing the original arrangement, and the modern method in which several generating units are used with a high bus, a low bus, and a middle bus. The body of the paper compares the different types of apparatus used in 3-wire Edison systems, the discussion including two arrangements of single 3-wire generator, a 2-wire generator, two generators in series, and synchronous converter. An interesting table shows a comparison of some of these different arrangements on a basis of weight, floor space, efficiency, etc.; while a further table with accompanying text is given in which costs, efficiencies, weights, etc., of synchronous and induction motor-generator sets and synchronous converters for substation service are compared.—Editor.

The direct current system of distribution for lighting and power is extensively used by the central station companies in nearly all large cities in their business districts (or where a load is concentrated); in industrial plants where the variable-speed motor is the determining factor; or for isolated plants such as hotels, office buildings and hospitals.

As originally designed by Edison, the 3-wire system for direct current distribution is shown in Fig. 1. The method of utilizing several generating units in connection with a high bus, a middle bus and a low bus is shown in Fig. 2. Usually a pressure of approximately 250 volts is maintained between the outside wires, with half that amount between the outer and the neutral. The neutral is usually grounded, thus limiting the pressure above ground to about 125 volts; although there are two central stations in the United States, viz. Richmond, Va., and Providence, R.I., where the business district is fed by a 500/250 volt source. While this unquestionably possesses the economic advantage of small line loss (which decreases as the square of the pressure increases) and permits the interchanging of railway generating and converting equipment with that used for lighting, its use will probably not be extended, owing to the increased fire risk and the disagreeable shock resulting from 250 and 500 volts. It is interesting to note that the principles as originally laid down by Edison for direct current distribution are today still made use of with little inherent change. It is analogous to the case of James Watt and the broad principles which he discovered with reference to the steam engine, which for many years was not subjected to any radical improvement.

The writer recalls an interesting example of this in a town of some 150,000 inhabitants in the Middle West where the original Edison 3-wire central station was located approximately at the load center of the business district. Its location was not changed, but from time to time it was supplemented and enlarged so that it finally became a combined generating station and substation of some 25,000 kw., supplying alternating and direct current. As the central station added to its load, the alternating current system began to be subjected to short-circuits or surges, causing disastrous shut-downs which were an incessant source of annoyance. Disconnecting switches were thrown open by the rush of current, oil-switches were destroyed, and busbars were torn from their supports in the busbar com-

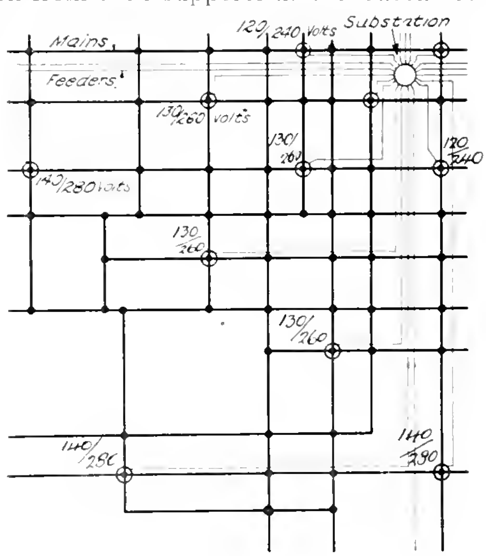


Fig. 1. Edison 3-wire System of Distribution

partments and twisted together. The central station was confronted with the very serious problem of the loss of some of its largest customers unless they could be assured of its realizing again the practically continuous operation which was achieved on the previous schedule. The direct current load was increasing from time to time; but no trouble was experienced, the increment being satisfactorily taken care of by simply adding generating and converting apparatus. In other words it was flexible, lending itself readily to expansion along the lines at which it had originally been laid out. It was soon apparent, however, that although the direct current system might be expanded almost indefinitely, the alternating current had reached a critical point in its development. It had outgrown its controlling switchgear and protective apparatus, so to speak, and therefore it had to be radically changed. This was done by adding latches to the disconnecting switches, putting in larger oil-switches capable of rupturing "the power behind the short," the insertion of current limiting reactances in the leads of the alternating generator, the installation of electrolytic lightning arresters to dissipate the energy of the surges, and increasing the mechanical strength and ruggedness of the switchboard and the busbar compartments.

TABLE I

Showing effect on a 110 volt, 56-watt 16 c-p. carbon filament lamp, by reducing the voltage 2 per cent., 10 per cent., 20 per cent., and 30 per cent. below normal.

Percentage rated watts Normal 110 Volts	Percentage rated C-P. Normal 16 C-P.	Percentage rated watts per C-P. Normal 3.5 watts	Percentage rated watts Normal 56 watts
100	100	100	100
98	95	103	97
90	56	145	81
80	29	235	64
70	12½	386	45

The presence of inductive drop in an alternating current system of distribution with large conductors is attended by several disadvantages as regards voltage regulation. The size of the conductor is economically limited. For example, quadrupling the cross-section of a conductor will give one-fourth the direct current voltage drop, but the reactance of the circuit is very slightly decreased. In a No. 0000 solid conductor, the voltage drop will be perceptibly greater in transmitting a given amount of power than the IR drop. In other words, the direct current system is better designed to equalize the pressure on different parts of the mains. It permits the direct current from a more distant feeder to be utilized.

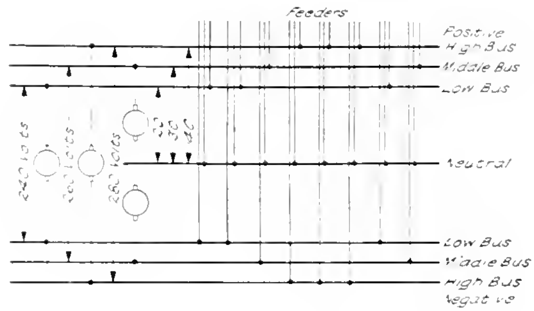


Fig. 2. Edison 3-wire Substation

While the advisability of maintaining close voltage regulation at the lamps (as indicated by Table I) is generally known, the necessity for operating motors at their rated voltage is not always so keenly appreciated. A recent investigation of a substation carrying a mixed load consisting of elevators and newspaper presses showed that at times the pressure on the motors driving the presses dropped 30 per cent. below normal. Table II shows the approximate effect on a line of direct current, shunt wound belted motors caused by reducing the applied voltage 10 per cent. 20 per cent. and 30 per cent. below normal.

The efficiency, of course, is slightly lowered with decreasing voltage due to the increased I^2R loss.

In 1908 the author of this article read a paper before the N.E.L.A. in which he compared different types of apparatus used in Edison 3-wire systems. Some of his statements may with advantage be introduced at this point. The following order is observed in making the comparisons:

TABLE II

Normal voltage	100 per cent. speed	100 per cent. amp. load	40 deg. rise temperature
10 per cent. reduction in voltage	95 per cent.	111 per cent.	plus 10 deg.
20 per cent. " " "	90 per cent.	126 per cent.	plus 23 deg.
30 per cent. " " "	84 per cent.	143 per cent.	plus 43 deg.

(A) One 250/125-volt three-wire generator with collector rings and compensator.
(B) One 250/125-volt three-wire generator with auxiliary winding in the main armature slots, and one collector ring.
(C) One 250-volt two-wire generator with motor-generator balancer set.
(D) Two 125-volt generators in series, each having half the kilowatt capacity of "A."
(E) Synchronous converter with step-down transformers.

(A) *One 250/125-volt three-wire generator with collector rings and compensator.* The three-wire 250/125-volt generator is very similar to the standard 250-volt two-wire machine. Its armature is tapped at points 180 electrical degrees apart, after the manner of a single-phase synchronous converter, and leads brought out to a pair of single-phase collector rings. The compensator used with this machine is a transformer with a single winding, having its extreme ends connected to the brushes which bear on the collector rings. A tap is brought out from the middle point of the winding on the compensator and connected to the neutral wire of the three-wire system to which it supplies continuous current. The unbalanced current flowing in the neutral wire of a well-designed lighting system seldom exceeds 10 per cent of the rated full-load current in the outers. Standard three-wire generators, however, are so designed that when 25 per cent. of the rated full-load current is flowing in the neutral, and 250 volts is held constant, the voltage at the machine between either outside wire and the neutral will be maintained within 2 per cent of 125 volts, or $2\frac{1}{2}$ volts. The 250 volts generated between the outers is, therefore, divided unequally, the voltage across the loaded side being less than 125 volts, whereas it should be greater; and one of the inherent limitations of a three-wire machine is that it offers no means of shifting the neutral to compensate for the difference in *IR* drop between the two sides of the system. A booster may be inserted in series with the neutral wire to shift the potential, although on account of the added expense and complication it is seldom advisable.

The principal advantages of a three-wire machine when contrasted with the other methods are saving in floor space and weight, reduction in first cost, gain in efficiency and ease of inspection and repair. The compensator being a static piece of apparatus means one less machine with revolving parts to engage the attention of the operator. The lack of means for shifting the neutral is generally more than offset by the advantages named; and, in consequence, we find the three-wire generator with collector rings and compensator very widely used in isolated lighting and power plants.

(B) *One 250/125-volt three-wire generator with auxiliary winding in the main armature slots, and one collector ring.* The three-wire generator considered under this heading has an auxiliary winding imbedded in the same slots as the main armature winding, the middle point of this winding being connected to the neutral wire through a single collector ring. This method of construction renders an external compensator unnecessary, and reduces the number of parts to a minimum. It should be noted that any damage to the auxiliary winding means a complete shut-down while the repairs are being made; and in case of a short-circuit in this winding the main armature coils are apt to be injured. Its characteristics and limitations are similar to those of the three-wire generators with external compensator. It is somewhat more expensive, but occupies less floor space; and although not so generally used as the external compensator method previously described, it is nevertheless very widely used in lighting and power plants.

(C) *One 250-volt two-wire generator with motor-generator balancer set.* This method employs a standard 250-volt two-wire generator to furnish power, and a motor-generator balancer set consisting of two standard 125 volt machines operating in series between the 250-volt mains, to establish and control the neutral. On those systems where the feeders are long, or where the load is such that it would materially unbalance the lamp voltage if no method of controlling the neutral were available, the balancer set is particularly serviceable. If the load is balanced no current flows in the neutral wire, the voltages across each side are equal, and, therefore, both machines float on the line as motors, only the running-light current being consumed. When the load is unbalanced the voltage on the loaded side falls below 125 volts, and the machine on that side immediately begins to act as a generator.

Balancer sets should always be rated in neutral current. Approximately one-half of this current is supplied by each machine, the division being governed by the voltages and losses. The motor, since it supplies the losses of the set, must carry the greater load, and although the generator carries the lesser load it must be a duplicate of the motor, so that the set may be reversible. The current capacity, therefore, which determines the rating of the individual machines is generally from 55 to 60 per cent of the neutral current. For example a 100-ampere balancer set would consist of two 57-ampere machines. A system of distribution depending upon a balancer set for its neutral should be protected against the effects of overload or short-circuits on one side of the system, which may impress a relatively high voltage on the other side and burn out the lamps or other apparatus which it supplies with current. The protection sought may be gained by the use of a differentially-wound relay connected across the two sides of the system, and so adjusted that with balanced voltages its contacts will remain open. If, however, the voltages unbalance beyond a predetermined amount the relay contacts will close a circuit through the shunt trip coils and thereby open the circuit breakers on the main generators.

When contrasted with the methods previously described, the two-wire generator with balancer is found to be higher in first cost, to occupy more floor space, and to require a greater amount of care to operate. It affords, however, a very convenient means for controlling the neutral; and for this reason alone there are many cases where it can be used more advantageously than the generator with collector rings and compensator.

(D) *Two 125-volt generators in series, each having half the kilowatt capacity of A.* The simplest method of operating a three-wire system is, of course, to connect in series two 125-volt generators. They are subject to the disadvantages, when compared with methods previously mentioned, of weighing more, requiring more floor space and being less efficient, and (in common with three-wire generators) of giving reduced kilowatt output on unbalanced loads. For example, the rated output of two 50-kw. generators operating on a system with 25 per cent unbalancing would be reduced from 100 kilowatts to $87\frac{1}{2}$ kilowatts. It has the practical advantage of permitting entirely independent voltage regulation on each side of the system, and of being able to safely handle large amounts of unbalancing.

(E) *Synchronous converter with step-down transformers.* The fact that collector rings are already a part of the converter equipment immediately suggests the desirability of deriving the neutral from the secondary of the step-down transformers. It is practicable to operate a synchronous converter inverted from a direct-current source of supply and obtain a neutral from the point of the compensator connected to its collector rings. This arrangement is seldom found in practice, as it offers no means of controlling the voltage; but it is mentioned here as a possible means for deriving the neutral.

Automatic voltage regulation can be obtained on three-wire systems supplying a mixed lighting and power load by the installation of generator voltage regulators. The field current of the generator usually exceeds the capacity of the largest regulator available; and it becomes necessary to separately excite them from a three-unit exciter set, and to control the voltage of the bus by varying the fields of the exciters, and consequently the excitation supplied to the main generators. The arrangement herein described is particularly applicable to three-wire systems with neutral derived from two 125-volt generators operating in series, since it can be adjusted to hold the proper voltage on both sides of the system for any degree of unbalancing within the limits of the apparatus controlled. Central stations supplying a mixed lighting and power load with motors connected across the outers, and between the neutral and the outers, can secure equal voltages between the two sides of the system at the center of distribution by connecting the pressure wired from this point to the control magnets of the regulators.

Summary

In conclusion it may be suggested that the selection of the different types of apparatus for a direct-current three-wire system of distribution should, therefore, be governed by the amount of unbalanced current to be handled, and the necessity for shifting the neutral to compensate for inequalities in the IR drop between the two sides of the system. Generally speaking, it is advisable where the unbalancing is excessive to use two low-voltage generators in series; and, where the unbalancing is small, to use a high-voltage generator with suitable facilities to establish and control the neutral, thereby securing the advantages of higher efficiency, cheaper first cost, decreased weight and economy of floor space.

The relative advantages of the three-wire-generator method and the balancer set may be summarized by saying that, when the approximately even division of voltage at the busbars which the former type gives results in good service at the lamps, the three-wire generator is desirable, on account of its rugged construction, cheapness and efficiency. The balancer set requires more careful attention; but, in those cases where skilled operators are already employed for the purpose of looking after other machinery, the balancer set justifies itself not only by reason of its ability to give extra voltage where such voltage is needed, but also because it permits the 250-volt generator with which it is used to deliver full kilowatt output when the load is unbalanced.

A comparison of apparatus for direct current substation work has been worked out for convenient reference, and is given in Table III.

Synchronous Motor-generators, Induction Motor-generators and Synchronous Converters: Comparative Data

The transformers are the 60-cycle single-phase air-blast type, having 6600 volt primaries and secondaries suitable for supplying current to the converters. This primary voltage was chosen on account of its being a transmission line voltage common to both frequencies, and on account of its adaptability to the capacities of motor-generator sets used in the following table. The high tension winding will have four $2\frac{1}{2}$ per cent. reduced capacity taps, and the secondary will have a neutral connection for a 3-wire system. The converters will be started from the direct current end as most lighting companies prefer this method.

The prices have been made up to include the necessary field rheostats, starting resist-

TABLE III

GENERATORS WITHOUT BASE, SHAFT OR BEARINGS, BUT WITH RHEOSTATS FOR DIRECT CONNECTION TO HIGH-SPEED ENGINES

		1-250-volt Gen. with 250 125-volt Balancer	1-250 125-volt Gen. with Collector and Compensator	2-125-volt Gens. in series of half the kilowatt capacity of 250-Volt Gens. and of higher speed than "A"
Weight per kilowatt of generating equipment	50 kw.	87.00 lbs.	+3.4 per cent.	+10 per cent.
	100 kw.	78.40 lbs.	+4.0 per cent.	+ 0 per cent.
	150 kw.	91.50 lbs.	+2.0 per cent.	−20 per cent.
	200 kw.	82.42 lbs.	+2.1 per cent.	−12.5 per cent.
Efficiency full load; no current in neutral	50 kw.	89.0 per cent.	90.5 per cent.	87.5 per cent.
	100 kw.	90.0 per cent.	90.25 per cent.	90.0 per cent.
	150 kw.	90.5 per cent.	91.5 per cent.	90.5 per cent.
	200 kw.	90.5 per cent.	91.5 per cent.	90.75 per cent.
Floor space of generating equipment	50 kw.	15.35 sq. ft.	−10.0 per cent.	+13.0 per cent.
	100 kw.	20.40 sq. ft.	+ 1.0 per cent.	+16.0 per cent.
	150 kw.	28.50 sq. ft.	+ 4.5 per cent.	+ 2.5 per cent.
	200 kw.	33.26 sq. ft.	+ 3.0 per cent.	+15.0 per cent.
Size of switchboard panels	50 kw.	20 in.+24 in.	20 in.	20 in.
	100 kw.	20 in.+24 in.	20 in.	20 in.
	150 kw.	20 in.+24 in.	22 in.	20 in.
	200 kw.	20 in.+24 in.	20 in.	20 in.
Cost per kilowatt, including switchboard: 10 per cent unbalancing	50 kw.	$26.70	− 9.0 per cent.	+ 5.0 per cent.
	100 kw.	18.26	− 5.5 per cent.	+10.0 per cent.
	150 kw.	19.40	−14.0 per cent.	−14.5 per cent.
	200 kw.	16.55	− 4.5 per cent.	− 3.5 per cent.
Compensation for line drop on heavier side?		Yes	No	Yes
Designed for extreme unbalancing?		No	No	Yes
Percentage of rated kilowatts delivered, when 10 per cent. unbalanced current is flowing in neutral wire		100 per cent.	95 per cent.	95 per cent.

ance, end play and speed limit devices for the converters; field rheostats, speed limit device and a starting compensator without switches for the motor-generator set. Overloads, 50 per cent. for 2 hours; 100 per cent. momentarily. The efficiencies take into account the losses of the different units; and there has also been made a slight allowance for cable loss between the machines and the switchboard.

The synchronous motor-generator sets used in the following comparisons are standard high-speed 6600-volt sets, and are without direct-connected exciters. All converter equipments have means of regulating the direct current voltage between the limits of 250 and 300. The ratings, however, are based on 275 volts, as are the ratings of the motor-generator sets.

The figures under price, floor space and weight, include a suitable blower set for supplying ventilation to the transformers and regulator. The efficiencies do not include the blower with the other losses.

TABLE IV

SYNCHRONOUS MOTOR-GENERATORS; INDUCTION MOTOR-GENERATORS; AND SYNCHRONOUS CONVERTERS

		Comparative Data With syn. mot. gen. sets as a basis at 100 per cent.					
Kw.	Apparatus	Price per Kw.	Efficiency Full Load	Efficiency 3/4 Load	Efficiency 1/2 Load	Net Weight	Floor Space
500	Synchronous Motor-generator	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
	Induction Motor-generator	104.4	98.0	98.0	98.0	110.5	105.0
	Synchronous Converter, No. 1*	134.5	104.2	105.2	106.8	105.7	123.2
	Synchronous Converter, No. 2	129.0	103.7	105.4	105.5	98.0	118.8
	Synchronous Converter, No. 3	130.5	103.8	104.6	105.5	119.3	137.8
1000	Synchronous Motor-generator	100.0	100.0	100.0	100.0	100.0	100.0
	Induction Motor-generator	96.2	98.3	98.7	98.8	84.0	100.7
	Synchronous Converter, No. 1	127.4	103.7	104.2	107.4	113.6	134.7
	Synchronous Converter, No. 2	116.0	103.7	104.2	107.4	81.0	97.2
	Synchronous Converter, No. 3	119.2	104.1	103.3	104.3	109.7	151.0
1500	Synchronous Motor-generator	100.0	100.0	100.0	100.0	100.0	100.0
	Induction Motor-generator	104.1	98.5	98.5	98.2	100.4	102.5
	Synchronous Converter, No. 2	105.5	104.5	104.6	104.3	85.2	95.7
2000	Synchronous Motor-generator	100.0	100.0	100.0	100.0	100.0	100.0
	Induction Motor-generator	100.8	98.1	98.0	97.2	98.2	102.8
	Synchronous Converter, No. 1	124.7	104.2	104.7	104.9	118.7	125.1
	Synchronous Converter, No. 3	118.0	104.2	104.8	105.1	120.0	122.4

* No. 1 is a simple shunt wound converter; No. 2 commutating pole shunt wound converter; No. 3, regulating pole converter. No regulator is required with the No. 3 converter.

HYDRO-ELECTRIC DEVELOPMENT AT INGHAM MILLS, N. Y.

By John Liston

Publication Bureau, General Electr

ERRATA

50 Kw. should read 50000 Kw.

While the average engineer takes a more lively interest in t great hydro-electric developments (say 50 kw. and over) than he sho installations, nevertheless the successful development of the small- economic importance if a national program of conservation is to be c tion may be said to be typical of the best examples of this latter class departures from accepted standards; but, both on the hydraulic and el be the most modern approved practice. It is described in this article very thoroughly. The maps and views will serve, with the text, to convey a very exact idea of the system and apparatus; while the article is of additional value in that it constitutes the first published description of this thoroughly representative small-capacity development.—Editor.

With the rapid diminution of the larger available water-power sites in the Eastern States, the future developments in hydro-electric practice in that section of the country must, of necessity, tend toward the economic utilization of the numerous streams which afford a dependable source of energy with comparatively low heads and moderate volumes of flow.

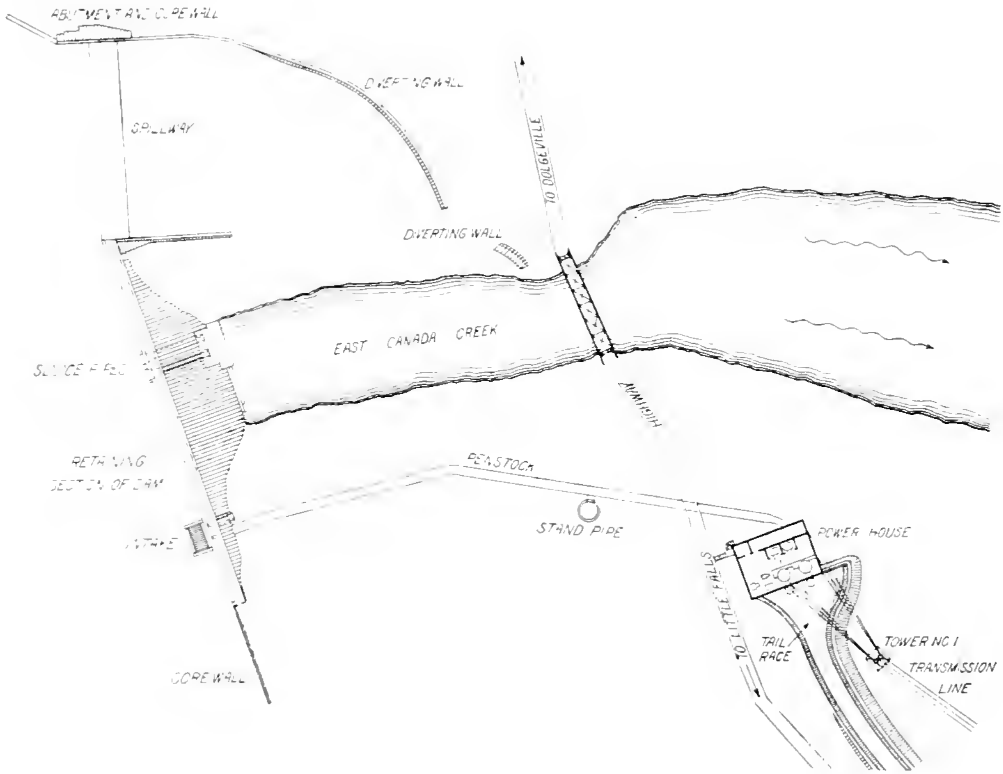


Fig. 1. General Plan of Ingham Mills Development

An excellent example of a power station of this type with an ultimate capacity of 7500 kw. is found in the development of the East Creek Electric Light & Power Company of St. Johnsville, N. Y., located on East Canada Creek about five miles northeast of Little Falls, N. Y. This station has been in successful operation since January 1, 1912.

East Canada Creek is a tributary of the Mohawk River and has its source in the southern slope of the Adirondack mountains, flowing in a generally southern direction. The drainage area back of the dam at Ingham Mills is approximately 286 sq. miles, a large part of this area being well timbered and the resulting run-off giving very favorable conditions for a well sustained water supply during the summer months. The average flow is about 300 second-feet, with an ordinary low flow of about 100 second-feet. The stream is not subject to extreme high water, as the

Fig. 2. General View of the Hydro-Electric Development at Ingham Mills, N. Y.
East Creek Electric Light & Power Co., St. Johnsville, N. Y.

greatest recorded flood did not exceed a maximum flow of 11,000 second-feet.

The present dam is situated about five miles from the junction of the creek with the Mohawk River and backs the water up to Dolgeville, N. Y., forming a reservoir about

Fig. 3. View From Down Stream Showing Spillway and Impounding Section of Dam

three and one-half miles in length and giving a storage capacity of 150 million cu. ft., which is in itself sufficient for approximately four days normal operation. The current supply is not, however, dependent on water storage, as the generators operate in parallel with the steam power plant of the Fonda, Johnstown & Gloversville Railroad at Tribes Hill, N. Y., which has sufficient reserve capacity to supply the distribution system

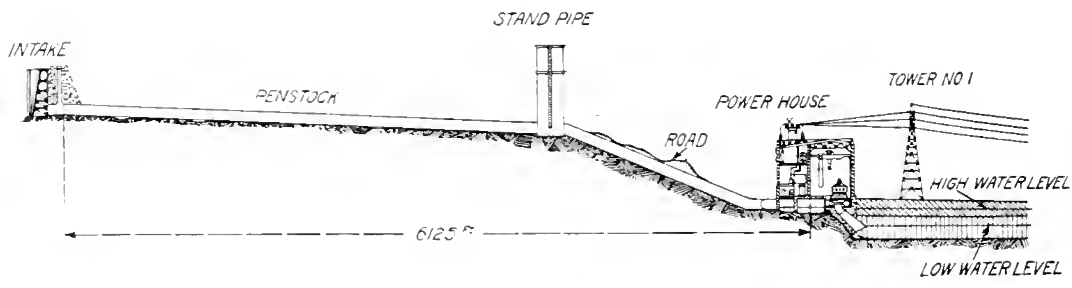


Fig. 4. Elevation of Development Showing Course of the Water from Intake to Tail Race

during any periods of low water that may occur.

A narrow gauge in the stream at Ingham Mills was chosen as the best location for the dam, as it permitted the building of a relatively short dam on a bed rock foundation, and also rendered possible a short pipe line and a close grouping of the various features of the development, as shown in the drawing, Fig. 1.

The retaining section of the dam is about 400 ft. long at the crest, with a length of approximately 100 ft. at the water level. The maximum height is 123 ft. and the greatest width through the base 84 ft., while the crest is uniformly 13 ft. wide. The spillway section is of the ogee type, and has a length of 205 ft., a uniform thickness of 28 ft. at the base, and a maximum height of 28 ft. Arrangements have been made for the use of flash boards, which will give an additional height of 4 ft. on the crest of the spillway. At both ends of the dam core walls are provided; and, from the shore end of the spillway section, there is a curved diverting wall located so that the water passing over the spillway is returned into the main stream channel. There is also a short retaining wall at the point of junction of the retaining and spillway sections of the dam.

The masonry work (see Fig. 3) is of concrete throughout, about 41,000 cu. yds. in all having been used. In building the main dam, cyclopean concrete construction was adopted, and the masonry was built up in vertical sections so as to minimize interruption to the work from floods.

Two sluices are located in the retaining dam at a level 100 ft. below the crest, in order to drain the reservoir if required, to by-pass the water to a power station down stream, or, in case of extreme high water, to act as auxiliaries of the spillway. These sluices consist of two 6 ft. riveted steel pipes provided with hand operated butterfly valves, the sluices and spillway combined being able to pass a flood of about 15,000 second-feet. There are no other openings in the dam, except at the intake, which is located at the shore end of the retaining section and consists of two short concrete piers at right angles to the dam, with grooves at the outer ends for stop logs. The trash racks are 27 ft. long and 38 ft. deep, and are protected from logs and debris by a floating boom located in front, between the piers. Three manually-operated head-gates are located in the intake, two of which admit water to a 9 ft. penstock serving two waterwheel generator sets; the third gate at present closing a 6 ft. 6 in. pipe, which is dead-ended just below the down-stream face of the dam and is intended for a second penstock to serve an additional generator unit when the development is completed. In order to eliminate danger from cavitation stresses and to permit the ready entrance of air into the penstock when the head-gates are closed, two 3 ft. vent pipes are run vertically through the concrete from the penstocks to the crest of the dam.

The existing 9 ft. penstock is 625 ft. in length and is of the ordinary riveted steel construction with lap joints, 3/8 in. metal being used at the upper end and 1/2 in. at the lower end. Angle stiffener bands have been used to reinforce the penstock throughout its entire length and are spaced approximately 12 ft. apart. The penstock supplies water to two 4000 h.p. turbines, the normal operating head being 115 ft. and the minimum 100 ft., while the velocity of the water at maximum load is about 9 ft. per second.

As shown in Fig. 4, the penstock runs at a slight downward grade (4.223 per cent.) for a distance of 415 ft. from the intake to the crest of the hill overlooking the power station, at which point it is joined to a standpipe by means of a 7 ft. connection. The standpipe is 20 ft. in diameter and 75 ft. high, with its top about 20 ft. above the level of the crest of the dam to take care of surges in the penstock. From the standpipe the penstock

Fig. 5. Section of Penstock Between Stand Pipe and Power Station

descends to a header located just outside the power station, the grade of this section being about 41 per cent. (Fig. 5), and the horizontal distance 60 ft. It enters the building at the level of the wheel pits, and is designed at this end to withstand double the static pressure in order to be safe against any water hammer effect which may be produced by closure of the turbine gates.

The standpipe is built sufficiently high so that it will not overflow when the gates are suddenly closed and while the water is flowing at its maximum velocity. There are two 3 ft. 6 in. nipples left in the penstock, one opposite the standpipe and the other at the point of entrance to the power station. These nipples are for connection with the future penstock so that it will not be necessary to provide a second standpipe, although it may be found advisable to increase the height of the present

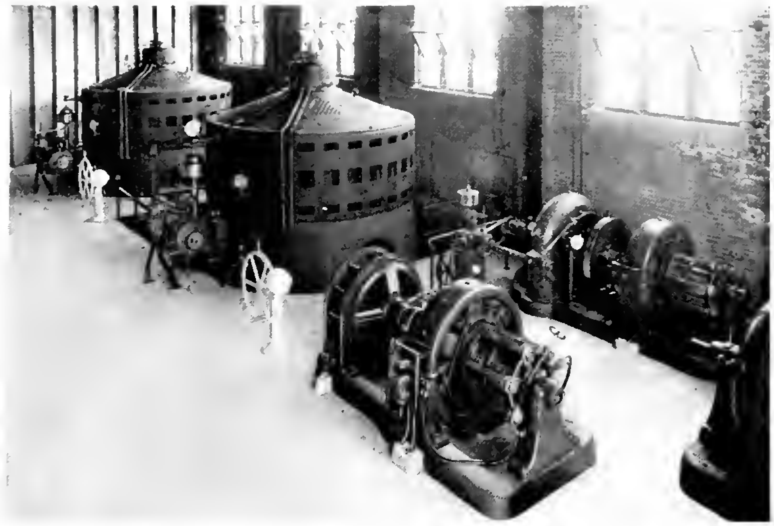


Fig. 6. Arrangement of 2800 Kv-a., 25-Cycle, 2300-Volt Water-Wheel-Driven Alternators and Exciters

one by about 8 ft. Throughout its length the penstock is supported on concrete piers and is covered with earth, while at the vertical angle and also at the power house, heavy concrete anchorages are provided. There are no air-valves, relief-valves, or blow-offs, and but two expansion joints, which are located on either side of the standpipe connection. Just before entering the power station the penstock is divided into two parts, each 6 ft 6 in. in diameter, leading to the two main water wheels; and from one of these there branches a 16 in. pipe which serves the exciter turbine. Each of these branches is provided with a hand-operated butterfly valve located at a point just before the entrance to the turbine casing.

The power house is a steel frame and brick wall structure with substantial concrete foundations, and is provided with a 35-ton motor-operated crane arranged to handle all the machines in the buildings. The transformers, which are mounted on trucks, can be rolled out of their pockets into the generator room under the crane. A temporary wall has been used for one end of the building to facilitate the additional work necessary to complete the structure when the third turbo-generator is installed.

The high water level in the tail-race backs up nearly to the center line of the turbines, and the outside walls of the foundations are therefore made water-tight; and as an additional precaution, a sump with a small motor-driven pump has been provided to keep the foundation dry. The barriers and compartments for the switches, busbars, etc., are constructed of brick and concrete.

The two main turbine units are each rated 4000 h.p. at 300 r.p.m., with a 115 ft. head. They are of the single-runner vertical shaft inward and downward flow Pelton-Francis reaction type, having a cast iron spiral casing and pivoted guide vanes of forged steel. The top of the turbine casing is provided with a cast iron foundation ring to support the superimposed generator stator, and the governors for each wheel are mounted immediately in front of the units they control. Oil pressure for the governors is obtained by means of two motor-driven oil pumps located at one end of the building.

The turbines were manufactured by the Pelton Water Wheel Company, and have a guaranteed efficiency of 84 per cent. at $\frac{3}{4}$ load; under test they showed larger capacities with better regulation than guaranteed.

On leaving the wheel bases the water enters draft tubes, the upper portions of which are inside the building and are made of cast iron; while the lower sections, which pass through the concrete of the foundation, are made of plate steel. The tail race is about 800 ft. long, and the waterway at low water is 20 ft. wide by 10 ft. deep. The excavation averages about 20 ft. in depth, and the velocity of the water with the present units operating at full load is about $3\frac{1}{2}$ ft. per second at low water. A considerable part of the excavation was in hard pan, but the waterway is altogether in solid rock. The capacity of the tail race is sufficient to take care of the water discharge when the installation is completed by the addition of the third turbo-generator.

The generating equipment is illustrated in Fig. 6 and comprises two 2800 kv-a., 10-pole, 2300 volt, three-phase 25 cycle vertical shaft alternators direct-connected to the water-wheels. The weight of all rotating parts, including the water-wheel runner, is carried on a roller suspension bearing located at the top of the alternator and supported by the armature frame. An auxiliary or guide bearing is provided just below the suspension bearing; and oil for lubrication is supplied by means of an individual circulating pump for each unit, the oil entering the uppermost or roller bearing and flowing by gravity through the guide

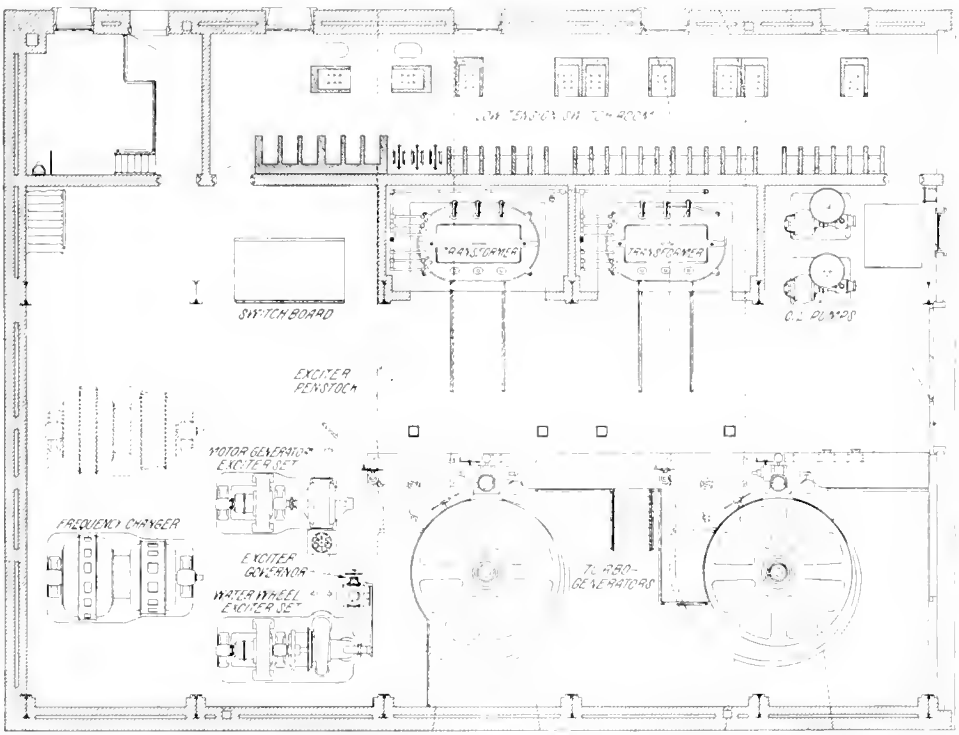


Fig. 7. Plan of Main Floor in Power Station Showing Location of Electrical Apparatus

bearing. The flywheel effect of the revolving element at 300 r.p.m. is equivalent to 850,000 pounds at one foot radius, the weight being about 70,000 pounds. These alternators were guaranteed with regard to heating, efficiency, regulation, wave form, short-circuit, insulation, excitation, etc., in accordance with the usual standards for water-wheel generators of this type, and were subjected to exhaustive tests before acceptance.

Excitation current for the alternators is supplied by a water-wheel driven generator and a motor-generator exciter set, as shown in Fig. 6, each set having a capacity of 125 kw. at 125 volts. The water-wheel set is driven by a 200 h.p. horizontal single-runner Francis turbine, direct coupled to and mounted on a common base with the generator, speed control being effected by an oil pressure governor, similar in form to those used for the main units. The motor-generator set consists of a 200 h.p., 2300 volt, three-phase, 25 cycle squirrel-cage induction motor, driving a generator of similar rating to that of the water-wheel set. The two exciters can operate successfully when connected in parallel and feeding a single set of exciter busses; they are compound wound for the same potential at no load and full load; and the series field is provided with a short circuiting switch which, together with the equalizer and negative bus switches, is mounted on the exciter frame. Both sets operate normally at 750 r.p.m.

When the development is completed the energy will be transmitted to the substation at Tribes Hill, N. Y., at 60,000 volts, the entire station equipment being designed for operation at this potential. At the present time, however, the transmission line is not fully loaded, and current is delivered to the conductors at 30,000 volts.

The general arrangement of the apparatus on the main floor of the power station is indicated by the drawing, Fig. 7. The power transformers consist of two three-phase,

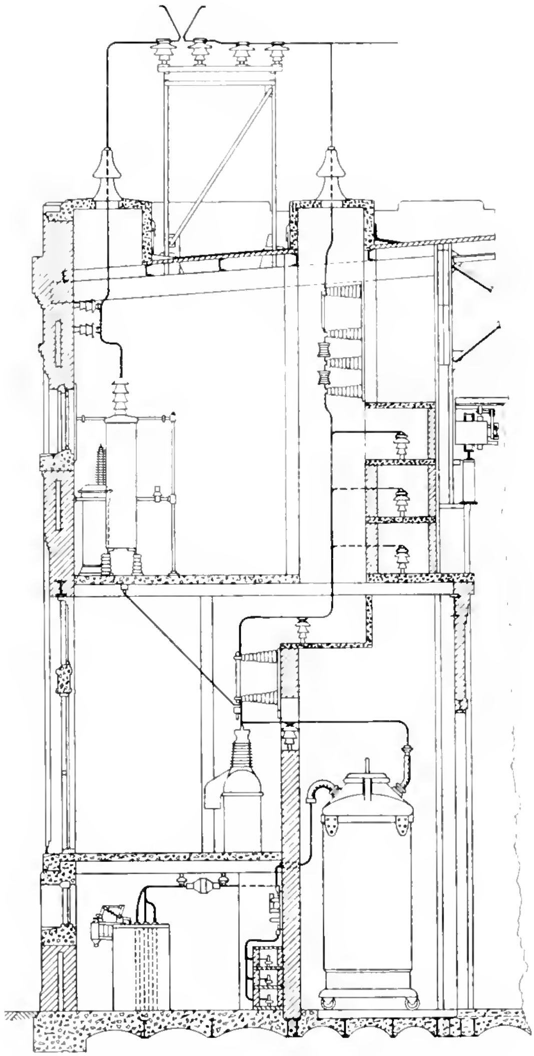


Fig. 8. Cross-Section of Power Station Showing the Relative Location of Transformers, Switches, Wiring, Etc.

25 cycle, 2800 kv-a. water cooled oil-insulated shell type units, designed for a primary potential of 2100 2200 2300 volts, and a secondary potential of 30,000 60,000 volts, delta connected. They are installed in open brick compartments.

Prior to the development at Ingham Mills, the East Creek Electric Light and Power Company had established a small hydroelectric plant about three and a half miles further down stream. This plant is still in operation and has an output of approximately 1000 kw. at a frequency of 60 cycles; so that in order to operate the old and new plants in parallel, it was necessary to provide a 25 60 cycle frequency changer set. This has been installed in the new power house, as shown in Fig. 7 and is connected with the old power station through a 16,000-volt single circuit pole line. The set is reversible, and consists of two units, one of 500 kw., 60 cycles, 16,000 volts, and the other of 560 kw. 25 cycles, 2300 volts. Both machines are mounted on a common base, constituting a compact two-bearing set, and are designed for operation either as alternating current generators or synchronous motors. The 2300-volt unit has an amortisseur winding and is equipped with a starting compensator to bring the set up to speed (750 r.p.m.) from the 25-cycle end. It serves to interconnect the two plants without the interposition of transformers, so that current may be distributed from either power station to both the old and new distribution systems, thereby adding to the factor of safety from interrupted service. The rheostats for both units are electrically operated and are controlled from the switchboard.

This high potential set has been in successful operation since first placed in service, and additional sets of similar type will be provided ultimately when the plans are completed for an up-to-date station to supersede the old 60-cycle plant and more effectively utilize the water power available at that site.

The switchboard is located on the main floor of the station and consists of eight rear and eight front panels of natural black slate. The front of the board is shown in Fig. 11. The equipment of instruments includes frequency and synchronism indicators for the frequency changer set, and a voltage regulator for the exciters mounted on one of the rear panels; while the front of the board contains a set of mimic busbars with the necessary lights and mimic disconnecting switches for indicating the various switching operations.

The low-tension busbar room is located just back of the switchboard with the high tension switches installed on the floor above. Automatically-operated top-connected oil-switches are used throughout for the main switching operations, those on the low-tension side having a maximum busbar capacity of 13,800 kw. at 2300 volts, while the switches on the high-tension side (Fig. 9) can safely carry 20,000 kw. at 60,000 volts. For the 16,000-volt line connecting with the old down-stream plant, the switches have a maximum busbar capacity of 6200 kw. at the line voltage.

The relatively compact but conservative arrangement of the transformers, switches, lightning arresters, wiring, etc., of this station are indicated by the drawing (Fig. 8). It will be noted that the height of the transformer compartments is equal to the combined height of the low-tension and high-tension switch rooms, and that the high potential leads from the transformers are carried horizontally over pin insulators mounted in circular openings in the brick wall, directly to the terminals of the high-tension switches. From the oil-switches current passes through disconnecting switches into the uppermost room, which contains the high-tension busbar compartments, choke coils and additional disconnecting switches, from which the out-

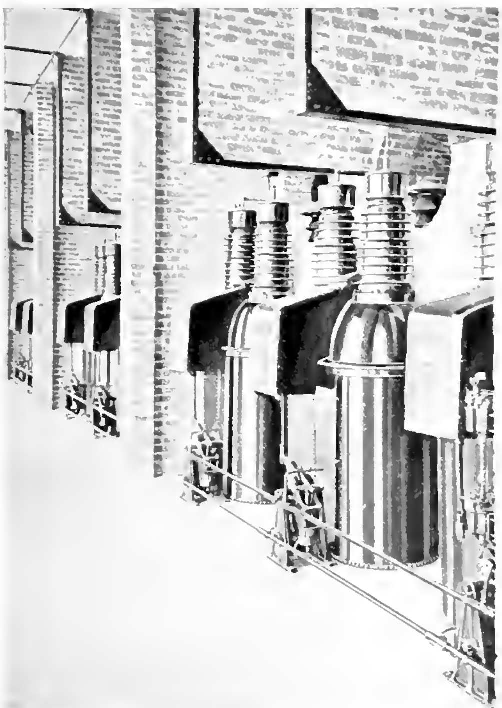


Fig. 9. Arrangement of 70,000-Volt 150 Ampere Oil-Switches

going conductors pass through the roof insulators to the transmission lines. At either end of the room on the side opposite the high-tension compartments is a three-phase 70,000-volt electrolytic lightning arrester set (Fig. 10) arranged for present operation on a 30,000-volt ungrounded system, but provided with tanks for future 60,000-volt delta opera-

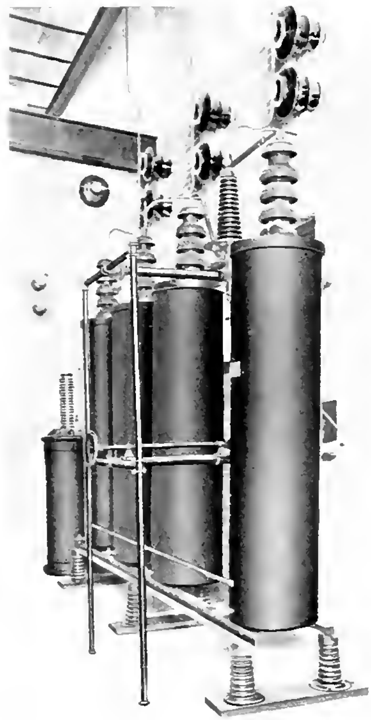


Fig. 10. One of the 70,000-Volt Electrolytic Lightning Arrester Sets in High Tension Room

tion and equipped with disconnecting switches, choke coils, and discharge alarm. The horn gaps and outgoing conductors are located on the roof directly above, with the insulators mounted on a structural steel frame work, as shown in Fig. 12.

From the roof of the power station the conductors pass directly to tower No. 1 of the twin-circuit transmission line. The line of towers has a length of about twenty-eight miles and terminates at the Tribes Hill, N. Y., substation.

There are in all 248 towers with an average spacing of approximately 600 ft. The conductors, of No. 2 B. & S. gauge round solid copper wire with a conductivity of $97\frac{1}{2}$ per cent. and a breaking strength of 3080 pounds, are carried in vertical relation on three cross-arms, each ten feet wide and spaced so as to give a vertical distance of six feet between conductors. In order to neutralize inductive effects between phases, there are eight complete transpositions of each circuit in the line.

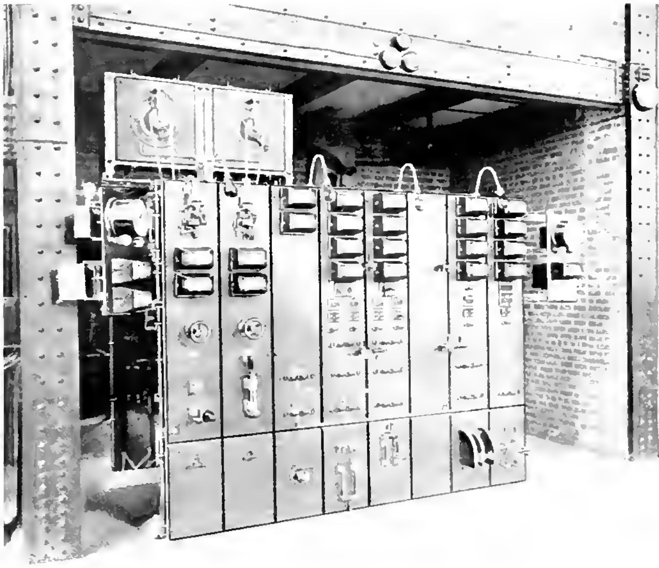


Fig. 11. Front Panels of Main Power Station Switchboard

The towers are built up of medium galvanized steel having an ultimate strength of 70,000 pounds per square inch. The standard type, of which there are 233 in all, are 60 ft. high, 14 ft. 3 in. square at the base, and weigh about 3750 pounds each. Twenty-six towers are provided with concrete foundations, and nineteen are rock bolted, the remainder being simply secured by six foot metal stubs embedded in the ground; no additional braces or guy wires being used. There are only fifteen special towers in the line, two of these being of standard height, and seven 77 ft. high; and at two points, where the conductors pass over railroad tracks, the towers are provided with grounding arms. A lightning guard wire is carried along the peaks of the towers for the entire length of the line, and is grounded at each tower. The towers were assembled on the ground.

While current is at present transmitted at 30,000 volts, the transmission system, like the power station equipment, is designed for an ultimate 60,000 volt service. Single "Thomas" pin insulators are used for each wire on standard towers, while the six angle towers in the system utilize three insulators per conductor.

As these insulators have withstood 132,000 volts under wet test with precipitation at the rate of one inch in five minutes, they give an ample factor of safety for 60,000 volts transmission, and it was therefore not considered necessary to adopt a suspension type. Experience with the clamps that were used during construction work showed that they could not be depended

Fig. 12. Roof of the Power Station Showing Arrangement of Horn Gaps and Outgoing High-Tension Conductors

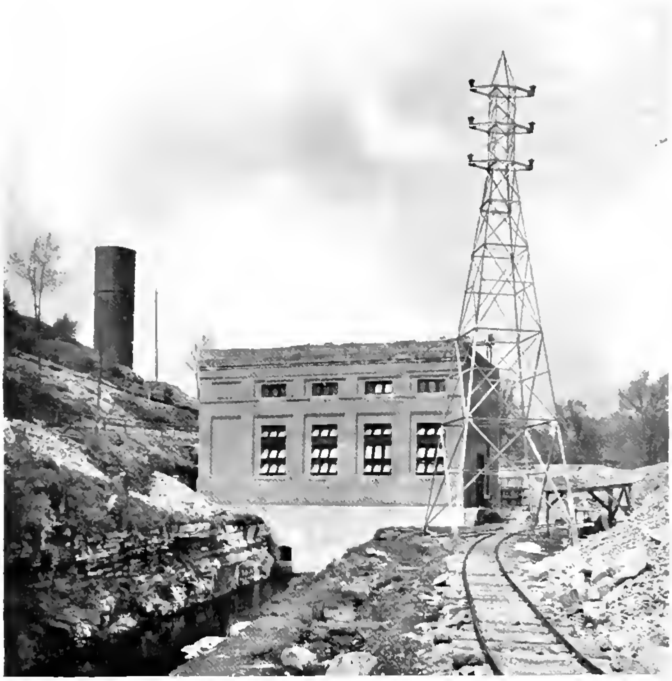


Fig. 13. View Looking up Tail-Race Showing Standard Transmission Tower No. 1

upon to insure freedom from breakage with the strain necessarily imposed on the relatively small conductors by the 600 ft. tower spacing, and wires were finally adopted for holding the conductors in the insulator grooves.

A systematic patrol of the transmission line has been established, the route covered being indicated in Fig. 14. A No. 6 B.W.G. telephone line is strung on the towers, transposed on each tower, and for the protection of the patrolmen each telephone set is equipped with a line insulating transformer.

Both as regards general system and apparatus, this installation represents what may be regarded as the best modern practice for small-capacity plants of this character. The entire development was designed and all construction work supervised by Viele, Blackwell & Buck, Consulting Engineers, 49 Wall Street, New York, while the electrical apparatus was supplied by the General Electric Co.

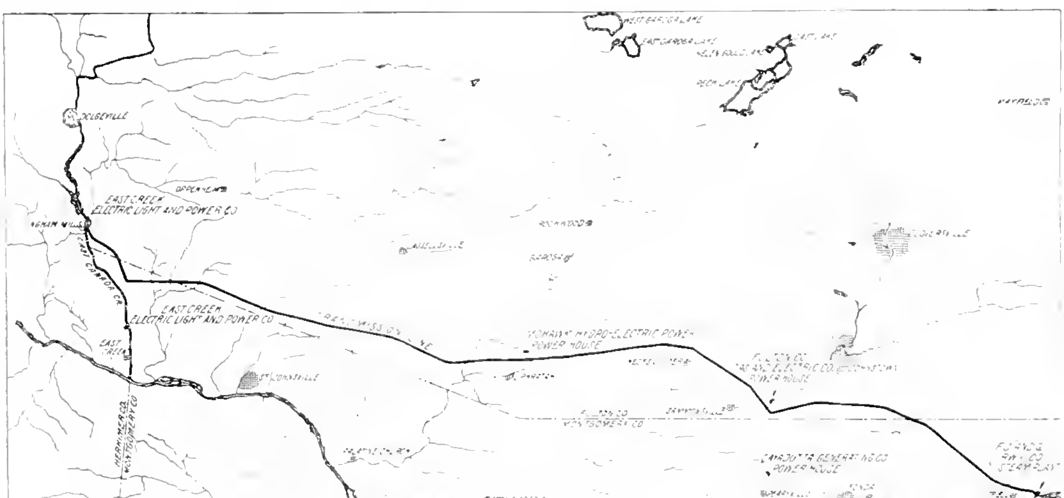


Fig. 14. Route of the Transmission Line from Ingham Mills to the Substation at Tribes Hill, N. Y.

BOOK REVIEWS

ELEMENTARY LECTURES ON ELECTRIC DISCHARGES, WAVES AND IMPULSES, AND OTHER TRANSIENTS

By Charles Proteus Steinmetz
McGraw-Hill Book Company

150 pages 64 Illustrations Price, $2.00 net

The general theory involved in continuous and alternating current circuits has been pretty thoroughly developed by a number of authors, so that it is a comparatively easy matter to solve the ordinary problems which arise in engineering practice. The problems usually encountered, however, deal with circuits in which the energy involved is in a permanent condition; for instance, a generator is to be designed to deliver continuously a specified amount of energy, or a transformer is to be built of such dimensions as to receive energy continuously at one voltage from a generating station and deliver it at another voltage to a transmission line. In either of these cases the energy involved is fixed, or permanent—so much is stored in the magnetic and dielectric fields and so much is being continuously transformed from one kind or form of energy into another. This energy can be readily calculated and its characteristics are well known; but should the generator be suddenly short-circuited, or the transformer suddenly disconnected from the line, then the phenomena taking place are quite different from those which exist under continuous operation. It is with such "transient phenomena" that Dr. Steinmetz's new book deals.

The subjects treated in this book are becoming of more and more importance; the increasing length of transmission lines, the extensive use of wireless telegraphy, and the demand for the concentration of large amounts of power, make a knowledge of the peculiar problems connected with them indispensable. It is undoubtedly with the purpose of giving the future engineer a working knowledge of these problems that the author has undertaken their investigation.

An earlier book by Dr Steinmetz, *Transient Electric Phenomena and Oscillations*, deals with the same subject but in a much deeper manner, and in parts is highly mathematical; but in the present work the analysis is quite elementary and recourse is had to mathematics only to that extent which will render it possible to make approximate estimates of the magnitude of the phenomena. Thus it may be considered as an introduction to the former book. It opens with a lecture on the nature and origin of transients, which is followed by a discussion of transients in continuous and alternating current circuits, including a careful analysis of the electric circuit; frequent comparisons being drawn between electric and magnetic fields. The explanation of alternator short-circuits is quite complete and a number of oscillograms taken on various machines are shown in half-tone. The starting current of a transformer, line oscillations, standing and traveling waves are discussed in detail. Simple calculations are shown whereby it is possible, for instance, to determine the current rush when a transmission line is thrown on a live transformer, and what the frequency is of the oscillation produced by this switching. Several oscillograms of line transients illustrate the text. These were taken on a large transmission system and serve to show how very practical the subject matter is in relation to the operation of large long-distance transmission systems. The book closes with a lecture on the calculation of inductance and capacity of round parallel conductors, and derives equations which apply to overhead transmission lines as well as to underground cables.

This book and the other more complete work form a very thorough exposition of what takes place in electric circuits under special or abnormal conditions.

PRINCIPLES OF ELECTRICAL ENGINEERING

By Harold Pender
McGraw-Hill Book Company

438 pages Illustrated Price, $4.00 net

This book is a development of a course of lectures given by Prof. Pender to the junior class in electrical engineering at the Massachusetts Institute of Technology; and constitutes an exposition of the physical principles upon which the art of electrical engineering is based. It is indeed perhaps more in the nature of a treatise on physics than on electrical engineering. In this respect at least the book is superior to the majority of others on this subject; which, purporting to deal with principles, introduce many subsections not strictly pertinent, such as chapters on the design of electrical apparatus, etc., upon which more complete and recent data may be obtained elsewhere. Bearing in mind that the treatise is intended primarily for junior students, it may possibly appear surprising (as it is certainly unusual) to find the calculus employed throughout. The author rightly holds, however, that, since the calculus is an instrument fit for practical service and an invaluable labor-saving device, full advantage should be taken of its use, especially since it is a regular part of the curriculum at every technical school in the country. For the sake of those whose ability in working with the calculus is untried, and also for those who have never studied its use, the physical meaning of the formulæ is given in all cases. Each chapter is followed with a valuable summary of important principles and definitions; while distinctly practical matters are touched upon in the set of problems which follow the summary.

VALUATION OF PUBLIC UTILITY PROPERTIES

By Henry Floy
McGraw-Hill Book Company

402 pages Illustrated $5.00 net

Up to the present no complete treatment has been made and published of the theory and practice of the valuation of public utility property, all the information on the subject being scattered through various financial and engineering journals, and the transactions of professional societies. In view of the rapid growth of electrical public utilities in the last two decades, and the scant knowledge which the average engineer possesses of the finances and the valuation of their physical and intangible property, the volume under notice, which formulates a theory and summarises the best existing practice, should be of the greatest possible value to electrical men. One of its chief sources of strength is the aptness and copiousness of the references to various judicial authorities, which the author, from his intimate knowledge of the subject, is able to introduce very effectively, these references including extracts from the findings of Judges of the Circuit Courts, the Supreme Court, and various Public Service and other Commissions The volume is meeting with a very favorable reception at the hands of electrical engineers.

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City of Santos, Brazil. View showing quay wall in front of Customs House between warehouses Nos. 5 and 6.
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GENERAL ELECTRIC REVIEW

COMPARATIVE DESIGNS FOR HIGH TENSION SUBSTATIONS

The article by Mr. Rhoades on page 606 presents some comparative designs which have been carefully worked out for a particular problem in high-tension substation design. It is not possible to consider the question of outdoor substations in general terms because it is impossible to fix on any equipment or wiring diagram as typical, the purposes of such substations being so varied. The results of this study do not show any marked advantage for the outdoor design; although this advantage may become more marked as apparatus becomes more highly developed and lower in cost. All our investigations so far point to the fact that for stations of importance and considerable size the advantage of the outdoor construction is very small. Its field for some time to come will probably be limited to small transformer stations and transfer or switching stations. To the limited extent that we may make general statements on the subject at present, we believe that the semi-outdoor type represents the preferable practice as compared with the outdoor type; and that it has such distinct advantages over the outdoor construction as to warrant its use until further experience and development in apparatus clearly show the outdoor construction to be superior.

August H. Kruesi.

STANDARDIZATION IN CENTRAL STATION PRACTICE

Engineers of all generations have talked freely of current practice and modern standards; and, although new experiences, acquired even in a short life-time, should have advised them that what is considered good practice to-day is exceedingly inefficient practice to-morrow, they have believed that perfection and complete standardization have been attained.

Although this tendency is not so marked among electrical engineers, it may still be noted. Each succeeding five-year period sees radical changes in most lines of electrical engineering. Central Station engineering is but one phase. When we turn up statistics showing the number of large central stations put down in 12 months in this country alone, we might think that inevitably this means that some degree of standardization has been reached. We cannot know that this is so. We do know the nature and the variety of the problems that come up perennially for discussion; and we know that there are hundreds of independent workers spending all their time in solving problems which have remained unsolved for 25 years, and other problems which have only made their appearance on the successful solution of questions which the preceding generation regarded as all-important. It would be unsafe to say that current practice as regards even, say, the boiler room layout, expresses finality in any degree, although that department has probably attained a greater measure of standardization than any other in the large steam station of 1912. This, however, is but one detail, and in the engine room itself great changes are certain to be made as years progress, albeit possibly so gradually that the engineer of the day takes but little note of their significance.

Under excitation may be placed another category of central station problems. Practice has changed considerably in the last few years, and no one can say exactly what constitutes current practice to-day nor how long the present-day methods most usually employed will remain in vogue. We believe that the article on page 626 of this issue will be read with considerable interest by operating engineers. This deals with *practice*, and touches physical questions—arrangements, machines, and so on. The article on page 634 treats of excitation in a rather broader sense—the magnetization of synchronous and asynchronous machines, transmission lines, transformers and other inductive apparatus.

HIGH TENSION SUBSTATIONS

By C. M. Rhoades

Construction Engineering Department, General Electric Company

Mr. A. H. Kruesi, Engineer of the Construction Engineering Department, calls attention to this article on page 605, and makes some further comments on the comparison of high-tension substations of the outdoor, semi-outdoor and indoor type.—Editor.

The desire for information which has been shown by engineers regarding arrangements and comparative costs of outdoor substations compared to indoor stations for the higher voltages, say 60,000 volts and above, has led to the preparation of the following description of three distinct types of stations. We will speak of them as outdoor, semi-outdoor and indoor stations.

In the case of the outdoor station, all of the high-tension wiring and apparatus is out of doors, and is merely controlled from a board centrally located in a part of a building provided for the board and for general repairs and for pumps. In the semi-outdoor station it is planned to protect the high-tension oil-switches, and the necessary disconnecting switches for clearing the oil-switch, in light shelter houses, with the remainder of the high-tension wiring and apparatus out of doors. In the indoor station all of the high-tension wiring and apparatus, with the exception of the lightning arrester tanks and horn gaps, would be placed indoors. Lightning arrester tanks of the aluminum cell type should be protected when exposed to extreme temperature conditions, say of over 110° F. or below 26° F.

To make comparative cost estimates of the three types of stations, we have settled on a scheme of connections which gives the greatest flexibility and yet is simple to operate. The scheme, while not a typical one, is one that might readily be met and one which would call for one of these three types of construction. In each of the three types a design has been made of the best kind that could be devised appropriate to the conditions, and lasting as to material. No wood or other combustible material is required to carry out the designs, except possibly doors and window-frames in the indoor station. The general scheme of connections is given in Fig. 1. It comprises a double-circuit line of 110,000 volts with taps to give two separate 110,000-volt busses for operating two distinct sets of transformers, viz., 110,000 volts to 70,000 volts, and 110,000 volts to 45,000 volts. The connections are such that it can be used as a cross-over or switching station. Leading from the 70,000 volt and 45,000-volt busses two feeders each are shown.

The general plan and sections of the outdoor arrangement are shown in Figs. 1 and 2, while the plan and sections of the semi-outdoor arrangement are shown in Figs. 3 and 4. The arrangements are identical, with the exception of the oil-switches and the steel towers supporting the high-tension wiring. The oil-switches in Figs. 3 and 4 are protected from the weather by light shelter houses with corrugated or expanded metal and plaster sides, which are placed so as to give the most protection to the oil-switches, and yet provide light and ventilation and permit taking the high-tension lines in and out of the shelter house without line entrance bushings. As compared with the indoor construction, this is an important feature in reducing the cost and the possibility of break-down. The sides are to run to within four to five feet of the ground and to within eight or ten feet of the roof, depending on the voltage and on the width of the overhanging eaves.

In Figs. 1 and 2, it was found necessary to use a third line of steel towers, as the span for the high-tension wiring, with the necessary number of strain insulators, would otherwise cause such an amount of sag as to be dangerous, both mechanically and electrically. The maximum span of such nature when interspersed with link insulators is 55 or 60 feet. To maintain a factor of safety of three throughout the design, the units of the link insulators require that the sag shall not be less than one foot. In both the outdoor and semi-outdoor arrangements, the heights of the steel towers were determined by the necessary height for operating the disconnecting switches in bad weather and by the necessary clearances for busses and connections. The steel towers were designed to carry stresses due to anchorage of transmission lines, while the lattice-bracing ties the towers together and serves to support the busses and cross-connections. In the indoor arrangement as shown in Figs. 5 and 6 the general scheme of connections is the same, with the exception that oil-switches have been placed between the low side of the transformers and the bus, in place of the bolt-type disconnecting switches. This is a necessary feature incidental to the indoor construction, as bolt-type switches could not be used inside such a building. The transformers in all three types of station are connected delta-delta. All of the 70,000 and 45,000 volt oil-switches are shown set up on concrete piers so that none of their live parts are within reach of the operator.

The following figures have been tabulated to show the costs of the three types of stations. The figures throughout are based on heavy-capacity switches on the transmission lines, with medium-capacity switches for transformers and outgoing lines. The two banks of transformers are of 4500 kw. each, with space for two future banks of the same capacity. In the case of the oil-switches, the figures are estimated to include a grade of oil suitable for a climate such as that of the Southern States. If the temperatures are below 32° F., the comparison should be based upon the employment of a higher grade of oil, which would increase the price of the switches approximately 10 per cent. The cost of the building for the indoor arrangement is based upon a building of sheet metal, or metal and cement plaster, to avoid prohibitive expense. If built of brick or concrete the comparison of costs would be quite different.

As shown below the cost is in favor of the outdoor and semi-outdoor stations by a very small percentage of the total cost. When operating conditions are considered, the semi-outdoor arrangement has distinct advantages over the outdoor in convenience of operation of disconnecting switches in bad weather, when generally there will be most frequent occasion to operate them. The advantage of being able to open and work on the oil-switches in place is obvious.

TABLE I.—COMPARATIVE COSTS

KIND AND TYPE OF APPARATUS	OUTDOOR	SEMI-OUTDOOR	INDOOR
Building, foundation, walks, cranes, fences, etc., towers	$20,000.00	$29,000.00	$33,000.00
Electrical equipment, including transformers (110,000 70,000 volts, and 110,000 45,000 volts), lightning arresters (110,000, 70,000 and 45,000 volts) oil-switches (110,000 volts, 70,000 kv-a. rupturing capacity, 70,000 volts, 30,000 kv-a. rupturing capacity, and 45,000 volts, 30,000 kv-a. rupturing capacity) *	95,414.00	89,714.00	89,850.00
Choke-coils, disconnecting switches, bolt-switches, strain and post insulators, wire, tubing and miscellaneous hardware	8,773.00	8,910.00	9,974.00
Labor installation	8,000.00	8,300.00	5,200.00
TOTAL	$132,187.00	$135,924.00	$138,024.00

* The rupturing capacity of the 70,000 volt and 45,000 volt oil-switches included in the figures for semi-outdoor and indoor substations is actually 40,000 kv-a.

TABLE II.—SPACE REQUIRED

TYPE	GROUND DIMENSIONS	GROUND AREA
Outdoor	194 ft. by 250 ft.	1.1 acres
Semi-outdoor	230 ft. by 230 ft.	1.2 acres
Indoor	160 ft. by 160 ft.	.58 acre

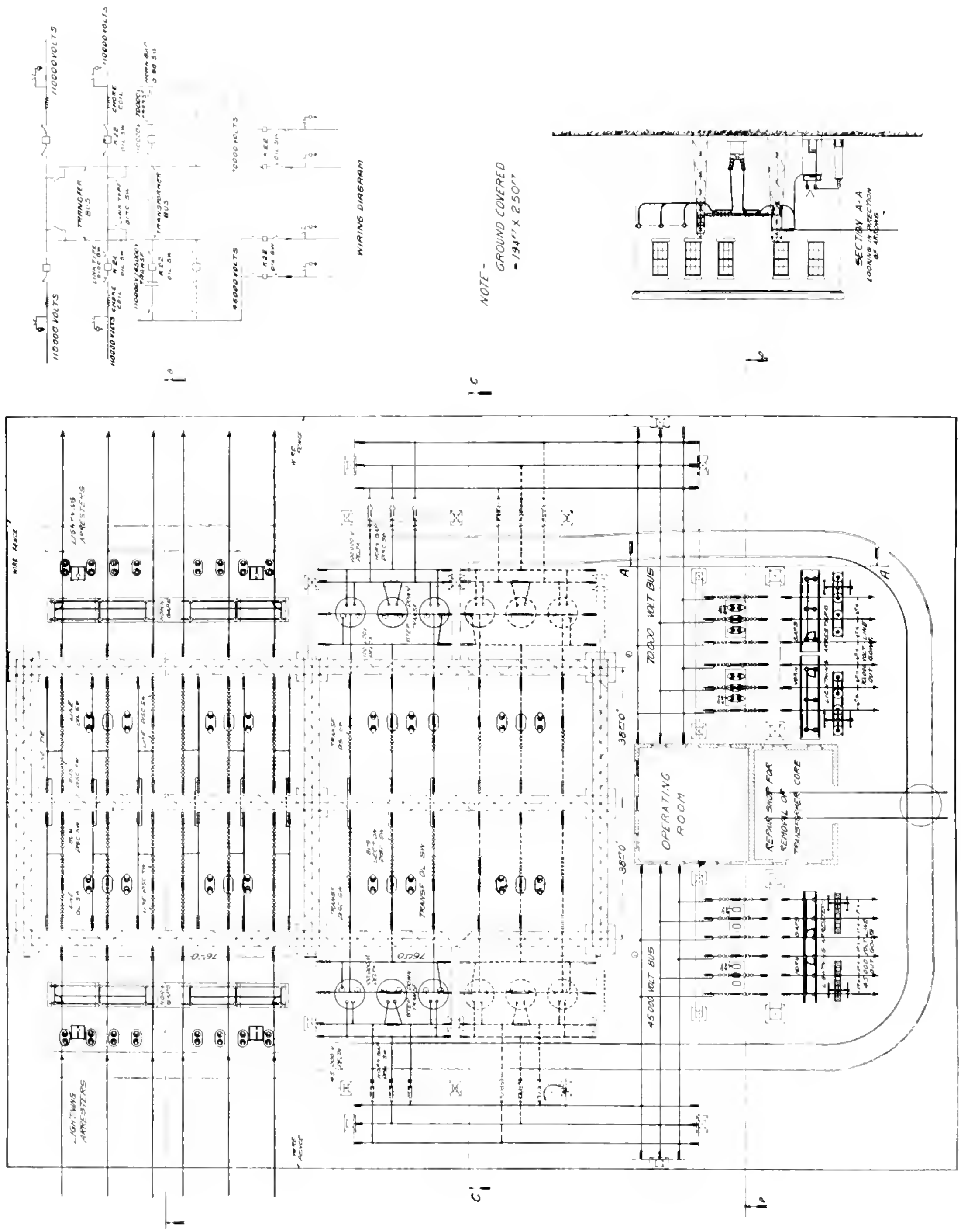


Fig. 1. Plan of Outdoor Substation for 110,000/45,000 Volt Circuits

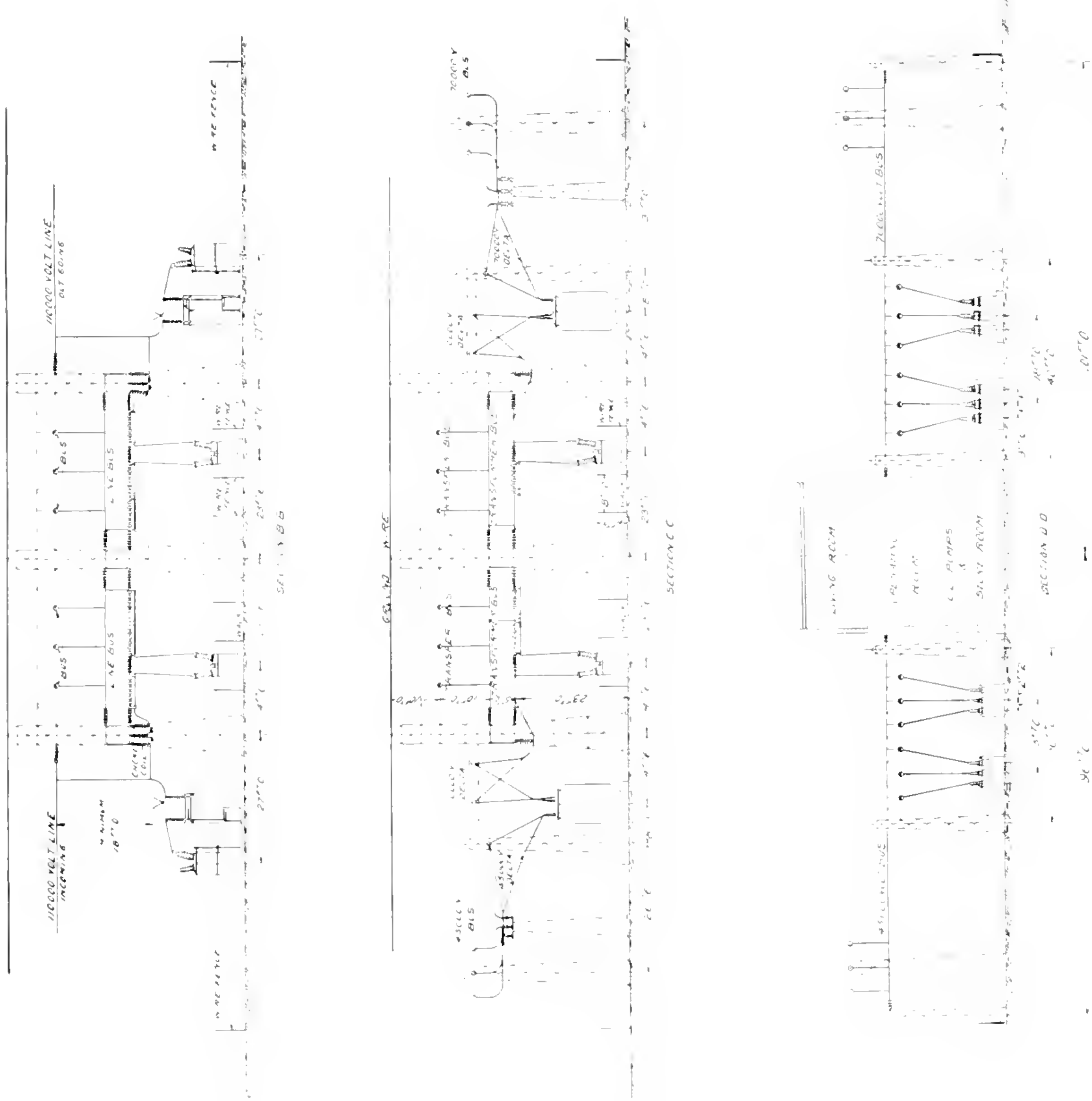


Fig. 2. Sections of Outdoor Substation for 110,000–45,000 Volt Circuits. Sections taken in direction of arrows shown in Fig. 1.

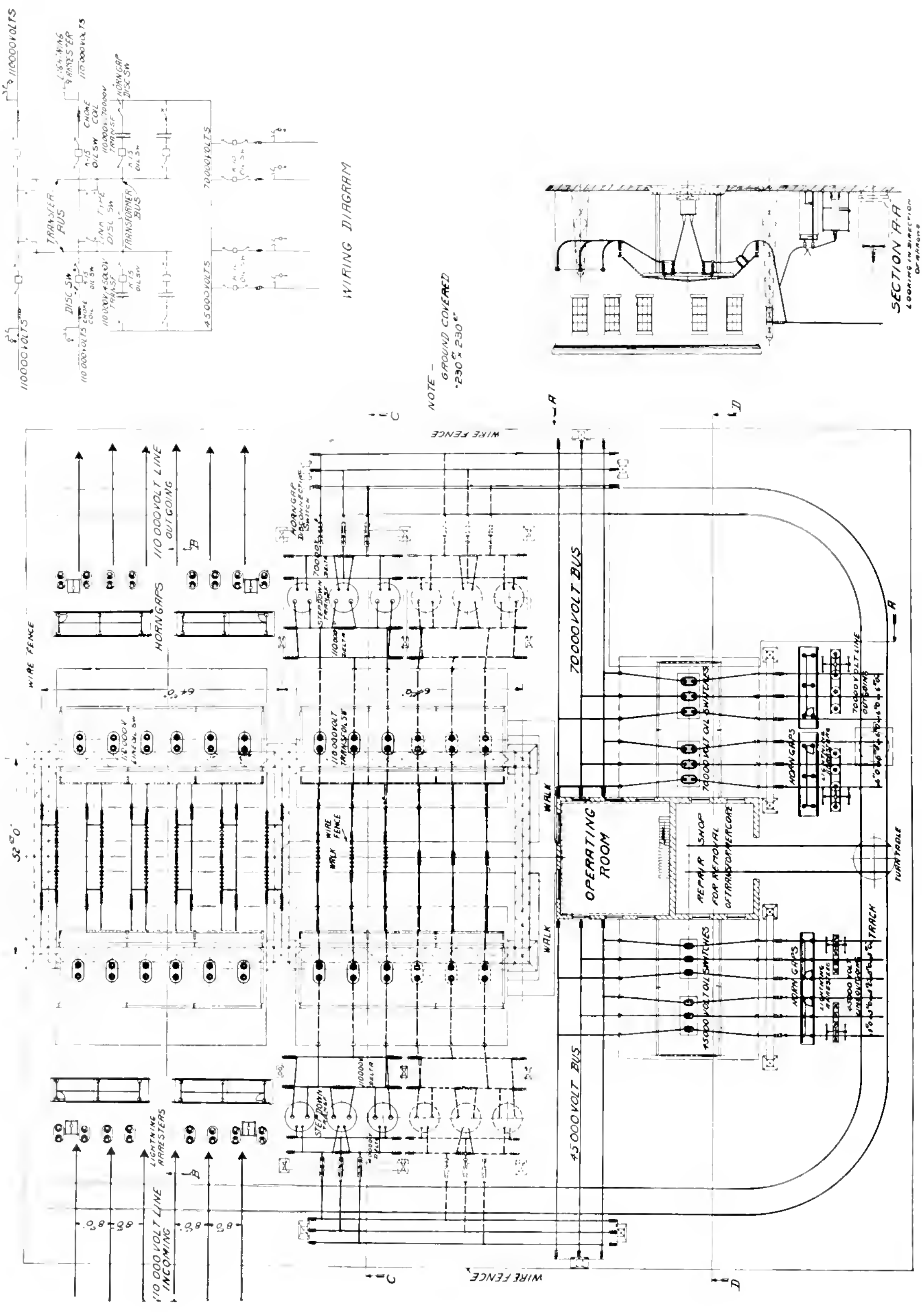


Fig. 3. Plan of Semi-Outdoor Substation, for 110,000/45,000 Volt Circuits

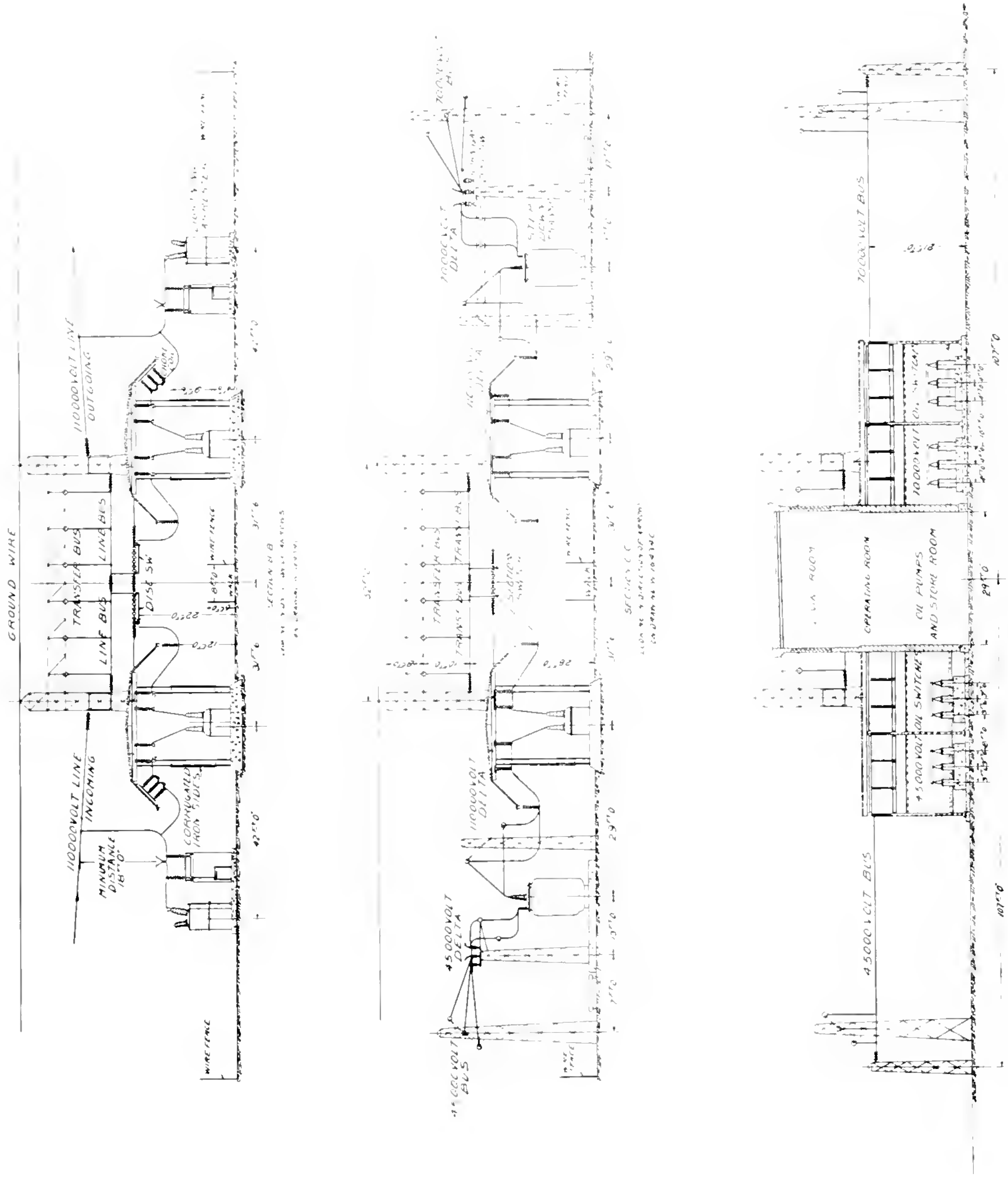


Fig. 4. Sections of Semi-Outdoor Substation, for 110,000-45,000 Volt Circuits. Sections taken in direction of arrows shown in Fig. 3.

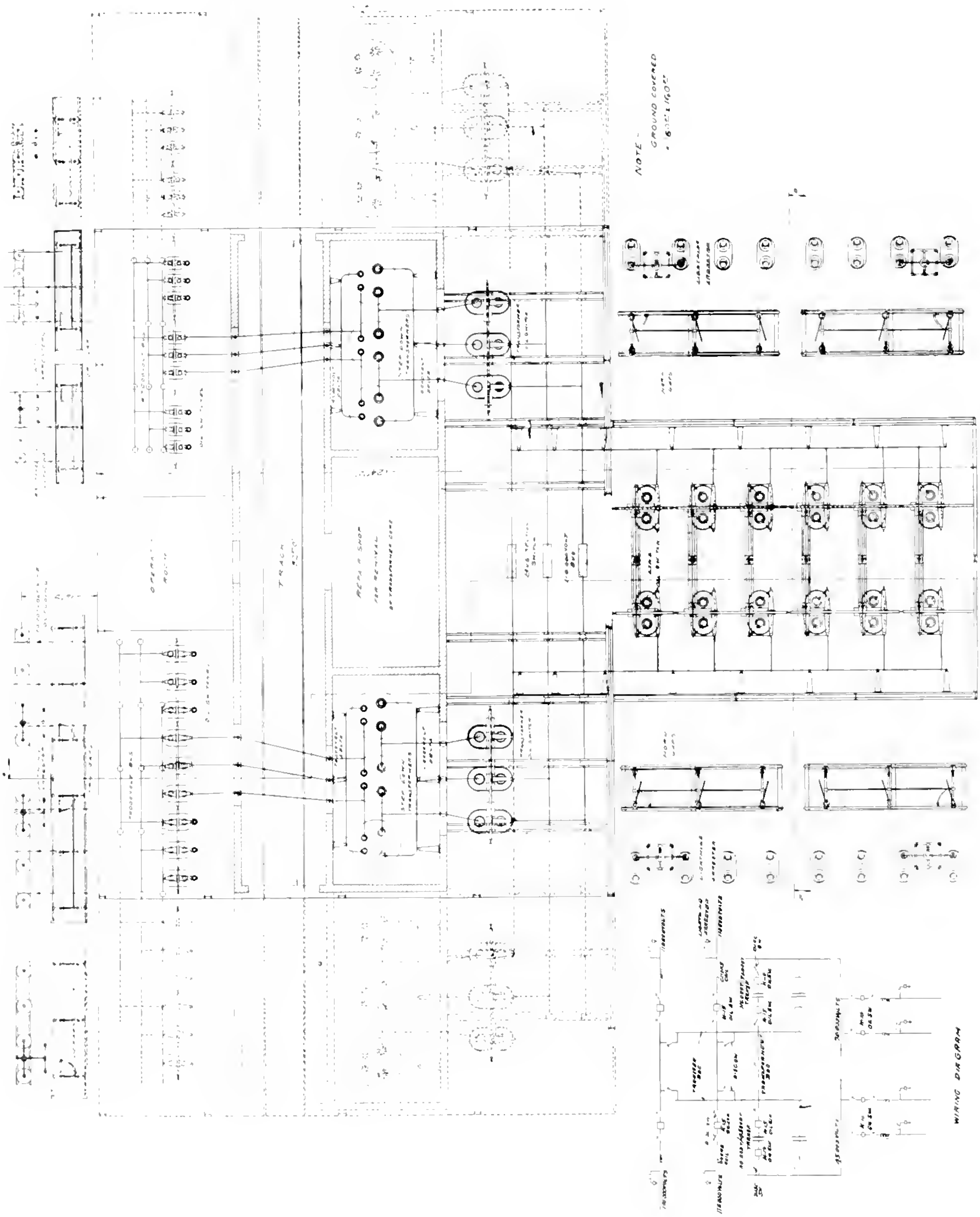


Fig. 5. Plan of Indoor Substation, for 110,000/45,000 Volt Circuits

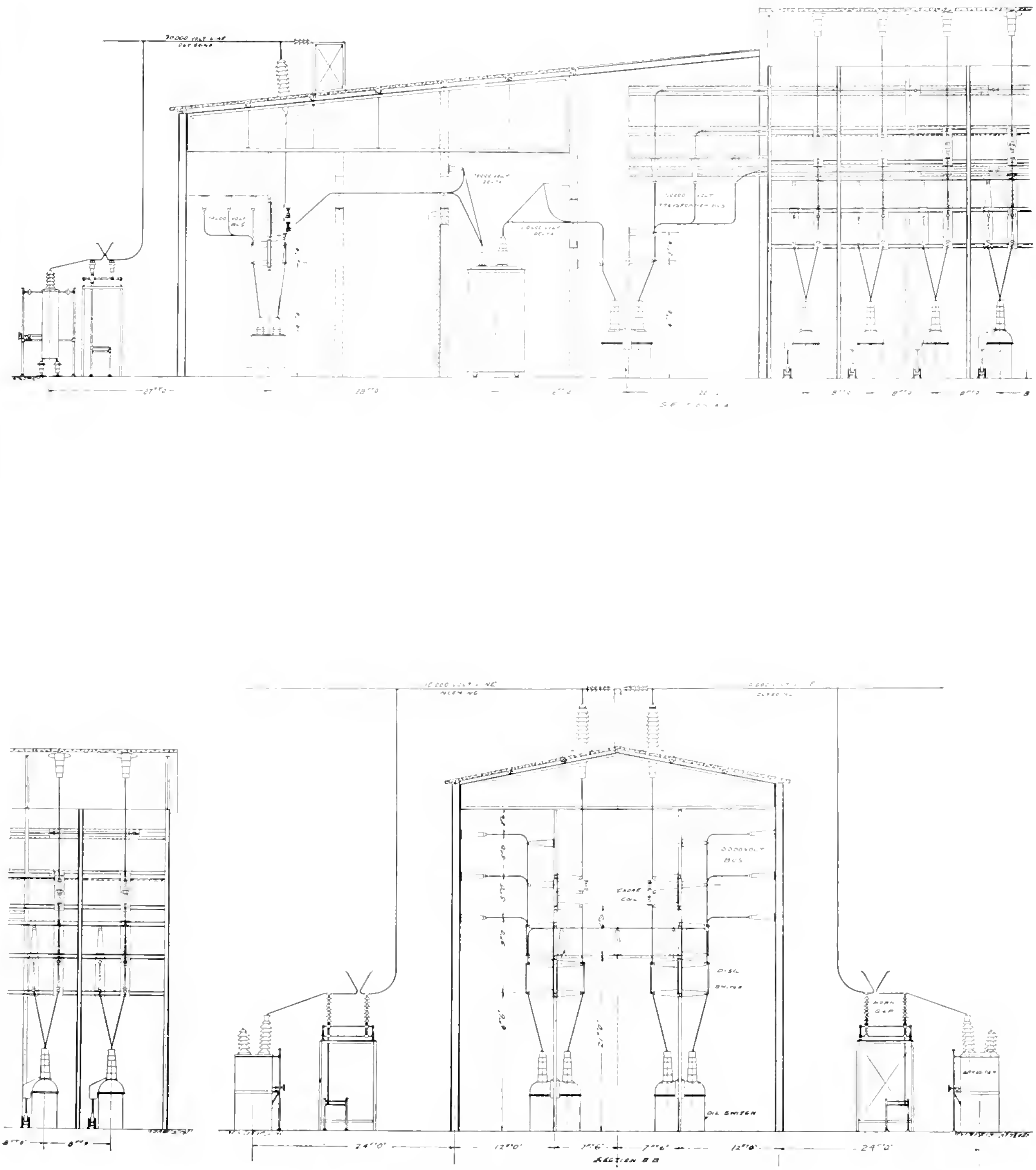


Fig. 6. Section of Indoor Substation for 110,000 45,000 Volt Circuits. Sections taken in direction of arrows shown in Fig. 5

PHENOMENA BEYOND THE ELASTIC LIMIT

By Charles P. Steinmetz

Chief Consulting Engineer, General Electric Company

The feature of greatest interest in this exceedingly valuable paper of Dr. Steinmetz is his discussion of the bearing which the elastic limit and the disruptive limit have upon the commercial utility of any material and the analogies which he draws between mechanical, magnetic, and electric phenomena. Most theoretical investigations into the mechanical system have been limited to the range below the elastic limit; notwithstanding the fact that the range above that point is of greater importance, since in this range all materials are formed and shaped for their industrial use. If the curve of mechanical hysteresis, as a function of temperature, for instance, were known, the power required by a rolling mill under any conditions of operation could be calculated with the same exactitude as the power consumed by the alternating magnetism of a transformer is calculated from the magnetic hysteresis law of the iron. In studying these mechanical phenomena above the elastic limit, it should be possible to obtain great assistance from the corresponding, but far better-known, phenomena of the magnetic and electrical systems, since these analogies are not accidental, but are actually general phenomena of all energy transformations. In the article itself will be found definitions of the salient terms, and the principles upon which the analogies are established. The substance of this paper was originally delivered by the author as a lecture before the Stevens Institute, and is now reprinted from the Stevens Indicator. —Editor.

The first question which arises is: What is the elastic limit, and does such limit actually exist?

If a mechanical force of moderate value is applied to a structure it produces a deformation which is proportional to the applied force (or at least depends on it by a definite law), and which therefore disappears again when

Fig. 1.

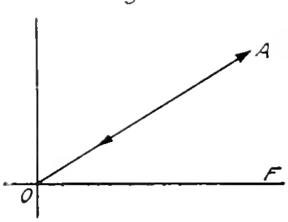
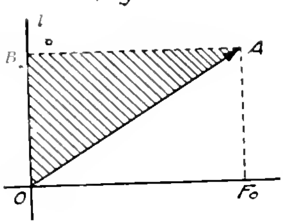


Fig. 2.



the mechanical force is withdrawn. Thus, a weight suspended from a steel wire or iron rod produces an elongation which is proportional to it (if the weight is not too large), and which, therefore, increases with increasing weight and decreases with decreasing weight, and finally disappears with a withdrawal of the weight. The relation between the applied weight or force F, and the elongation l produced by it, can thus be represented by the straight line OAO in Fig. 1, with the force F as abscissæ, and the elongation l as ordinates.

With forces of moderate value, this process of applying a force and withdrawing it again is *reversible*, and thus represents a reversible energy transformation. In applying the force mechanical energy is impressed upon the steel wire or iron rod, and at any moment is equal to the applied force, F, times the elongation produced by it, and thus is represented by the shaded area OAB in Fig. 2. This mechanical energy is stored in the structure as the potential energy of the elastic forces produced by the elongation, and is reconverted into mechanical energy at the withdrawal of the force.

This phenomenon of a cyclic energy transformation at the application or withdrawal of a force is experienced not only with mechanical forces, but occurs with all forms of energy: magnetic, electrical, thermal, etc. Thus if we have a magnetic system, as a wire coil C in Fig. 3, and apply a magnetic force F (or, as usually called, a "magnetomotive force") to it, i.e. pass an electric current i through the wire coil, then we produce a magnetic deformation in the space inside of the wire coil, called a magnetic field ϕ, which is proportional to the magnetomotive force F, and thus appears and disappears with it, and can be represented in Fig. 4 by the same kind of diagram as the mechanical system in Fig. 1. This magnetic field ϕ is a condition of stress in space, which represents stored magnetic energy, shown by the area OAB in

Fig. 3.

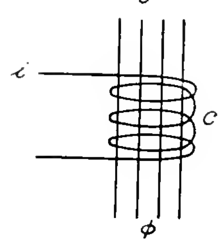


Fig. 4.

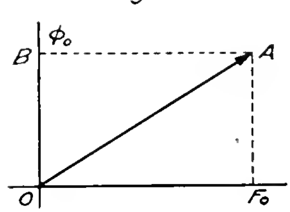


Fig. 4, and equal to $W = \frac{F\phi}{2}$ just as the stored mechanical energy in Fig. 2 equalled $W = \frac{F\,l}{2}$.

If we have an electric system, such as two parallel cylindrical conductors, a and b, Fig. 5, like the wires of an electric transmission line, and apply an electric force (usually called an "electromotive force") E between the conductors, i.e. connect them to a source of voltage, then we produce an electric deformation, i.e. an electrostatic or dielectric field ψ between the conductors a and b. This field is again proportional to the applied force, and represents the stored energy $\frac{E\psi}{2}$, shown by the area OAB in Fig. 6.

Thus the phenomena are entirely analogous in the mechanical and the magnetic and the electrical systems in air: a deformation proportional to the deforming force, representing a cyclic energy transformation from applied energy to the stored or potential energy of elasticity, magnetic or electric field, and back.

If now, in the mechanical system, we still further increase the deforming force, and load the steel wire or iron rod for instance with greater and greater weights, finally a point is reached where, after withdrawing the force, the deformation produced by it does not completely disappear, but a permanent set remains. The steel wire, on taking off the weight, does not return to its original length, but a permanent or "remanent" elongation remains, and the relation between the applied force and the elongation then is represented by a diagram like OAR in Fig. 7. OA is the elongation during the increase of applied force from O to F_0, and AR the curve of elongation during the decrease of applied force, leaving OR as *remanent elongation*.

In this case, not all the energy impressed

Fig. 5.

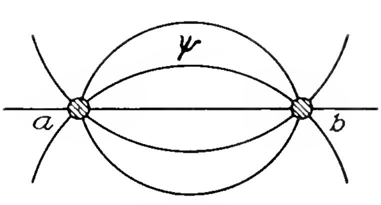
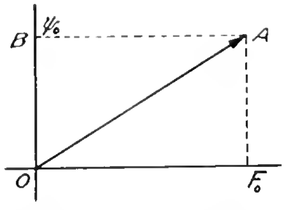


Fig. 6.



upon the steel wire by the applied mechanical force is returned. The applied energy is represented by the area OAB, and of this energy only the part represented by the area ABR is returned at the withdrawal of the force; while the difference, or the energy represented by the area of the loop OARO is lost during the cyclic energy transformation, i.e. is converted into heat by *molecular mechanical friction*.

In such an irreversible cycle, as shown by Fig. 7, with the same applied force, the elongation is less with increasing force than with decreasing force; that is, with a cyclic change of force the elongation lags behind the force which produces it, and this phenomenon is therefore called *hysteresis*, that is, lag, and in the present case, *mechanical hysteresis*. Mechanical hysteresis thus represents the energy loss by molecular mechanical friction during a cyclic application of mechanical force beyond the elastic limit, and the *elastic limit* is that point where the cyclic process ceases to be reversible, i.e. an energy loss

Fig 7.

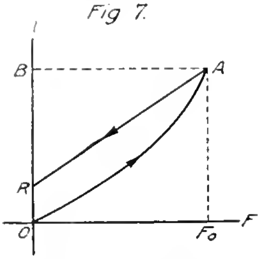
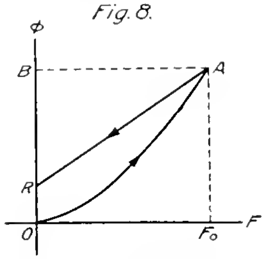


Fig. 8.



appears, and with it a lag or hysteresis, and a permanent deformation.

In the magnetic system in air no elastic limit exists, but the cyclic process remains reversible up to the highest magnetomotive forces. Irreversible cycles, however, appear in magnetic fields containing iron or other so-called "magnetic materials," and in these the curve of rising magnetization, OA in Fig. 8, is different from and lower than that of decreasing magnetization, AR. These curves represent, respectively, the rising and the decreasing magnetic characteristic. Thus a loop is formed, OAR, the *hysteresis loop*, which by its area represents the energy consumed by *molecular magnetic friction*, and at the withdrawal of the magnetomotive force a "*remanent magnetism*" OR remains.

In the magnetic system containing iron or other magnetic materials the elastic limit is at zero; that is, even at the lowest magnetomotive forces the process is irreversible and hysteresis exists. It is thus interesting to note that the magnetic system represents separately and in different materials—air or unmagnetic materials on the one hand, magnetic materials on the other—the two types of the phenomenon, which in the mechanical system occur successively; the reversible process below, and the irreversible process above the elastic limit.

In the electric system air has no hysteresis, and the cyclic process is reversible. If, however, the two conductors, in Fig. 5, between which the electric field is produced, are enclosed by a solid insulating material, the cycle of application and withdrawal of electromotive force, also becomes irreversible, at least at higher values of the force, and energy loss by *molecular dielectric friction* occurs and is measured by the *dielectric hysteresis loop.*

Fig. 9.

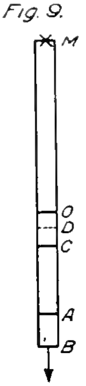
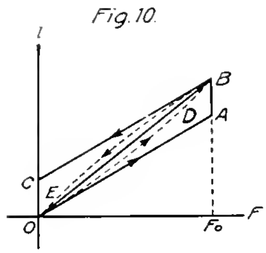


Fig. 10.



Below the elastic limit, in the mechanical system the energy transformation is reversible, i.e., perfect; or in other words, the efficiency of energy transformation from mechanical to elastic energy, and back, is 100 per cent. An energy transformation without any loss is, however, against all experience, and the question thus arises whether below the elastic limit the process is really perfectly reversible, and whether the structure, as the steel wire, returns exactly to its original state at the withdrawal of the applied force. It is more probable that the elastic limit is that point above which the permanent deformation becomes appreciable, that is, above which an appreciable energy loss by mechanical hysteresis exists; while below the elastic limit the cyclic process may for all practical purposes be considered as reversible, that is, the permanent deformation and the energy loss during the mechanical cycle may be neglected under the condition of practical application. This makes the elastic limit a relative and not an absolute point, and with sufficiently accurate methods of measurement, permanent deformation may be observed below the elastic limit. This is in agreement with experience. While under average conditions of investigation, the elastic limit is fairly definite, we know that even far below the elastic limit a permanent deformation occurs if the force is applied for a long time, perhaps centuries, as in supporting structures. Furthermore, where the material is exposed to very many mechanical cycles below the elastic limit, as under oscillating or vibratory stress, a structural change of the material finally occurs, which represents energy effects, and thereby shows that the cycle cannot be perfectly reversible, i.e., the energy cannot be completely returned.

There also is a time effect, a *viscous hysteresis*, which consumes appreciable energy even below the elastic limit, if the mechanical cycle is performed with sufficient rapidity. It is best demonstrated on materials such as rubber, which give a large elongation below the elastic limit.

Assume that a rubber band, Fig. 9, supported at M, is loaded by a weight or force F_0 at O. When suddenly applying the force F_0, an elongation of the rubber band MO takes place, to MA, and the elongation as function of the rapidly applied force is given by OA in Fig. 10. Leaving the force F_0 constant, the rubber band continues to stretch, first rapidly, and then more slowly, and reaches final elongation MB, as in Fig. 9. Suddenly withdrawing the force F_0 now causes the rubber band to contract again, but not to its original length, but to a greater length MC, leaving an elongation OC after the withdrawal of the force F_0. However, this elongation is not permanent, but gradually decreases, until finally the rubber band has returned to its original length MO. The elongation, as a function of the applied force, thus traverses the cycle OABCO in Fig. 10, where OA and BC represent, respectively, the elongation and the contraction at the sudden application and the withdrawal, respectively, of the force F_0, and AB and CO represent, respectively, the gradual creepage succeeding the application and the withdrawal of the force F_0. The area OABCO then represents the energy consumed in the rubber band by conversion into heat, during the rapid change of force, by "*time hysteresis*" or "viscous hysteresis."

If, however, the force F_0 is gradually applied and withdrawn, with extreme slowness, the elongation and the contraction follow the reversible cycle OBO in Fig 10, and no energy loss occurs. Depending then upon the rapidity of application and withdrawal of the force, any curve within the area OABCO may be traversed by the rubber band, and thereby any hysteresis loss experienced, varying between zero for infinitely slow application and withdrawal of the force, and a maximum OABCO, for instantaneous application and withdrawal of the force. Thus OBCO would correspond to slow application, but instantaneous withdrawal of the force, OABO to instantaneous application and slow withdrawal. Other curves are indicated by ODBEO, etc. This time hysteresis apparently exists, more or less markedly, in all materials exposed to mechanical forces, and is variously referred to as "after effect," "temporary set," "transient deformation," etc. Possibly it supplies the energy, which in the continued application of vibratory stresses causes the structural changes spoken of as crystallization, etc.

In the magnetic system an analogous energy loss, depending on the rapidity of the cycle, is caused by the "*eddy currents*," even in unmagnetic materials, in which the elastic limit is at infinity; that is, the magnetic cycle is perfectly reversible, if performed with sufficient slowness. In magnetic materials, as iron, at very low densities even a true viscous hysteresis occurs.

In the electric system in solid dielectrics the time effect is very pronounced, and is spoken of as "soaking in of charges," "residual discharges," etc. Thus, if a charged condenser, as a Leyden jar, is discharged by short-circuiting it, after taking off the short-circuit gradually a charge appears again, and the condenser can once more be discharged; a third charge appears, and so on, giving a number of successive residual discharges of rapidly decreasing intensity, just as the rubber band in Fig. 9, when stretched to B for some time and then released, would contract to C. If locked at C, internal stresses would gradually build up, and when released the band would again contract to D; if locked at D, stresses would again appear, giving another contraction at release, etc.

In a mechanical system if we apply a force beyond the elastic limit, as for instance a tensile force F_0 to an iron rod, the elongation l_0 produced by it, OA in Figs. 7 and 11, does not disappear at the withdrawal of the force, but the iron rod contracts on the curve AR, leaving a permanent set, or a remanent elongation OR. A reverse force OC, Fig 11, is thus required to bring the iron rod back to its original length; that is, reduce the elongation to zero. This reverse (in the present case compressive) force may be called the "*coercitive force.*" Still further increasing the reverse force to the value $-F_0$, we now get a deformation (compression in the present case) equal to the elongation l_0 resulting from the same tensile force (provided that the deformation is not so large as to change the shape of the body). Withdrawing the compressive force $-F_0$, the compression decreases, on the curve BR′ of Fig. 11, leaving a residual or remanent compression OR′, which requires the application of a reverse coercitive force OC′, to be reduced to zero. Thus by cyclically varying the applied force between equal and opposite limits F_0 and $-F_0$, that

Fig 11.

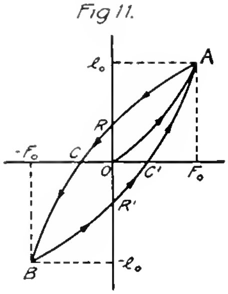
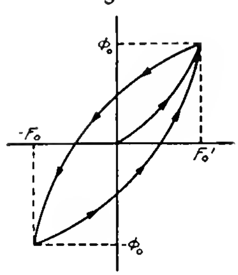


Fig 12.



is, between tension and compression, a cycle of deformation results, as shown in Fig. 11. Such a cycle ARCBR′C′A is called a "*hysteresis cycle*," or "*hysteresis loop.*" Its area measures the energy consumed in the material during the cyclic change of force, as *molecular mechanical friction*, as has been shown before; OR and OR′ are the residual or *remanent deformations*, OC and OC′ the *coercitive forces* required to overcome these deformations.

This cycle of mechanical hysteresis is the exact analogue of the cycle of magnetic hysteresis, Fig. 12; but while the cycle of magnetic hystersis has been extensively studied and its laws are fairly well known, practically nothing is known regarding the cycle of mechanical hysteresis. Very little also is known about the corresponding electric cycle, the dielectric hysteresis.

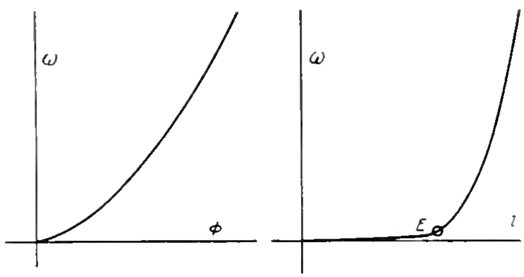
Obviously, instead of between equal and opposite values of force, the cycle could be performed between any two values, of the same or opposite sign, and in the magnetic system such unsymmetrical cycles have been studied to some extent.

By observing hysteresis cycles between different limits of force F_0 and measuring their area, that is, the energy loss during the cycle, we can determine and plot in curves the energy loss per cycle, as a function of the limits between which the cycle is traversed.

In the magnetic system such hysteresis curves have been determined and studied for many years, and empirical equations found for the same. Usually they are plotted with the magnetic field, i.e., the deformation produced by the force as abscissæ and the energy loss as ordinates, as shown in Fig. 13.

Corresponding curves of mechanical hysteresis could be determined, and plotted with

Fig. 13. Fig 14.



F_0 or l_0 as abscissæ, and the energy consumption w as ordinates.

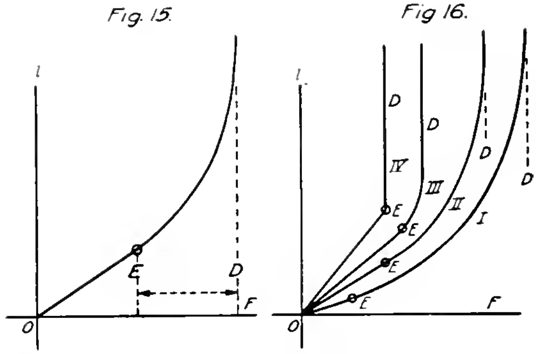
Since in the mechanical system the cyclic process is reversible, or practically so, up to the elastic limit, the hysteresis loop would collapse, that is, include practically no area up to the elastic limit, but begin to broaden out beyond the elastic limit, and the curve of mechanical hysteresis would thus have a shape somewhat like Fig. 14, being practically zero up to the elastic limit E, and then rapidly rising. It is, however, practically unknown, and the entire field of irreversible mechanical processes has been very little explored. For this reason the analogy with the magnetic and electric system is of importance, as the latter has been studied to a considerable extent, and thus valuable conclusions may be drawn from the well-known magnetic phenomena regarding the practically unknown mechanical phenomena.

Up to the elastic limit E, the relation between the mechanical force F and the deformation l produced by it is usually a straight line, or nearly so, like OE in Fig. 15. Beyond the elastic limit, the deformation usually increases more than proportionally to the force, as shown in Fig. 15. Thus by increasing the force F still further, finally a value D of the force F is reached, at which the curve of elongation becomes vertical; that is, the elongation l becomes infinite, or the structure of the body is destroyed; the body is pulled apart with tensile, crushed with compressive, forces. This limiting force D, at which destruction of the body occurs, is thus called the *disruptive limit*, or the *breaking strain* of the material.

When considering the relation between force and deformation up to high values of deformation, obviously not the total force and total deformation must be considered, but the force per unit section of the body, and the deformation per unit length of the body. Otherwise, for instance, with a compressive force, owing to the increase of section by compression, a force which is beyond the disruptive limit for the original section of the body might still be below the disruptive limit for the increased section, and a tensile force below the disruptive limit of the original structure may cause disruption of the lessened section of the body, resulting from its elongation. In the same manner, in the magnetic system the relations are always given between magnetic field, i.e., magnetic deformation per unit section, and magnetizing force or field intensity, i.e., magnetomotive force per unit length of the magnetic system. In the following, therefore, when considering the relation between mechanical force and deformation, the force per unit section, and the deformation per unit length will always be considered.

There exists, then, two characteristic points on the deformation curve of a mechanical structure: the elastic limit E, where the mechanical cycle ceases to be practically reversible and appreciable mechanical hysteresis loss begins, and the disruptive limit D, where the deformation curve becomes vertical and mechanical destruction occurs.

Fig. 15. Fig 16.



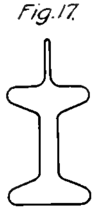
The mechanical utility of materials very largely depends on the relative position of these two points with regard to each other.

A permanent deformation is produced, by forces between E and D, and thus the shape of the body changed. Materials in which the range between the elastic limit E and the disruptive limit D is wide, as shown in curves I and II of Fig. 16, are called ductile, such as lead or gold. Materials in which the range is very small, or D and E coincide or practically coincide as shown in curves III and IV of Fig. 16, are called brittle, such as glass, etc.

It is interesting to consider the analogous phenomena in the magnetic and the electric systems. Magnetic forces have no disruptive limit, that is, the disruptive limit is infinity. Since with magnetic materials, such as iron, the elastic limit is at zero, such material thus shows in the magnetic system the analogue to perfect ductility. In unmagnetic materials the elastic limit is at infinity, and such materials thus show the phenomena of the reversible process below the elastic limit, over the entire range of forces. Thus the characteristics, namely, reversibility and ductility, which in the mechanical system succeed each other in the same material with increasing applied force, and can thus be observed in their purity over a limited range of forces only, appear in the magnetic system separated in different materials, and in each extending over the entire range from zero to infinity, and so can be studied over a very wide range.

In the electric system, with air, the disruptive limit coincides with the elastic limit at 30 kilovolts per centimeter, and air is thus dielectrically perfectly brittle. Electrically ductile bodies also exist; in many solid insulating materials there apparently exists a

Fig. 17.



range of voltage application below the disruptive voltage, in which a permanent electrical change of the material occurs; that is, insulating materials are permanently impaired electrically by a continued application of electric forces below the disruptive limit, but above a more or less indefinite elastic limit.

Owing to the existence of a definite disruptive limit, in the electrical system the same partial breakdown may occur as in the mechanical system. For instance, if a beam of the shape shown in section in Fig. 17, that is, with a narrow rib, is loaded, the disruptive limit may be exceeded in the rib long before

Fig. 18.

the elastic limit is reached in the beam. If the material of the beam is ductile, a deformation of the rib occurs which brings the stresses in it down below the disruptive limit. If the material is brittle, the rib is crushed or broken down. Thus in the electric field between two parallel conductors, such as two transmission wires shown in Fig. 18, with increasing voltage or electromotive force between the conductors, the disruptive limit of the air is passed at and near the conductors and the air thus breaks down at the conductors, and luminosity and energy loss occur, the so-called "*corona*."

The electrostatic corona thus is electrically the same kind of partial or local breakdown through exceeding the disruptive limit, as is common in mechanical systems where an element or part of an element of a structure may fail by overstrain without involving the rest of the structure, as illustrated in Fig. 17.

In general, the phenomena of the mechanical system, reversibility below the elastic limit, ductility between the elastic limit and the disruptive limit, and energy loss by molecular friction, represented by a hystersis loop, appear more clearly defined and more sharply separated from each other in the magnetic system and the electric system; and thus have been much further studied and are far better known and understood in the latter systems, the more so as, in experimental investigations, the magnetic and the electric systems allow a more perfect control of all conditions of experiment, and afford simpler and more accurate methods of measurement than the mechanical system. For this reason, in the study of the phenomena of the mechanical system, especially those beyond the elastic limit, which are of the utmost industrial importance, a very material assistance should be afforded by the analogy with the corresponding, but far better known, phenomena of the magnetic and electric systems, and often of other systems, such as the thermal, the chemical, etc. Thus the phenomena of perfectly reversible processes are most clearly represented in the magnetic field in air and other magnetic materials, the phenomena of brittleness in the electric field in air, of ductility in the magnetic field in iron and other magnetic materials, etc. It must be realized that these relations are not accidental analogies, but their meaning is that the phenomena of reversibility and irreversibility, of hysteresis and molecular friction, etc., are not specific mechanical, or magnetic, or other phenomena, but are general phenomena of energy transformation, and thus occur in all energy transformations, modified only in accordance with the nature of the energy. Thus the hysteresis loop appears as magnetic and dielectric hysteresis as well as mechanical hysteresis, as chemical hysteresis, as thermal hysteresis, etc.

Most theoretical investigations of the mechanical system have been limited to the range below the elastic limit, that is, the range where the processes are reversible, as the simplest case. When we consider the complexity of many theoretical investigations dealing with the relation of mechanical and elastic forces within the range of reversibility, the difficulty is realized of extending the investigation into much more complex range of irreversible processes beyond the elastic limit. In practice, however, the range beyond the elastic limit is fully as important as, if not more important than, the reversible range below the elastic limit, because it is in the range beyond the elastic limit where all materials are formed and shaped for their industrial use. Above the disruptive limit are carried out the operations of cutting, sawing, filing, drilling, and lathe and planer working. Above the elastic limit, but below the disruptive limit, rolling, drawing, forging, molding, swedging, etc., are done. The processes beyond the disruptive limit are not difficult in the calculation of their industrial energy relations; the problem is to apply energy in such a manner and of such intensity that the force at the point of impact of the saw, drill, etc., exceeds the disruptive limit of the material acted upon, and the disruptive limit is a fairly definite value.

Far more difficult is the problem of dealing with the industrial operations which are carried out between the elastic and the disruptive limit, in the range where the cycle of mechanical hysteresis represents the energy required in shaping the material. If the curve of mechanical hysteresis, as a function of temperature, etc., were known, the power required by a rolling mill under any condition of operation could be calculated with the same exactness as the power consumed in the alternating magnetization of a transformer is calculated from the magnetic hysteresis law of the iron.

The mechanical hysteresis essentially depends on temperature and on time; for instance, in carrying iron through a mechanical cycle a very high energy is required at ordinary atmospheric temperature. Much less energy is required at dull red heat, and at white heat the energy of the mechanical hysteresis cycle of iron becomes very small. The elastic and the disruptive limit also greatly depend on the temperature; bismuth, for instance, which is very brittle at atmospheric temperature, can be drawn into fine wire near its melting point. Cast zinc, which is brittle and crystalline, can be rolled into thin sheets within a certain temperature range. Time also exerts a material influence; asphaltum, for instance, which shatters under a sudden blow as a brittle material, spontaneously flows, that is, changes its shape, under the small, but continuous, force of gravity.

Here, then, in the range of mechanical forces beyond the elastic limit is a wide field for further investigation, in which relatively little is known beyond isolated and more or less disconnected facts, but for which no comprehensive laws have yet been derived, like those which have brought the corresponding phenomena in the magnetic and the electric system within the reach of exact calculation.

A NOTABLE HYDRO-ELECTRIC DEVELOPMENT IN SOUTH AMERICA

By Paul Frederick

Transformer Engineering Department, General Electric Company

Santos, in the republic of Brazil, is one of the great coffee-shipping ports of the world, and for the development of its water front has required an elaborate system of quays. These have been developed by the Santos Dock Company, which holds a concession for the whole water front. The company, needing electric power for its own use, has developed the system described in the following article, deriving its power from a point about 30 miles from the city, where a small stream plunges down the sea-coast from the mountain range that runs along it. The engineers have estimated that eventually they can obtain 100,000 h.p. from this source if desired, although the present capacity of the plant is only 15,000 kv-a. The system and the equipment exhibit no radical departures from current American practice; but, through the trouble and money which have been lavished upon them, the whole development stands as a conspicuous example of the soundest modern hydro-electric engineering—Editor.

No doubt most of the readers of this paper are acquainted in a general way with the work going on in the electrical field in South America, and they may be interested in knowing some of the important details of one of the larger installations recently completed at Santos, Brazil.

The *Companhia Docas de Santos* (the Santos Dock Company), is chiefly interested in shipping, and in late years has grown to such proportions that it requires considerable power to do its own work. The *Cia Docas* has a concession from the Brazilian Government which gives it the right to build docks the entire length of the city of Santos, a town of 60,000 people. The construction of this dock was by no means a simple matter, since a foundation for the masonry work had to be laid in the banks of a swampy inlet from the Atlantic Ocean.

At the time the *Cia Docas* started the construction of its quays, Santos was one of the most fever-stricken cities in any country. Conditions were such that for a greater part of the year the city was quarantined, and cargo vessels left their crews at a point some miles from the city whence native sailors brought them into port. The *Cia Docas* therefore was not only faced with the natural difficulties of building its quays, but, in addition, it had to fight the fever as well. At the present time, through the efforts of the company's engineers, Santos is equipped with a good sewerage system; and the tropical rains, instead of stagnating in the streets, breeding mosquitoes and fever, are carried off by large open canals which run the length of the city. Difficulties were overcome in the actual construction of the quays that would have discouraged men of less determination. One by one the engineering problems were solved; and as a reward the *Cia Docas* has a system that is a credit, not only to itself, but to the country as well. The quay itself is now completed for 4720 meters, and as the demand for more berths develops this length will be increased. Along the quay the company has built a double-track road connecting with the Sao Paulo Ry. Co. so that cargo can be loaded directly from the freighters to the cars by means of hydraulic cranes. At the back of this track is a double row of large storage warehouses. These buildings have a framework of structural steel, and corrugated sheet iron roof and sides.

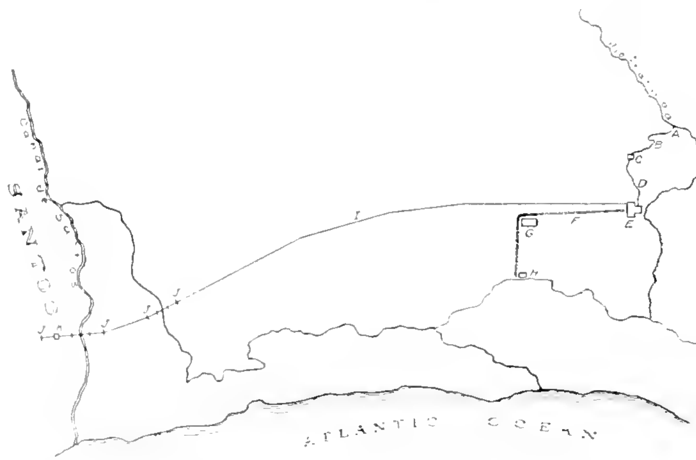


Fig. 1. Map of Cia Docas de Santos Hydro-electric System. A, intake; B, flume, C, forebay; D, pen stocks; E, power house; F, narrow gauge railway; G, general store; H, point of debarkation; I, transmission line; J, dead ends; K, substation.

To provide power for itself the Dock Company decided to take another big step and develop one of the numerous water falls in the vicinity of Santos. The falls chosen lie some 30 miles north of the city and 4 miles from the Atlantic Coast. A stream,

Fig. 2. View Showing Construction of Flume

called the *Rio Itatinga*, drains a plateau at the back of the mountain range along the coast. This range is very abrupt; and the Itatinga flowing from the plateau to the sea makes it possible for the Dock Company to utilize a head of 640 meters in a very small horizontal distance. An idea of the general development scheme may be obtained from Fig. 1.

It was necessary to build a flume about 2000 meters in length to carry the water to the most advantageous position. This flume follows the contour of some very steep hills and had to be cut out of solid rock every inch of the way. The section of this canal is 100 by 150 centimeters, and the inside surface is finished with high grade cement to reduce friction. The construction of the flume was a very difficult piece of engineering owing to local conditions and the elements. Tropical rains on numerous occasions started landslides on the hills above the canal, and these slides destroyed the results of many days' labor. At several points concrete sheds had to be built over the flume to provide a passage way for the streams flowing down the hills—streams which, ordinarily dry, develop during the rains into torrents of considerable size. Cement, sand and all tools were hauled from the foot of the hill to the flume, by a series of winches driven by two 45 h.p. stationary engines. The flume construction is shown in Fig. 2.

The penstocks consist of welded steel pipes of German manufacture and vary in diameter from 90 cm. at the forebay to 60 cm. at the power-house. Each section of pipe is supported on a concrete base and at every fifth length the penstock is imbedded in a mass of concrete. Each section of the penstock is six meters long, with an average weight of 2000 pounds. The total length of the penstock is approximately 2000 meters. In the valve room, adjacent to the generating stations, the piping is so arranged that the water from any penstock may be made to supply any turbine. A view of the penstocks is shown on the cover of this publication.

The Company's engineers have estimated that they can obtain 100,000 h.p. from the Itatinga; and with the idea of increasing the capacity of the plant as necessity demands, they built the penstocks large enough to

Fig. 3. View of Intake

supply water for 100,000 h.p. Each penstock is sufficient to supply water for the combined capacities of the generators at present installed; and any desirable future increase in the capacity of the plant can therefore very readily be made. Having regard to the location of the power house—on the river bank and on the edge of a swamp—a foundation 60 feet deep had to be laid. In this foundation there is about 100 tons of 1 in. bar-iron used to reinforce a mass of concrete. The building itself (Fig. 5) is of granite blocks cut from a quarry near the station and is a most solid structure. It is built in a T shape with the generators in the leg and the switchboard, high tension busses, oil switches, etc., in the cross-bar. The arrangement of the interior of the power house is shown in Fig. 6. A 30-ton hand-operated traveling crane runs the length of the main floor. On this floor five three-phase 2300-volt 60-cycle generators, each of 3000 kv-a. capacity, are installed. Impulse type waterwheels drive the generators at a speed of 514 r.p.m. To take care of a varying load on the generators the turbine governors do not decrease or increase the supply of water, but deflect the jet so that a smaller or larger quantity strikes the buckets. Should a valve suddenly close, the shock would place a tremendous strain on the penstock due to the high pressure, and serious trouble might be expected. A water cushion is provided directly under the turbine, to absorb the force of the water which does not strike the turbine buckets. On the same floor with the generators are three (150 kw.) exciters individually driven by the same type of impulse wheel. These exciters are compound wound and generate at 220 volts.

Fig. 5. Exterior of Power House

Fig. 4. Forebay 640 meters above Power House

The voltage from the generators is stepped up to 44,000 volts, through fifteen single-phase water-cooled transformers of 1000 kv-a. capacity each. These transformers are connected in banks of three for delta-delta operation. A complete hot-air system for drying the transformers and oil has been installed, as well as a complete oil-piping system, including two large oil-storage tanks. When it is necessary to treat the oil and transformer the oil is drained to the storage tanks by gravity and then pumped to the treating tank. The oil and transformer may be dried out at the same time. The cooling water for the transformer is taken from a small stream near the station and filtered to remove sand, leaves, etc. The switchboard

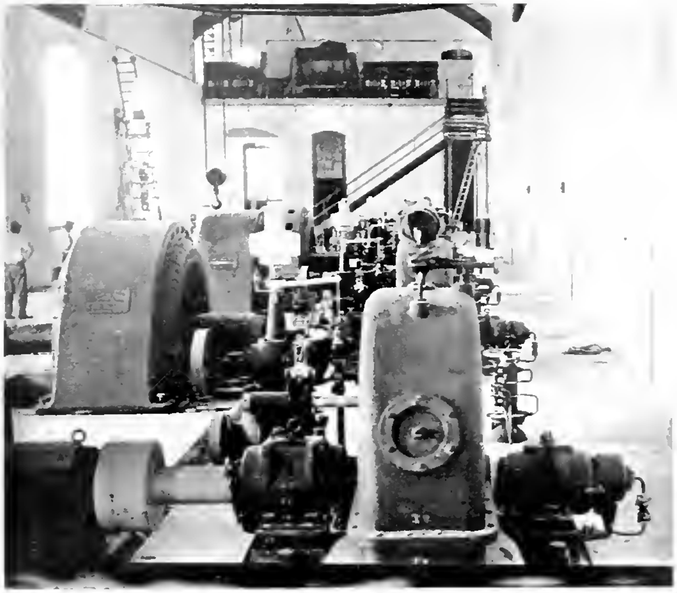


Fig. 6. Interior of Power House

is on a balcony so that the operator can overlook all of the machinery and keep in communication with the turbine operator. The switchboard is of the latest design with automatic voltage regulators, motor-operated oil-switches, etc. The transmission line consists of two three-phase circuits supported on galvanized steel towers. At both ends of the line the latest type of electrolytic lightning arresters have been installed. Severe electric storms are frequent in the vicinity, and the lightning arresters have proved their efficiency on this system.

The substation building (Fig. 7), like the power house, is built of granite blocks. Here the power is stepped down from 44,000 to 6600 volts through five three-phase water-cooled 3000 kv-a. transformers. One spare unit has been provided. The substation has twenty-one 6600-volt distributing lines. Most of these are used by the Dock Company for its own work. Its machine shops and carpenter shops are operated by motor-driven shafts. Power and light lines are run to the quays, where a complete series arc lighting system has been installed. Other lines run to the Santos Improvement Company carrying power for the street railways and city lights. Still another distrib-

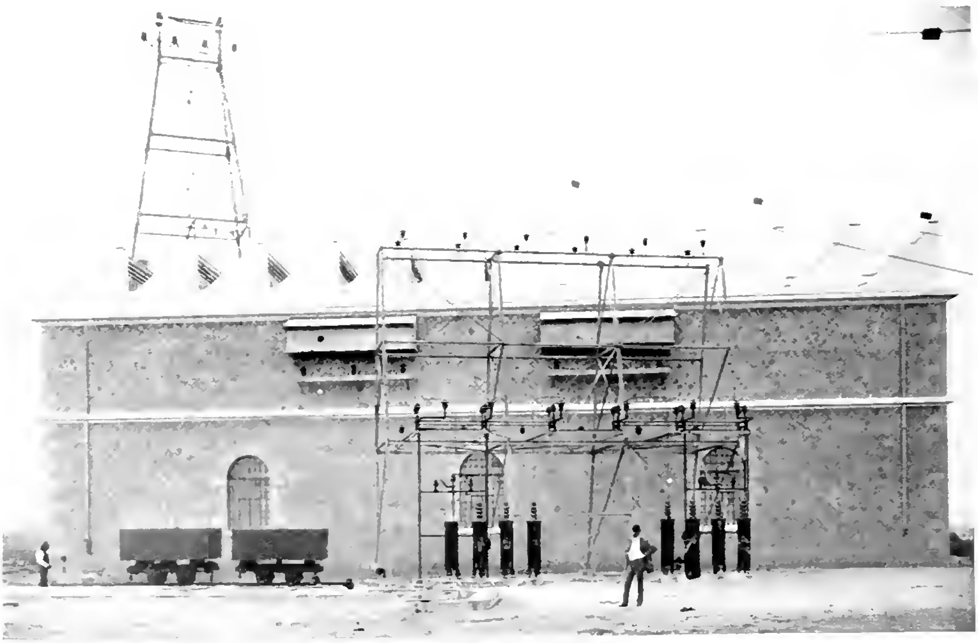


Fig. 7. Back of Substation showing High Voltage Line Entrance

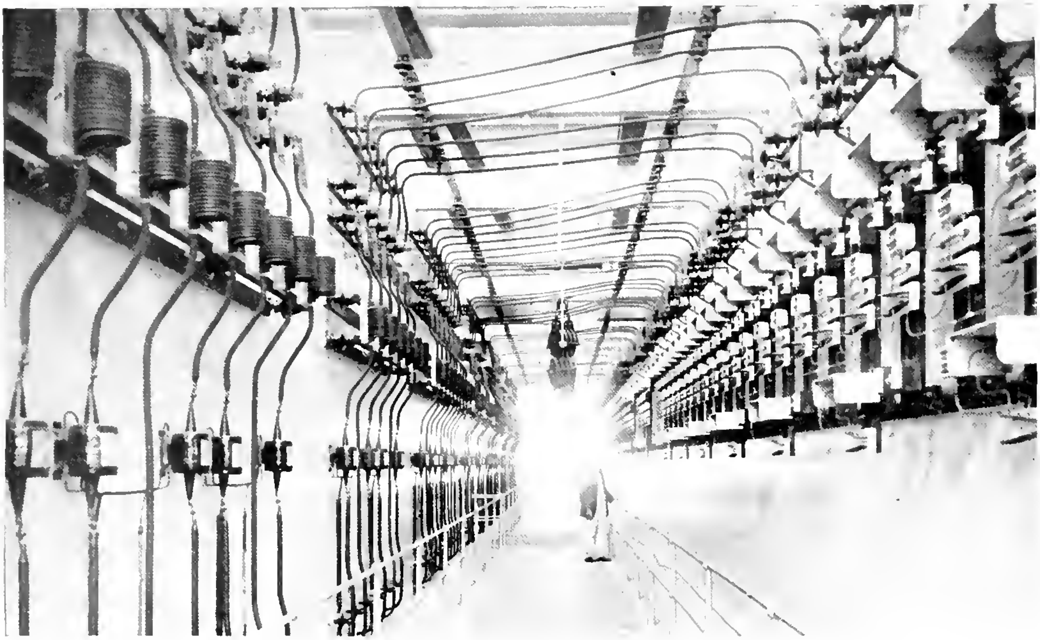


Fig. 8. Interior of Substation showing Lightning Arresters

uting line runs to the quarry of the Dock Company for motors driving compressors for air drills. The quarry uses about 500 kv-a. and it is from this source that the company obtains all the filling material for its quays. At present this stone is hauled to the quay over a narrow-gauge steam railway track about 5 kilometers long, but it is believed that this line will shortly be electrified.

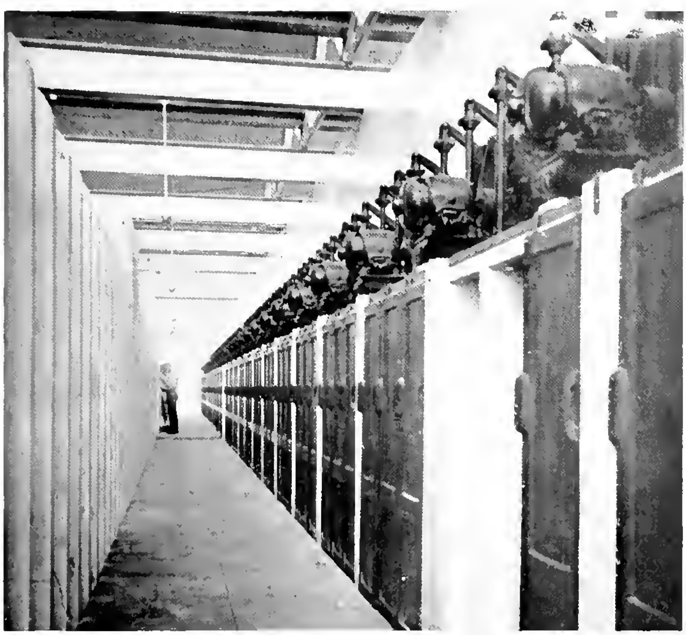


Fig. 9. Interior of Substation showing 6600 Volt Oil Switches

Electrically operated conveyors are being installed from the street back of the outside warehouse to the dock, where the sacks of coffee are discharged into the hold of the ship. This main conveyor runs through the outside warehouse, under the street between the two warehouses, and again through the warehouse on the dock. This conveyor is fed also by others running the length of each warehouse. This system will be of great importance to the Dock Company since the laborers, under the old method, were in a position to demand exorbitant rates for carrying the sacks from the carts on board ship during the shipping seasons. There are at present in operation thirty-one hydraulic cranes, ranging in capacity from $2\frac{1}{2}$ tons to 20 tons. Two engines, with a total capacity of 330 h.p., drive pumps supplying water at

50 atmospheres pressure for the cranes. Motors are to replace these engines. A fleet of 15 or 20 dredges owned by the company keeps the channel navigable for the largest steamers. A dry dock capable of handling boats of 700 tons enables them to make all necessary repairs to these dredges. The installation of twenty-eight 1½-ton, six 5-ton and one 30-ton electrically-operated derricks is now in progress.

In building up its entire system the *Cia Docas* has not considered expense, its one object being to have a completely modern installation which can be depended on to perform its work satisfactorily, economically and without interruption.

EXCITERS AND DIFFERENT EXCITER ARRANGEMENTS FOR LARGE GENERATING STATIONS

By E. A. Lof

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As pointed out in an article by Mr. C. W. Stone in the June Review, there has been much difference of opinion respecting the best methods of arranging and operating the exciter equipment for medium and large sized power stations, with the result that this vital part of the generating system has not become standardized to the same extent that has the rest of the apparatus involved. In the present paper will be found some recommendations covering the design, installation and operation of exciter plants, based on a thorough study of existing central station conditions. The author takes up successively the questions of proper exciter capacity, involving the additional excitation required at low power-factor and the provision of a separate unit for emergencies; the proper voltage, whether 125 or 250 (largely determined by the size of the station); methods of driving the exciters, either by direct-connected motors operated from the main system or from separately driven generators, or directly by prime movers; methods of mounting the exciters; electrical connections, providing for either one or two busses to which all the exciters are connected in parallel, or a separate exciter for each main unit connected directly to the alternator field; automatic voltage control by altering the strength of the exciter field; and lastly, the undesirability of installing circuit interrupting devices for the protection of the exciters.—Editor.

One of the problems in connection with large generating stations which has been given comparatively little attention until lately, is that of excitation. It is, however, of the greatest importance, as upon it depends to a large extent the successful operation of the plant. The capacity of the exciter units, the proper division of the required exciter capacity into several units, the method of drive, whether by separate prime-movers or by individual motors, the arrangements and connections of the different units, the proper system of automatic voltage regulation, etc., are all factors which should receive careful consideration when designing a power plant. It will therefore be the aim of this article briefly to outline some of the most important factors governing the selection of an exciter system, and also to show a few of the arrangements which are generally used in modern central stations.

Exciter Capacity

The exciters should have a capacity sufficient to excite all of the synchronous apparatus in the station when these machines are operating at their maximum load and at the true operating power-factor. It is not enough to provide for the excitation when operating at unity power-factor, because the excitation which is required at lower power-factors is considerably higher than at unity power-factor.

It is therefore a good practice to have the combined normal capacity of all the exciters correspond to the excitation required for all the generators, when these are operating at their maximum overload. As the exciters are generally designed for a 25 per cent two-hour overload rating, a safe margin in capacity will thus be left for operating auxiliary

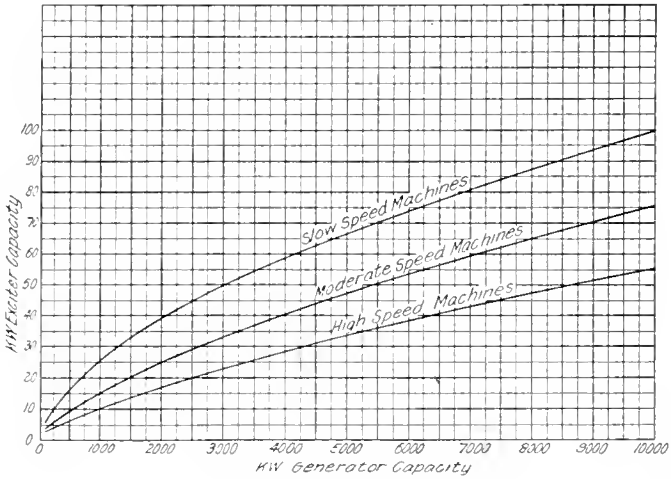


Fig. 1. Average Excitation of Alternators

station apparatus such as pilot lights, switch and circuit-breaker solenoids, motors, etc. A spare unit to be kept in reserve in case of the break-down of any exciter should generally be provided. This is especially desirable where an uninterrupted service must be secured at any cost and where the exciter units are few in number, as in such a case the shut down of one exciter would seriously cripple the system.

The amount of excitation that is required differs materially for different machines, depending upon their size, speed, etc. For generators of different capacities but otherwise similar, the relative excitation decreases as the size of the generators increases. High-speed machines with their smaller number of poles require less excitation than slow-speed machines. The air-gap is, however, generally smaller for the latter type and this somewhat offsets the increased excitation for the slow-speed type.

The curves in Fig. 1 give approximately the average excitation required for alternators of high, medium and slow speeds. It is seen that, as compared to the rating of the generator, it varies from one-half of one per cent. for large high-speed machines to several per cent. for small slow-speed machines.

Exciter Voltage

For installations of moderate capacity a 125-volt excitation pressure has been considered standard. Under such conditions and in order to provide for automatic voltage regulation, it is advisable to design the alternator so that the range in excitation from no load to maximum load at 80 per cent. operating power-factor does not exceed a ratio of one to two. With 125-volt excitation for maximum load, the corresponding pressure for no load should therefore be kept about 70 volts.

With reference to the exciters themselves, they should preferably have a time element and be responsive to changes in field excitation to the extent that, by inserting an external resistance equal to about three times the resistance of its field circuit, the voltage will drop from 125 to 25 volts in from four to six seconds. A good exciter designed along these lines should also momentarily give 165 volts at full field and the increase in the field current from 125 to 150 volts should not be over 50 per cent. It is necessary to design the exciter for low magnetic densities in order that it shall quickly respond to the short-circuiting of the field rheostat by the automatic regulator and thus insure the desired alternator regulation.

For large installations a 250-volt system of excitation will generally be found more economical than a 125-volt system. This higher voltage will permit the use of smaller exciter and field switches, while leads of reduced size from the exciters to the busbars and from the busbars to the generator field may be used, and the cross section of the busbars cut in two; all this being of importance in reducing the cost, especially in large installations. A considerable saving can also generally be accomplished in the exciter itself. Machines for 125 volts require a commutator twice as large as those for 250 volts; and, with waterwheel-driven units, where they must be designed to safely withstand double speed, the construction oftentimes involves considerable difficulties and expense.

Compound wound exciters seem to be preferred rather than shunt wound machines, a better parallel operation and division of the load being possible with the former, especially when the exciters are of different size.

Method of Drive

While the exciters can be either belt-driven or direct-connected to the machines driving them, the latter practice is almost exclusively used except in the very smallest plants. The direct connection may be either to the main generators, to separate prime-movers or to motors. Sometimes (although rarely) an exciter may be found that is connected both to a motor and a prime-mover, the prime-mover running idle when the motor is carrying the load, and the motor running idle when the prime-mover is doing the work. This method, however, seems to be rather complicated and can hardly be recommended unless certain special conditions would warrant the arrangement.

The practice of installing one direct-connected exciter for each main generator has been used to a considerable extent in the past, although in modern installations it is generally giving place to other systems. With very few generating units in the station, however, the method may be advantageously used; and in order to provide for the failure of one exciter, their respective capacities should be made such that the others could furnish excitation for all the generators until such time as the faulty machine could be repaired. It is therefore often found that the exciters in such cases are each given a rating equal to twice that required for the excitation of one generating unit. For plants with a large number of units, however, this system becomes rather complicated. Another dis-

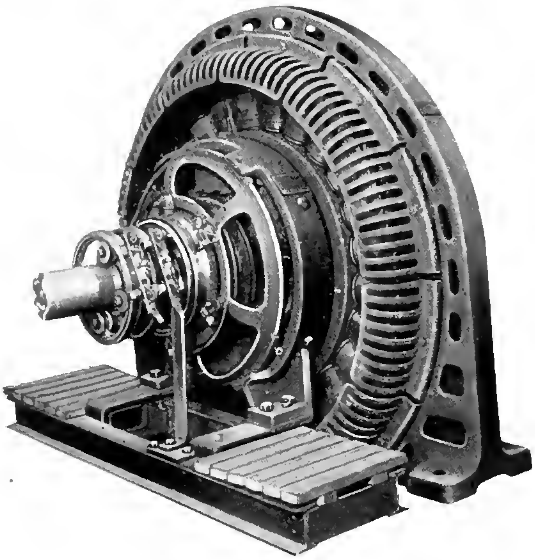


Fig. 2. Engine-driven Generator with Direct-connected Exciter

advantage resulting from the use of exciters direct-connected to the main units is that they will be affected by the speed variations of the prime movers caused by the variation in the load.

The system which seems to be the most widely used and which offers the greatest reliability, is that in which the excitation is obtained from a common source, consisting of as few exciters as possible. Three units are then generally provided, of which two, however, are all that are needed for supplying the required excitation, the third unit being held in reserve. Sometimes the two exciters first-named are driven by prime-movers, either steam engines or hydraulic turbines, while the third unit is motor-driven. This method may be the most desirable, especially in hydro-electric plants where the possibility of *debris* clogging up the small exciter turbines and shutting them down is always present. Under such conditions it would naturally be more advantageous to keep the motor-driven set in reserve for such an emergency. From an economical point of view, however, it is evident that two motor-driven units with a steam or waterwheel-driven set as the spare will cost less. The exciter driven by the prime-mover would have to be relied upon in such cases in starting up the system, unless a storage battery were provided, as is usually the case in large stations.

In some of the latest hydro-electric developments an entirely new and quite novel system of excitation is being used. Here one small motor-driven exciter set is installed for each generator unit. The exciter has a capacity corresponding to that required by its generator, and its terminals are connected directly to the generator field. The motors of the various exciter sets are fed from one or two low-voltage generators, driven by independent prime-movers. In addition, means are provided so that if necessary the motors may be connected to the main bus through transformers, two separate sources being

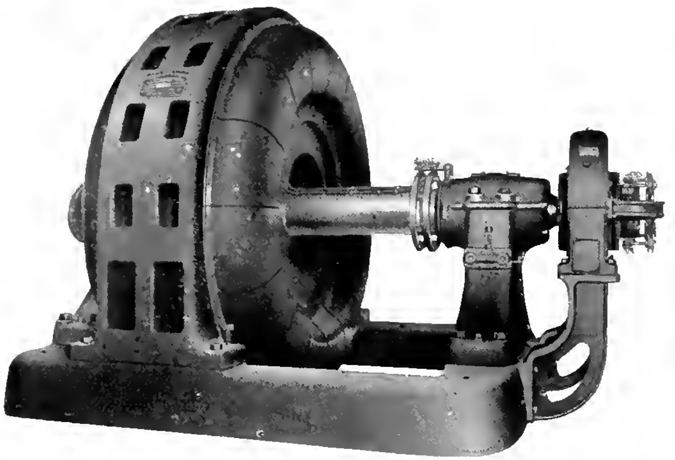


Fig. 3. Horizontal Waterwheel-driven Generator with Direct-connected Exciter

thus provided for driving them. With this arrangement the objection to motor-driven exciters on the ground that they are liable to fall out of step when a short-circuit occurs on the system has naturally no bearing, because the system of excitation is entirely separate from the alternating current system.

Mechanical Design

Almost all exciters are of the horizontal construction, although sometimes it may be found more economical to make them vertical; this, however, being generally due to certain advantages from the hydraulic point of view. Otherwise, there is not much difference in the mechanical design between exciters and other direct current generators.

Where separate direct-connected exciters are provided for each alternator they can either be mounted inside the bearing as shown in Fig. 2 or outside as shown in Fig. 3. Of the two methods the former is usually used only where the generator is driven by a steam engine and where the engine cranks would prevent the mounting of the exciter outside the bearings. The method shown in Fig. 3 is employed chiefly with direct-connected waterwheel-driven generators, motor-generators, etc. It makes a very substantial outfit, and at the same time permits easy access for inspecting and adjusting the brushes of the exciter. In case of trouble the exciter can be disassembled and removed in a very short time, after which the generator can again be started up and excited from the exciters of the other units if sufficient capacity has been provided.

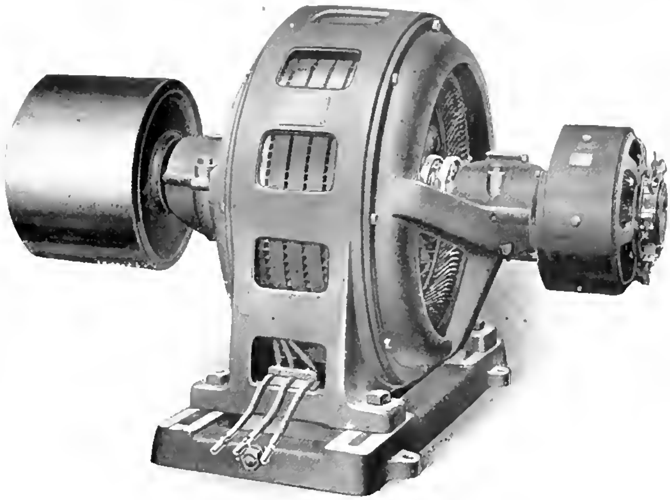


Fig. 4. Belt-driven Generator with Direct-connected Exciter

In certain smaller installations where the generators are belt-driven, the exciters can be mounted as shown in Fig. 4. This obviates the use of a separately-belted exciter and makes the outfit much more reliable, besides accomplishing a considerable reduction in the required floor space. If vertical units are

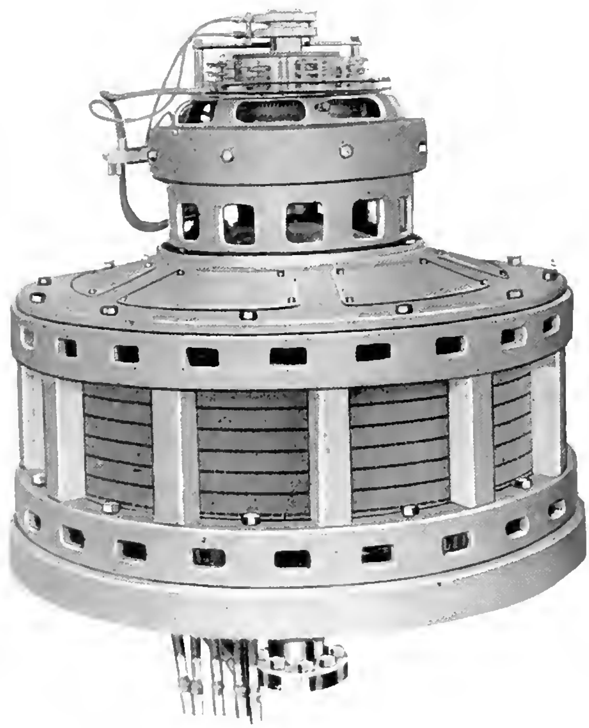


Fig. 5. Vertical Generator with Direct-connected Exciter

used, the direct-connected exciter is generally mounted on the top bracket of the main generator as shown in Fig. 5. The shaft is

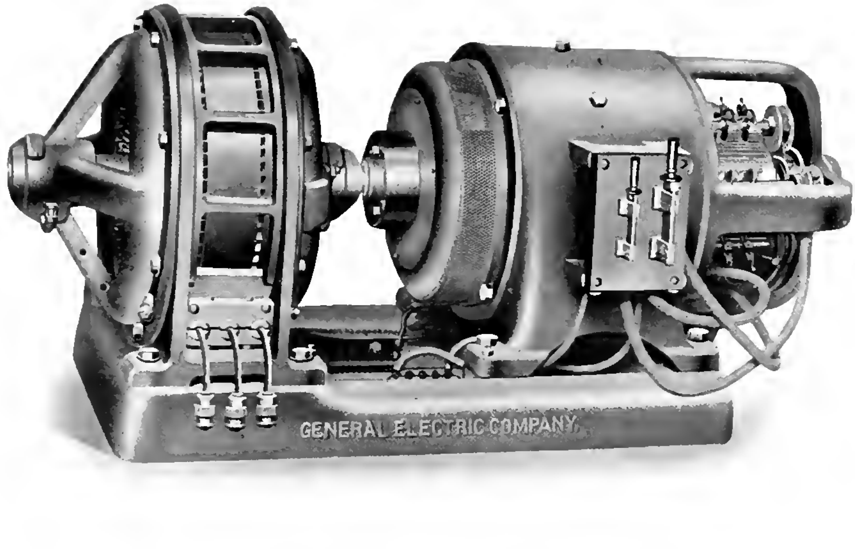


Fig. 6. Induction Motor-driven Exciter

extended and the collector rings for the generator field are mounted above the exciter as shown. A step-bearing is located underneath the turbine and a guide-bearing between the generator and exciter rotors. Fig. 6 illustrates an exciter driven by an induction motor, both units being mounted on a common cast iron base, in the same way that any ordinary motor-generator set is mounted.

Where the exciters are driven by separate prime-movers, such as steam engines or waterwheels, the method of mounting is the same as for other direct-connected generators. For engine drive the shaft, base and bearings are generally furnished by the engine builder, while for waterwheel drive these parts are usually included with the exciter. With vertical units the armature and revolving element of the waterwheel are generally supported from a roller suspension bearing mounted on the top bracket of the exciter. This bracket also contains the upper guide-bearing, while the lower usually forms a part of the wheel casing. Care should be taken in designing the bearings of all waterwheel-driven exciters to see that the water thrust is taken care of in the turbine, or proper allowance must be made therefor. All such exciters should furthermore be designed to safely withstand the runaway speed of the turbine, which is generally twice the normal speed.

System of Connections

The general practice is to provide one or two sets of common busbars to which all the exciters are connected in parallel and from which the fields of the different generators are excited, a rheostat being inserted in each field circuit. The diagram shown in Fig. 7 represents a system where every generator

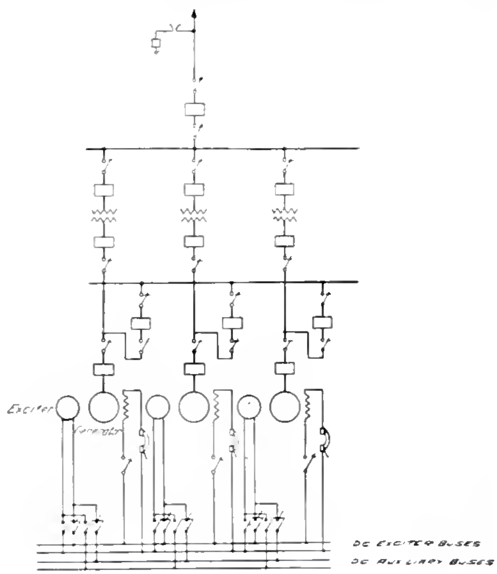


Fig. 7

is provided with a direct-connected exciter. There are two sets of busbars, one for excitation and the other for auxiliary service.

Switches are provided so that the exciters can be connected to either set as desired; and the advantage of this arrangement is that one exciter can be connected to the auxiliary bus while the others are operating on the exciter bus. Any fluctuation in the exciter voltage caused by an automatic regulator, for example, will therefore not be felt on the auxiliary or lighting bus, the pressure of which can be kept constant.

The arrangement shown in Fig. 8 is often used. Only one set of exciter busbars are shown, although frequently an auxiliary set is also provided as in the previous case. There are three exciters, two of which are driven by induction motors fed from the main busbars; while the third unit, which is held in reserve, is driven by an independent waterwheel. Only one starting compensator is needed for the two motors, a common starting and running bus being provided. The system can be sectionalized in two parts if desired, while switches are provided so that the waterwheel-driven exciter can readily be connected to either side.

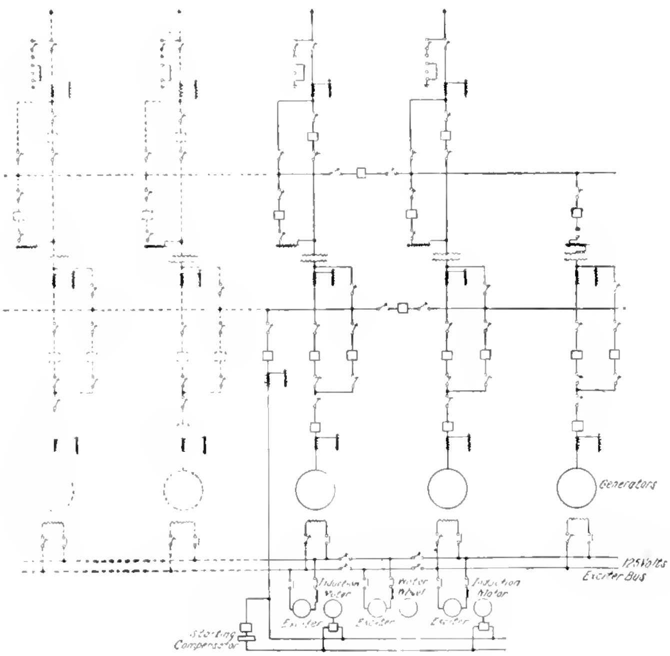


Fig. 8

Fig. 9 represents the latest practice in the way of arranging and connecting the exciters for a system of very large capacity. One induction motor-driven exciter is provided for each main unit, each exciter being directly-connected to the field of its respective generator. The exciters are not arranged for parallel operation, but are provided each with its own automatic regulator so that it is possible to compensate for wattless cross currents between the generators. In the system shown, the induction motors are fed either from two low-voltage alternating current generators driven by separate waterwheels, or alternatively from the main alternating current busbars through step-down transformers. The auxiliary low-voltage generators are, however, the normal source; and the exciter system is thus entirely free from voltage fluctuations or disturbances on the alternating current system. In another installation of this kind the auxiliary generators are provided for combination drive, one end being connected to a waterwheel and the other to an induction motor, which in turn can be connected to the main alternating current busses through step-down transformers, unless the voltage will permit of a safe operation of the motors without the transformers. In such an arrangement the exciter sets are not provided with independent group connections to the main bus, as shown in the illustration; as it is considered that a breakdown would most commonly be caused by a clogging up of the turbines, in which case the alternating current units could be driven by the motors. It would seem, however, that the scheme shown in the diagram is more flexible and reliable.

Voltage Regulation

On any alternating current system it is of the greatest importance that an accurate voltage regulation be kept, and this is especially true where the lighting load is a predominating factor. Besides the decreased life of incandescent lamps when used on fluctuating voltages, the illumination from such lamps is highly annoying. A considerable saving in energy can also be accomplished, because the exciters and generators deliver the exact power required in proportion to the demand made upon them. A slight increase in the voltage on a large system means an increased loss in the transformer cores.

Without some form of automatic voltage regulator it is impossible to take care of the heavy swings in the voltage caused by fluctuating power and railway loads. Even in the case of purely lighting load it is exceedingly difficult to properly take care of the voltage by hand regulation, especially at peak loads. The present tendency of designing generators for a high internal reactance, in order to reduce destructive short-circuit currents, results furthermore in a rather poor inherent regulation of the generators, and it is therefore essential for a good service to provide automatic voltage regulation.

Many different forms of automatic regulators have been devised. Some of them have been designed to operate directly on the alternating current generator field rheostat by varying the resistance. Such a system has, however, proved to be entirely too sluggish in operation. The most successful and best-known device for this purpose is one in which the regulation is effected entirely in the field circuit of the exciter, by rapidly opening and closing a shunt circuit across the exciter field rheostat. The system operates, therefore, at the highest efficiency and eliminates the losses which would result if operated directly on the generator field.* A chart of this regulator is shown in Fig. 10, the lower curve giving the voltage record obtained without the use of the regulator and the upper curve the record obtained after the installation of the regulator. A glance at the curves is enough to make one realize the enormous benefits derived from the use of such a device.

While the usual practice is to adjust the regulator for a constant busbar voltage, compensation for line drop may also be obtained by providing a special line drop compensator.†

Where separate exciters are provided for each generator, and these exciters are not operating in parallel as in the system shown in Fig. 9, the regulators can be used for preventing wattless cross-currents flowing between the generators. This is accomplished by installing current transformers for each generator and by connecting them 90 deg. out of phase with the potential transformer; so that, if cross-currents tend to flow between the generators, they will be reduced by the regulator action, which tends to strengthen or weaken the excitation of the units as required.

The fluctuating voltage of the exciter busbars, caused by the use of automatic voltage

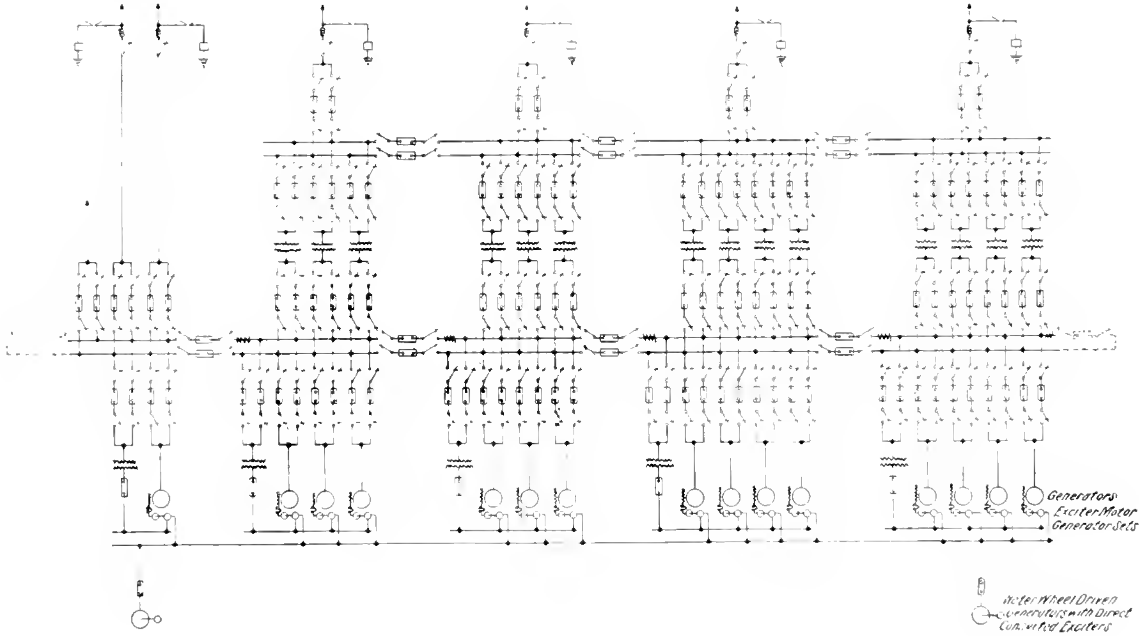


Fig. 9

* For a complete description of this regulator and its operation see GENERAL ELECTRIC REVIEW, June, 1909, "Regulators for Alternators," by H. A. Laycock.

† "Line Drop Compensators," by G. F. Gehrkens, GENERAL ELECTRIC REVIEW, March, 1912.

regulators of the type previously described, is sometimes objected to in cases where it is desired to operate station lights, oil switches, relays and other auxiliary apparatus from this same source of power. It is, however, possible to keep the exciter pressure constant, and to effect the voltage variation, necessary for the regulation of the alternating current generators, by means of a motor-driven booster. This booster is then controlled by an automatic regulator and can be made to either boost or buck the exciter voltage as desired, thus varying the pressure applied to the alternator field, while the potential of the exciter busses is kept constant.

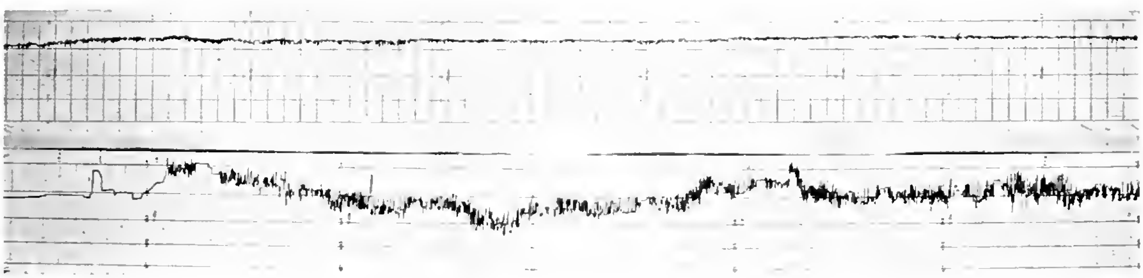


Fig. 10. Record Chart of Automatic Voltage Regulator

Protection

Overload protection is as a rule not recommended in connection with exciters, since it is usually more important to prevent any interruption in the supply of the field current to the alternating current generators, thereby insuring a continuous operation (which in most stations is an essential feature), than to protect the exciters themselves from damage. A further reason for omitting an automatic protective device is to prevent injury to the alternating current field windings. When trouble occurs in the exciting system and opens the overload devices on all the exciter circuit-breakers, the generator field circuits are broken at points where no discharge resistances are interposed, and the generator field windings are consequently liable to puncture by the high induced voltage to which they are subjected. In some cases, however, the protection of the exciters is of more importance than the above considerations, and fuses may be inserted in the exciter leads, however, when this is done it is advisable to make the fuses of sufficient capacity to insure that the exciter circuit will be opened only in case of very serious trouble.

For large plants where a number of large exciters are operating in parallel, it is sometimes customary to install reverse-current circuit-breakers without any overload attachment. The reverse-current device will then serve to disconnect a defective exciter while the remaining units continue to operate.

OPERATION OF SYNCHRONOUS MACHINES IN PARALLEL

By Lee Hagood

Lighting Department, General Electric Company

The question of the successful operation of synchronous machines in parallel or multiple has always attracted a great deal of attention on account of its important bearing on satisfactory and uninterrupted electric service. In the present paper Mr. Hagood takes up chiefly the question of the economical control of the exciting or wattless current in a system so as to obtain suitable voltages at the centers of distribution, and the economical use of the generators, transformers, and transmission lines involved. The importance of this problem appears chiefly where inductive loads occur. The treatment herein adopted is such as to render this paper a valuable contribution to the series on voltage and power-factor control by the use of synchronous machines, to which we referred in our September number; and in which the first article was by Prof. E. J. Berg on "Voltage Control using Synchronous Motors with Automatic Voltage Regulators." Mr. Hagood's paper will be continued in an early issue.—Editor.

Parallel Operation

For successful parallel operation alternators should have the same frequency, equal and opposite potentials at the time of synchronizing, suitable wave forms, and be properly excited at all times; furthermore, their prime movers should have substantially uniform angular velocity, with similar, but dropping speed characteristics. No practical difficulties of any magnitude are now experienced from any of these conditions, except the matter of angular variation in speed and the question of proper excitation.

In regard to angular variation in speed, it may be said that little trouble is experienced from this source where the prime mover is a waterwheel or steam turbine unit. It is inherent with these types to furnish constant angular torque, and on this account there is but little opportunity of setting up or sustaining periodic angular movements. With reciprocating engines, however, the driving torque is not uniform, and the angular torque therefore varies. This condition may promote angular movements in the alternator unless properly restricted, and these movements in turn will cause pulsating energy exchanges between the alternator in question and the other synchronous machines on the system. Such angular movements may take up a periodic vibration commonly known as hunting. In some cases hunting has been so excessive that machines would even fall out of step, causing serious interruptions in service.

It is well recognized nowadays that hunting occurs rarely except where reciprocating engines are used; and the cause is their property of creating and sustaining in alternators periodic variations, in other words, mechanical oscillations. However, by using the proper flywheel effect and suitable types of governors, etc., engine builders have long since been able to cope with these difficulties; in fact, any steam engine unit now furnished by a responsible manufacturer is suitable as a prime mover for an alternating current system. With gas engines, however, the problem has not been so simple in solution and it is necessary to equip alternators, when driven by them, with a special winding, usually a squirrel cage arrangement to damp out the oscillations.

Angular variations in speed of alternators, or hunting, which after all is entirely a question of prime movers, is certainly not a matter for further serious worry.

In the past slight difficulty has been experienced in parallel operation on account of poor wave-form in alternators. This, however, is no longer a problem, as most alternators provide good wave-forms. Even though the wave-form were very bad, the difficulties arising in parallel operation would be very insignificant except in a few rare cases. Another source of trouble in the past has been automatic division of load. This is entirely a matter of proper control of energy supply by the governing mechanism, and this has also been solved beyond dispute.

This paper will deal almost entirely with the question of proper field excitation for synchronous machines to accomplish suitable voltages and power-factors. This is in no sense a difficult problem, or one not understood, but the writer feels that it has not been given the attention by engineers that its importance really deserves. Though the subject will be confined to alternators and synchronous motors, nevertheless, the same principles would apply to synchronous converters. In regard to synchronous converters, however, it is not deemed desirable to build them so that they can be excited other than in the regular manner. With the present design of synchronous converter, they should never be used for power-factor control, since they are only intended to be run at near unity power-factor. Though they could, under certain conditions, be used over-excited, the instructions necessary to give operators on this point are complicated, and unless carefully followed there would be some danger of seriously damaging the machine.

To bring out properly the important features of this problem of economic field excitation, the writer will discuss, first some of the fundamental principles involved, and will then give some concrete examples of their application.

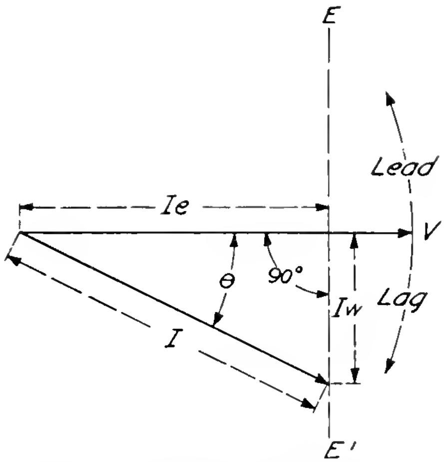


Fig. 1. Relation of Wattless Current to Power-factor and Actual Current Assuming Kilowatt Output and Voltage Constant

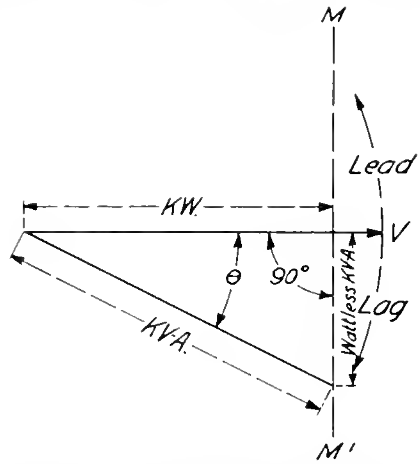


Fig. 2. Relation of Wattless Kv-a. to Power-factor and Actual Kv-a., Assuming the Kilowatt Output and Voltage Constant

V = voltage.
I = actual current.
I_e = energy component.
I_w = wattless component (magnetizing current). It is termed positive if lagging and negative if leading.
Cos θ = power-factor.
EE' is the locus of the terminals of the current vectors for various magnetizing currents, assuming both the energy delivered and its voltage to be constant.
MM' is the locus of the terminals of the kv-a. vectors for various magnetizing currents, assuming both the energy delivered and its voltage to be constant.

Exciting Currents on Alternating Systems

In the flow of alternating current energy, the current, as measured with an ammeter, may be conveniently resolved into two components, one the energy component and the other the wattless component. This wattless component is the exciting, or magnetizing current. It is so named because it exists in virtue of the fact that magnetic fields are required by inductance, transformers, induction motors, induction generators, synchronous motors and synchronous generators. The exciting currents for all of these magnetic fields are alternating, and are of the same frequency as, but out of phase by 90 deg. with the energy current. For convenience when representing the mean effective values vectorially, we designate them, when lagging, as positive, and when leading, as negative.

Figs. 1 and 2 illustrate the effect of magnetizing currents. Assuming that the energy delivered is constant and that the voltage is constant, EE' in Fig. 1 is the locus of the terminals of the current vectors for different magnetizing currents. It is sometimes more convenient to refer to wattless kv-a. rather than magnetizing current. The relations between kilowatts and kilovolt-amperes are represented in Fig. 2. MM' represents the locus of the terminals of the kv-a. vectors.

Inductance, transformers, induction motors and induction generators require positive exciting currents, while capacity requires negative. A synchronous motor might require from a system either positive or negative exciting current, depending upon its field excitation. For low field excitation the exciting current would be lagging, while for high field excitation the exciting current would be leading.

A generator supplying a load, and not in parallel with other synchronous machines, must supply all the exciting current required, and the field excitation will vary with this wattless current. This is clearer when we consider the cases of supplying a given kv-a. load at unity power-factor, at 0.80 power-factor, lagging, and at 0.80 power-factor leading. To maintain the same voltage and current in the armature of the generator, considerably more field excitation would be required at 0.80 power-factor lagging than at unity power-factor; and at unity power-factor, considerably more field excitation would be required than at 0.80 power-factor leading. If there is more than one generator, and they are in parallel, the same relations hold, but the matter of division of exciting current between the generators involved is entirely a matter of the relative field excitation. The generator with the stronger field excitation will supply the greater proportion of exciting current.

The fundamental consideration to observe about exciting currents on any system, is that their algebraic sum is zero, some being positive and some being negative. We meet with a slight practical difficulty in applying this conception, because it is convenient to consider that an over-excited synchronous motor and an over-excited generator supply exciting currents to a system, whereas, if they are under-excited, they demand exciting currents. The point of neutral excitation is where the machine in question is running at unity power-factor. A power-factor indicator indicates lagging exciting current for an over-excited generator, and leading for an over-excited synchronous motor. In either case, an increase of field excitation not only increases the voltage at the terminals of the machine, but increases its exciting current. The real physical difference is only in the direction of energy flow, since it flows into the motor, but out of the generator. Actually, however, the exciting current for the motor is opposite in sign to that of the generator. Notwithstanding this, it will be found a convenience to consider both of the same sign, and simply think of an over-excited synchronous motor as supplying exciting current to a system. This conception is not only convenient, but seems thoroughly justified when we realize that power-factor correction in a transmission line for an inductive load may be accomplished by either an over-excited synchronous generator or an over-excited motor located near the load. Furthermore, it may be considered that exciting currents are supplied to a system, by means of direct current excitation applied to the fields of the synchronous machines.

The investment of capital in any electrical system operating at a given voltage is dependent largely upon the kv-a. demand caused by the load at the distribution centers. This comes about for the following reasons: The price and losses of the transmission lines depend upon the current to be carried; for the given receiving voltage therefore, the price and efficiency would depend upon the kv-a. delivered; the price and losses of the transformers depend upon the kv-a. output; and the price of the generators, for a given speed, depends upon the kv-a. output. The efficiencies of generators are based both on the kv-a. output and power-factor. At 0.80 power-factor the efficiencies are about 2 per cent less than at unity power-factor. A matter of considerable importance in this connection is the efficiency of the prime mover. In the cases of reciprocating engines and waterwheels, the efficiency falls off considerably on light loads, and to a less extent on the heavier loads. This matter is of so much importance that every effort should be made to keep the prime movers fully loaded. On low power-factor we may reach the limit of generator capacity considerably before the limit is reached for the prime mover.

Now, on the other hand, the revenues which come in from customers depend substantially on the kilowatts delivered. Furthermore, for satisfaction on the part of the customer, this energy must be delivered at a suitable and uniform voltage. Various systems of rates have been established for the sale of electrical energy, which would bring about a proper charge to those customers whose service demands kilowatts at low power-factor. It might be said, in general, that no set of rates devised meets this condition entirely satisfactorily. It is therefore very important to have the kilowatts at the distribution centers approximately equal to the kilovolt-amperes demand. In other words, the transmission lines and long feeder lines should operate at near unity power-factor.

Loads usually dealt with at distribution centers have lagging power-factors. These are seldom worse than 0.60 power-factor and rarely better than 0.90 power-factor. Since the per cent of magnetizing current, or exciting current, is always the sine of the angle whose cosine is the power-factor, these may range from about 80 per cent to about 43 per cent of the actual current as measured with an ammeter. The causes of these exciting currents are due chiefly to induction motors and transformers; it is an inherent characteristic of both to require a definite excitation and this excitation is practically independent of the load, and is always positive in direction. Induction motors take from 40 per cent to 80 per cent in magnetizing current, while transformers take from 4 per cent to 8 per cent. The smaller induction motors always take the (relatively) greater exciting currents. With the transformers, however, the matter of size enters only to a small extent. In both cases, the percentage of magnetizing current refers to a percentage of normal current of the transformer or motor in question. For example, with a 3000-kv-a. transformer, having a 5 per cent exciting current, the wattless kv-a. would be about 150, whether the actual kv-a. load was 200 or 3000. With a 200-h.p. (165 kv-a. at 0.90 power-factor) induction motor, the wattless kv-a. would be about 72, and this would also be substantially independent of the actual load on the motor. The magnitude of this magnetizing current for either induction motors or transformers depends on matters of design. The exciting current of induction motors is relatively small, as compared with that of the transformers. In general, on systems with low power-factor, where the total wattless current is of considerable magnitude the cause is almost entirely induction motors.

Transmission lines have both inductance and capacity and therefore inherently require both positive and negative exciting currents. The amount of positive exciting current required by inductance is always comparatively small as compared with the negative exciting currents required to supply the capacity. Since these two effects are opposite, they will, to some extent, offset each other. However, the negative exciting current is usually in predominance. If a transmission line is of any considerable length, it may require large negative exciting current. It is constant in value since its magnitude is proportional to the voltage and physical characteristics of the line. Both the inductance and capacity are distributed along the line; hence the amount of exciting current varies directly with the length of the transmission line.

Unless properly controlled, exciting current is a serious matter. It uses up the capacity of expensive generating apparatus, transmission lines and transformers. It increases energy losses materially, due to I^2R losses; and finally, when there are any considerable reactances in the circuits of the generators, transformers and transmission lines, the voltage drops will be of large magnitude. To bring about the proper counteracting influence to keep these magnetizing currents confined in circuits where they do comparatively no harm is essentially a problem of parallel operation of synchronous machines.

Two Alternators with a Load

Let Fig. 3 represent two single-phase alternators in parallel, and Fig. 4 represent the vector relations of the common voltage between the two machines, their currents, power-factors, etc.

With two direct current generators in parallel their division of load is dependent upon the field excitation. Raising the excitation of one makes it take load because its speed will drop, and *vice versa*. This is assuming, of course, that each is driven by a separate prime mover and is governed in the usual manner, i. e. that an increase in load will drop its speed, and this in turn will cause an increase in the amount of energy admitted to the prime mover.

Now, with two alternators in parallel and each having its prime mover governed, both machines must always run in synchronism and there is nothing that can be done to either to change its relative load. This sharing of load between alternators is entirely the property of the speed characteristics of the prime movers. If the total load increases the frequency will tend to drop and both machines will pick up their respective loads, determined entirely by their prime movers' speed characteristics. Nothing therefore can be done inherently to either alternator, to change the division of load. A division of load can be accomplished only through the governing mechanism of the prime movers. This is done, in practice, usually by means of a motor attached to the governing mechanism and controlled from the switchboard. The effect of the motor is to change the speed characteristics of the prime mover in such a manner as to accomplish the proper control of energy. We could not therefore expect any change of load due to changes in the field excitation of one machine. However, as we have seen, this effects only a change in division of the exciting current, or wattless kv-a.

In the foregoing, it is seen that the division of energy output is a matter of controlling the incoming energy from the prime movers; and the effect of changing the field excitation is only to change the division of wattless kv-a. of the machines on the system.

These points may be made clearer by studying Fig. 4. I_L represents the load current at a power-factor equal to cos θ_L. The energy component OP, that is, I_L cos θ_L, can be drawn to scale to represent the kilowatt load, since it is assumed that the voltage is constant, and ON and OM can represent the kilowatts supplied by the generators respectively. The algebraic sum of their loads must always equal OP. This implies that either OM or ON may be negative; and such is the case, since the energy supply to one alternator's prime mover may be zero, and the alternator in question turn over as a motor. The condition of one machine running as a motor and the other as a generator is shown in Fig. 6.

I_1 must necessarily move towards leading, otherwise, the parallelogram of currents would be incomplete. Since we are not affecting the division of load, the line LL', at right-angles to the vector V, is the locus of the terminals of the current vectors of generator No. 2 at various excitations, provided the load is constant. In a similar manner, JJ' is the locus of the terminal of the current vectors of generator No. 1. By raising the excitation of generator No. 2, I_1 may be brought in phase with V so that generator No. 1 would be operating at unity power-factor

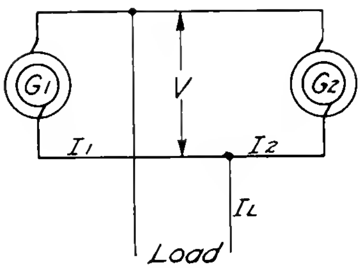


Fig. 3. Two Generators in Parallel

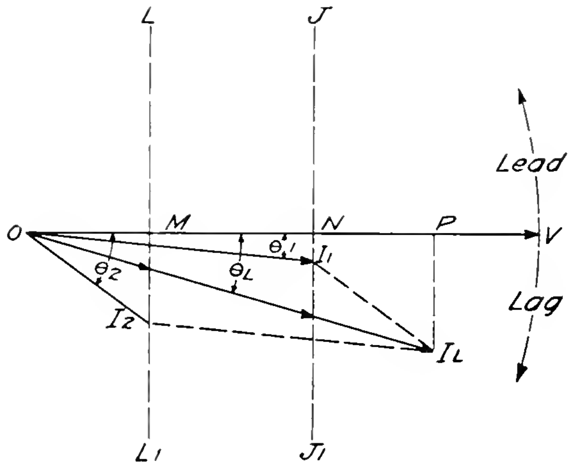


Fig. 4. Vector Diagram of Two Generators in Parallel

I_1 = current of generator No. 1.
I_2 = current of generator No. 2.
I_L = current of load.
V = voltage at point where metering is done.

$Cos\ \theta_1$ = power-factor of generator No. 1.
$Cos\ \theta_2$ = power-factor of generator No. 2.
$Cos\theta_L$ = power-factor of load.

To scale OM equals output of generator No. 2 since VI_2 cosine θ_2 represents the energy delivered.
To scale ON equals the output of generator No. 1, since VI_1 cosine θ_1 represents the energy delivered.
To scale OP equals the load, since VI_L cosine θ_L represents the energy consumed.
JJ' is the locus of the terminals of the vectors of generator No. 1 at various excitations, assuming the power delivered constant.
LL' is the locus of the terminals of generator No. 2 at various excitations, assuming the power delivered constant.

Referring again to Fig. 4, it will be seen that by varying the field excitation of the two alternators, moving first one field rheostat and then the other, both I_1 and I_2 may be brought in phase with I_L, in which case, the sum of the kv-a. capacities of the generators is at a minimum value. Under this condition, therefore, the power-factor of each machine would equal the power-factor of the load. Furthermore I_1 plus I_2 equals I_L. If I_1 and I_2 are in phase and we increase the excitation of No. 2 generator, this will make I_2 move towards lagging and accordingly and generator No. 2 would be carrying all the load's magnetizing current. In this case the sum of the kv-a. is greater than the kv-a. of the load, and whether or not we have increased the I^2R losses would depend on the relative values of the resistances in the circuits involved.

The magnetic effects of exciting currents on synchronous machines may be explained as follows. The ampere-turns on a polyphase armature have the property of maintaining a definite flux which revolves synchronously with respect to the position of the armature conductors. If the machine is of the revolving armature type, this flux takes a definite position in space. If it is of the revolving field type, it will revolve with the same frequency as the revolving field. For a given armature current, it is constant in value, and has a phase relation with the field flux, depending upon the exciting current. At unity power-factor, where the exciting current is zero, it is 90 deg. out of phase with respect to the field flux. At other power-factors, its position varies from the position occupied at unity power-factor by an angle equal to that of the angle whose cosine is the power-factor. The exciting current therefore causes an equivalent flux, which is either in phase, or 180 deg. out of phase, with the field flux. With a synchronous generator, lagging exciting currents set up a flux opposite, that is, demagnetizing, to the field flux, and leading exciting currents set up a flux in phase, that is, magnetizing, to the field flux. With synchronous motors, a similar condition exists, except that lagging exciting currents magnetize, while leading currents demagnetize.

When we raise the field excitation of one alternator we tend to raise its voltage, and if no increase of resultant flux occurred in the other machines the common voltage could not rise. As a matter of fact, the common voltage must rise, but it cannot rise to the value expected. This is the case because certain reactions take place. The alternator which had its field excitation raised will suffer an armature reaction tending to demagnetize its field since the power-factor will have swung towards lagging; the other alternators will suffer armature reactions tending to magnetize their fields, because their power-factors have swung towards leading. The system will, therefore, acquire a new voltage, exciting current being furnished by the machine on which we attempted to raise its voltage, to the load or to the other machines in the system.

It often happens that some generating stations in the system are run where a limited amount of energy is available, or where the energy is costly, and other stations have an abundant supply of energy, or that the same may be supplied at a low cost, and in this case it is, of course, a very great advantage to run the former at lower power-factor, carrying the wattless kv-a. load and run the latter at unity power-factor, thereby making the supply of cheap energy as great as is practicable. Furthermore, it is usual when this relation exists that the cheaper energy is supplied from a water power station over a long transmission line and a steam station (expensive energy) is located near the distribution point of the load. Obviously, operating the transmission lines near 1.00 power-factor could not only increase its energy output, but decrease largely the losses on the system due to I^2R.

In considering alternators which are located in the same station, or in close proximity, in general, all of them should be run at the same power-factor, so that the load kv-a. is approximately equal to the arithmetical sum of the kv-a.'s of the generators involved, as this will give the maximum use of generator capacity. Referring to Fig. 4, this condition is accomplished for the two generators in question, when I_1 and I_2 are equal to I_L. This setting of the generators can be accomplished by juggling the field excitation, and noting when the power-factors of the machines are equal. If power-factor indicators are not available, fairly good results may be attained by watching the generators' line and field ammeters. Local conditions, of course, may cause exceptions to the above. For example, one of the alternators, due to its design, may prove more adaptable to power-factor correction than another.

An Alternator with a Synchronous Motor and Load in Parallel

Let Fig. 5 represent an alternator and a synchronous motor in parallel supplying an inductive load, and Fig. 6 represent the vector relations of a common voltage between the two machines and the load, their currents, power-factors, etc.

We will assume the generator field current to be constant, and also that the load is constant and inductive. If the motor is neutrally excited its power-factor will be unity; if the motor is over-excited its current I_M will move towards leading, and the generator current must take a definite position in consequence. In Fig. 6, I_G represents such a position, it being the resultant of I_M and I_L. If the motor is under-excited, then its power-factor will be lagging, and if the motor current takes the position I_M', the generator current must necessarily take the position I_G', it being the resultant of I_M' and I_L. LL' and HH' are the loci of the terminals of the motor current vectors and the generator current vectors respectively.

The results effected by this arrangement are very similar to those just described with two alternators in parallel. The alternator, however, in this case, supplies all the energy but it is more convenient to express the load of the motor separately from that of the system. I_M and therefore I_G may be brought in phase with I_L by adjustment of the excitation, and when this is accomplished the power-factor of the generator will be the same as that of the motor and that of the load. There is obviously no advantage in this arrangement in general unless the kilowatt input of the motor is up to the limit of its kv-a. rating; under this condition it would be better to run the motor near unity power-factor; however, most synchronous motors are *designed to furnish the full kilowatt rating, and still have enough leeway of the generator, we would naturally expect some radical difference in the effect of changes in their respective field excitations, and such is the case; an increase of excitation of a synchronous motor swings its cur-

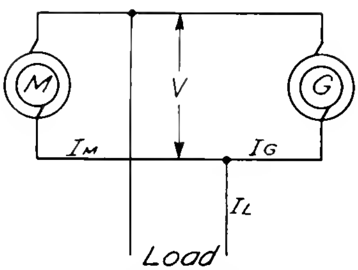


Fig. 5. An Alternator and Motor in Parallel

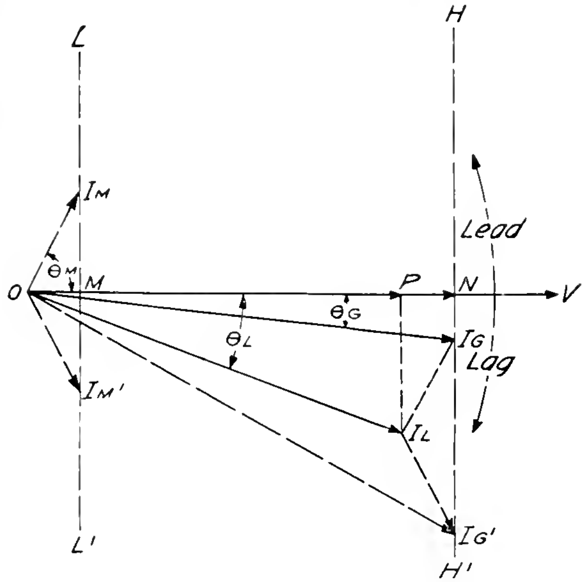


Fig. 6. Vector Diagram of an Alternator and Motor in Parallel

I_G = generator current.
I_M = motor current.
I_L = load current.
$Cos\ \theta_G$ = generator power-factor.
$Cos\ \theta_M$ = motor power-factor.
$Cos\ \theta_L$ = load power-factor.
V = voltage at point where metering is done.
To scale OM equals input to the motor since $V \times I_M \times$cosine θ_M represents the energy consumption.
To scale OP equals the load since $V \times I_L \times$cosine θ_L represents the energy consumed by the load.
To scale ON equals the energy generated since $V \times I_G \times$cosine θ_G is the energy put into the system by the generator.
LL' is the locus of the terminals of the motor current vectors at various excitations, assuming the motor load constant.
HH' is the locus of the terminals of the generator current vectors at various excitations, assuming the generator load to be constant.

in kv-a. capacity to stand considerable over-exciting.

Assuming, therefore, that the generator is running with a definite field current, and that we have a large enough synchronous motor, we could vary its excitation so that the wattless kv-a. of the load could be carried entirely by it, allowing the generator and transmission line to be at unity power-factor. Since the flow of energy is necessarily into the motor whereas it always flows out rent towards leading while with the generator it would swing towards lagging. The inherent reactions between the two machines are as follows: Should we increase the field current of the motor, we would tend to better the power-factor of the alternator, and the common voltage would tend to rise, its limit being determined by the mutual reaction set up causing a demagnetization effect on the motor and a magnetization effect on the generator.

(To be Continued)

* Synchronous motors on motor-generator sets may be designed for 0.70 or 0.80 power-factor at full h.p. load if desired. The synchronous condenser in fact is designed so that it can run supplying only wattless kv-a., that is, its excitation may be carried on no-load to give the full rated kv-a.

AN ARTIFICIAL TRANSMISSION LINE AND SOME DISTURBANCES OBSERVED ON IT

By Cassius M. Davis

Consulting Engineering Department, General Electric Company

This article relates to an artificial transmission line that was constructed for the purpose of overcoming one of the principal difficulties attending the study of long distance transmission line phenomena, i.e., that of obtaining for any length of time an actual commercial line on which to conduct experiments. A short description of the construction of the line and the methods of determining the electrical constants of inductance, capacity, and natural frequency are first given; the balance of the article being devoted to a discussion of the general characteristics of the line and some of the transient phenomena that have been observed on it during test. The oscillograph, of course, has played a prominent part in these investigations, and a number of interesting records are shown.—Editor.

The General Electric Company has had in its possession for about two years an artificial transmission line which it employs in the study of various phenomena that are common to power transmission lines. As constructed at present it has an equivalent length of about 128 miles, single-phase. No attempt will be made here to describe it in detail, as this has already been done elsewhere.*

In its general construction it consists of 400 glass cylinders each surrounded by a coil of insulated copper wire and lined with tinfoil. The inductance is furnished by the coils on the outside of the cylinders, and the dielectric capacity by the capacity between the coils on the outside and the tinfoil on the inside. This construction gives a line of uniformly distributed inductance and capacity throughout its entire length. The glass cylinders are 6 inches in diameter by 4 feet 6 inches long and approximately 1/8 inch thick. Upon each are wound 140 turns of No. 8 B.&S. double cotton covered copper wire, while the inside is coated with approximately 945 square inches (54 by 17.5 inches) of heavy tinfoil. The inductance of each unit is about 0.001027 henry, the capacity 0.00288×10^{-6} farad and the resistance 0.240 ohms. Thus the total constants are: inductance 0.41 henry; capacity 1.15×10^{-6} farad; and resistance 96.2 ohms.

The total inductance is measured by finding the reactance drop by voltmeter and ammeter readings and deducing the inductance from the measured value of reactance.

The total dielectric capacity is found from the charging current to the line when all the coils are connected and interconnected in multiple.

The equivalent length of line is calculated from the formula:

$$L = 186000\sqrt{LC},$$

which comes out to be 128 miles; and the natural period, or its resonance frequency, is derived from the formula:

$$f = \frac{186000}{4l} = 363 \text{ cycles.}$$

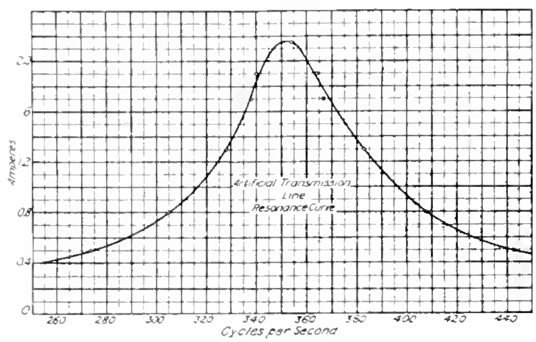


Fig. 1

A resonance curve is shown in Fig. 1. The points show actual readings of charging current and frequency.

This line has nearly all the characteristics of a large power transmission line; that is, it has "regulation," it is subject to phase control by synchronous apparatus, it has a capacity or charging current, it can transmit high frequency and low frequency disturbances, it can oscillate in part or as a whole against some other circuit to which it is electrically connected, etc., etc. An idea of the way in which it behaves under various conditions may be gained from the accompanying oscillograms, which have recently been taken upon it.

Fig. 2 shows the disturbances set up when the line is switched on and off the high tension side of a transformer. Note that the high tension current when closing the switch oscillates with the natural period of the line, and note also that when opening the switch the high tension voltage starts with a very high frequency oscillation and finally ends

* January, 1911 and May, 1912, A I E.E. Proceedings.

with a very low frequency oscillation. The line was open at the far end when the switching was done.

Fig. 3 shows how the line may oscillate as a whole. Here the line is oscillating as a part of a complex circuit consisting of a continuous current generator circuit with shunt and series resistance, a step-up transformer, and the line. After the first half wave it is seen that the frequency becomes constant and by comparison with the 60 cycle timing wave is 61 cycles. By carefully noting the first downward sweep of the current several small high frequency ripples of the line fundamental can be seen — about 360 cycles per second. These are emphasized in Fig. 4, which shows the discharge of a condenser into the middle of the line. Here the low frequency (6.2 cycles) oscillation between the condenser and the complex circuit of the line begins with a high frequency oscillation of about 660 cycles per second. The upper curve of this oscillogram is the current at the generator end of the line and shows almost no indication of the high frequency oscillations; which means that they were nearly dissipated in traveling one half the length of the line. This is typical of a lightning stroke out on a transmission line, which, due to its high frequency and low energy, is not noticeable very far from the place where it occurred.

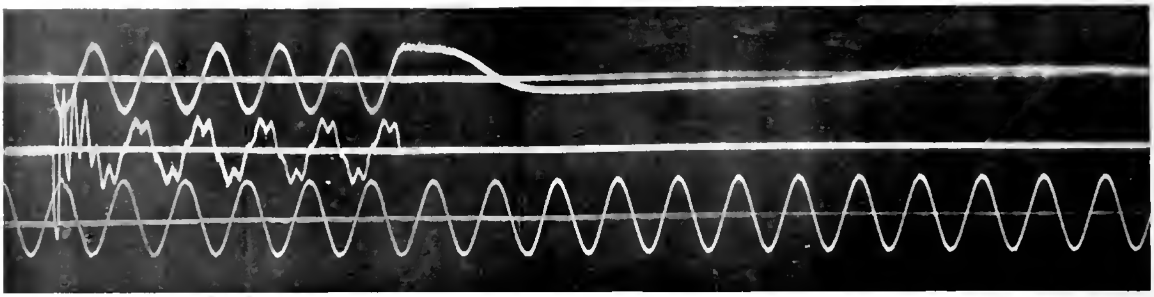


Fig. 2. Switching Line on and off with High Tension Switch. Upper curve, high tension voltage at generator end of line; middle curve, high tension current at generator end of line; lower curve, low tension voltage at generator end of line.

In order to study line disturbances on an artificial line, it is necessary to have a suitable means of producing these disturbances. This may be done in two ways: First, the actual conditions on a power transmission line may be reproduced as nearly as possible; and second, arrangements of circuits may be effected which will give results from which the actual results can be deduced.

As an example of the first method we may have a circuit consisting of an alternator, step-up transformer, line, and unloaded step-down transformer at the receiver end. The disturbance at the high tension terminals of the step-down transformer when switching in and out on the high tension side at the generator end are shown in Fig. 5. This shows very nicely the slowly decreasing starting current of the step-down transformer; the first few cycles of the right hand part of the figure showing its permanent condition. The circuit just described would represent fairly well a low voltage line; but in the case of a high potential line the representation would be only approximate, since in this case the windings of the transformers have no appreciable dielectric capacity as do the transformers for an actual line. Thus recourse would have to be had to the second method, where, for instance, part of the line could be rearranged to serve as a model transformer.

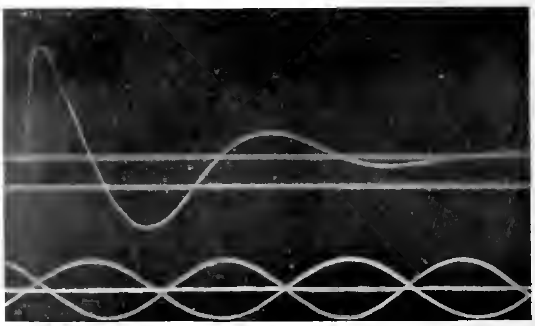


Fig. 3. Line Oscillating as a Whole. Upper curve, current at generator end of line; lower curve, 60-cycle timing wave.

The simplest kind of disturbance which can be readily produced is a single impulse of energy. Such an impulse is produced by suddenly impressing a small amount of energy upon a transformer, as by closing the low tension side upon a source of continuous current. As the current builds up in the low tension side it induces a voltage in the high tension side which lasts only while the low tension current is changing. This voltage causes a current to flow from the transformer into the line, the intensity of which varies, first rapidly to a maximum and then slowly to zero. The sudden rise at the beginning shows how fast the transformer is able to give up its energy to the line, while the more gradual decay of the remainder of the current shows how fast the continuous current in the low tension winding builds up, and hence depends upon the circuit constants affecting the low tension circuit.

If one of these single impulses of energy is impressed upon one end of a transmission line it will travel along and will reach the opposite end of the line only after an appreciable time has elapsed. The rate of travel of the impulse is the velocity of light or 186,000 miles per second, provided the transmission line is a straight line. However, the rate of travel is much slower in an artificial line as described here. This is due to the fact that the inductance and capacity per mile of wire are both greatly increased. On a straight aerial line of a given length and spacing, the inductance and capacity are a certain amount per mile, and if the spacing is changed, say by bringing the conductors closer together, the inductance will be decreased and the capacity increased, but this decrease and increase will always be of such amounts that $\sqrt{LC}$ will remain constant. Thus the speed by winding the wire into solenoids and by reducing the spacing between the line and the ground to about 1/8 inch both the inductance and the capacity are increased to such an extent that $\sqrt{LC}$ is about 3.65 times

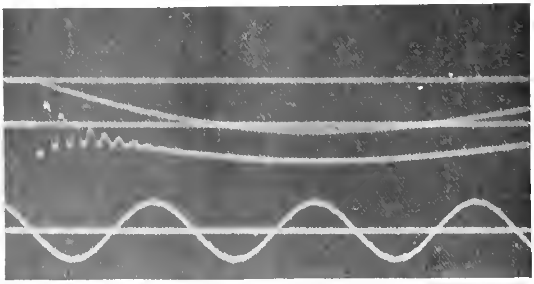
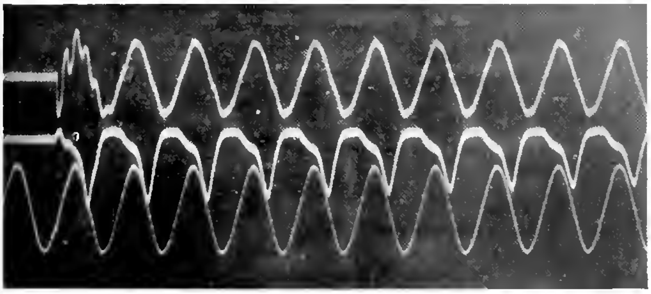


Fig. 4. Condenser Discharging into Middle of Line. Upper curve, current at generator end of line; middle curve, condenser current discharging into middle of line; lower curve, 60-cycle timing wave.

greater than in an aerial line of the same actual length of copper.

To observe the speed of propagation we have only to take an oscillogram showing the currents (or voltages) at different points along the line, and, knowing the speed of the film, measure the time interval between corresponding points on the successive current curves. Thus Fig. 6 shows an oscillogram of the current of an impulse at 0, 64, and 128 miles from the generator end of the line; t_1, and t_2 being the times required for the impulse to travel 64 miles, and t_3 the time for 128 miles.

When a disturbance is created at one end of the line it travels with the velocity of



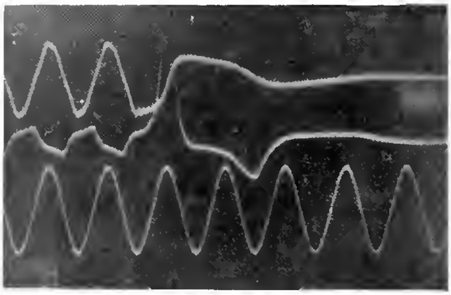


Fig. 5. Switching Line on and off with High Tension Switch. Upper curve, high tension voltage at receiver end of line; middle curve, high tension current at receiver end of line; lower curve, low tension voltage at generator end of line.

of propagation on an aerial line is not changed by changing the conductor spacing. The artificial line has an actual length of about 35 miles; that is, there are about 35 miles of copper wire wound on the cylinders; but light toward the other, and if it has energy enough it will reach the other end. Unless there is some apparatus there to absorb it, it will start back toward the first end, thus continuing back and forth along the line until all the energy is dissipated. If one end of the line is open-circuited or short-circuited, it has no ability to absorb energy; hence any disturbance reaching it goes back undiminished in intensity, or it is said to be totally reflected. Any other condition at the end of

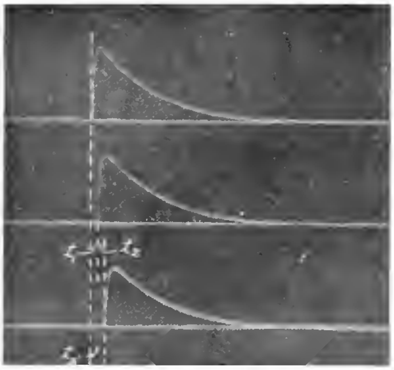


Fig. 6. Impulse Traveling Over Line. Receiver End Closed by the Surge Resistance. Upper curve, current at generator end of line; middle curve, current at middle of line; lower curve, current at receiver end of line.

the line will absorb more or less of the energy received and the part remaining goes back, being reflected, and the part absorbed being refracted. There is but one condition which will absorb all the energy of a disturbance and reflect none; viz., when the end of the line is closed by some circuit of the same surge impedance; that is, some circuit of inductance and capacity such that the ratio, $\sqrt{\frac{L}{C}}$ of this circuit is equal to $\sqrt{\frac{L}{C}}$ of the line; or where the line is closed by a non-inductive resistance which is numerically equal to that ratio.

Since when a line is closed by its surge impedance, or resistance, there is no reflection of disturbances, it gives the same effect as though the line were of infinite length and the disturbance went on until its energy was all dissipated. The oscillogram shown in Fig. 6 was taken under this condition.

Fig. 7 shows the same currents as Fig. 6, but in this case the line was short circuited at the end. Here the impulse comes back to the generator end of the line at a, which is t_4 seconds after it started. Incidentally, this gives a more accurate determination of the length of the line, since t_4 is twice t_3 of Fig. 6.

It is quite important to see what are some of the characteristics of a disturbance which has been refracted into some other circuit. If a disturbance originates in a transmission line which is connected at one end to a cable, part of it is reflected back into the transmission line and the rest of it goes on into the cable. When the disturbance reaches the point where the two circuits meet, or the transition point, it has a certain amount of energy and there are two outlets for it, one back through the transmission line and one through the cable. The amount which flows through each outlet is determined by the surge impedence of each. The surge impedence of the transmission line is high, while that of the cable is low and hence more of the energy passes on into the cable than is reflected back into the line. At any instant the power of a disturbance is $e\ i$, so if we represent some instantaneous value of power in the transmission line by $e_1\ i_1$ and similarly represent some instantaneous power in the cable by $e_2\ i_2$ we have at the transition point as a disturbance reaches it, $e_1\ i_1 = e_2\ i_2$, and from this $i_2 = i_1 \frac{e_1}{e_2}$

But $e_1 = i_1\ z_1$ and $e_2 = i_2\ z_2$

Therefore $i_2 = i_1 \sqrt{\frac{z_1}{z_2}}$

and since the surge impedance of the cable, z_2, is less than that of the transmission line, it follows that the instantaneous current of a disturbance going from the line into the cable is greater in the cable than in the line.

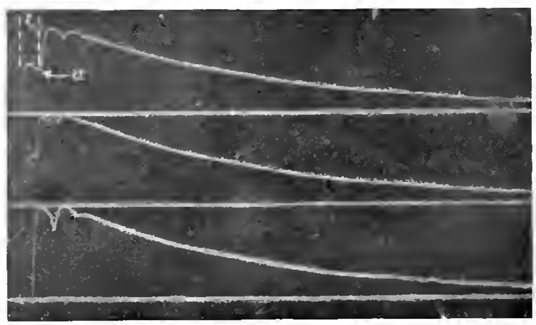


Fig. 7 Impulse Traveling Over Line. Receiver End Short Circuited. Upper curve, current at generator end of line; middle curve, current at middle of line; lower curve, current at receiver end of line.

Fig. 8 shows an oscillogram of an impulse which illustrates the above point. The units of the artificial line were reconnected in such a way that about 82 miles had a surge impedence of 600 ohms, representing a transmission line, and about 22 miles had a surge impedance of 300 ohms, representing a cable. An impulse was sent over this complex circuit from the line end, and an oscillogram was taken of the currents at the generator end and at the transition point as shown in the figure. The maximum value of the current at the generator end is 0.875 amperes. From previous oscillograms it was found that the energy of the impulse would be dissipated at such a rate that the maximum current value when the impulse reached the transition point would be 85 per cent of its original value, or in this case 0.745 amperes. The first maximum value of the current recorded at the transition point, however, is not 0.745 amperes but 1.07 amperes, or 43 per cent higher. Thus the current has been stepped up, so to speak, at the transition point and the impulse passes into the cable with a higher current value than it started out with. Applying the formula given above, it is seen that the ratio of impedances is 2 and the square root of the ratio is 1.41, and hence the theoretical value of the current at the transition point is 41 per cent higher than the initial current, instead of 43 per cent as measured from the oscillograms; which difference is well within the errors of measurement.

Since the instantaneous value of power in the line and the cable are equal at the transition point, it necessarily means that when the current is increased as the impulse enters the cable the voltage must decrease correspondingly. If the impulse had been sent into the cable first and from there into the line, the conditions would have been reversed and the voltage would have been increased at the transition point while the current would have been decreased.

These few illustrations outlined above serve to show the many uses to which an artificial line may be put. They show some of the characteristics of disturbances only, but it is equally easy to study line phenomena which are steady or permanent in their nature. Such a line has many advantages over an actual power line. One is the ease and celerity with which an experiment may be tried; it is but a few minutes work to connect

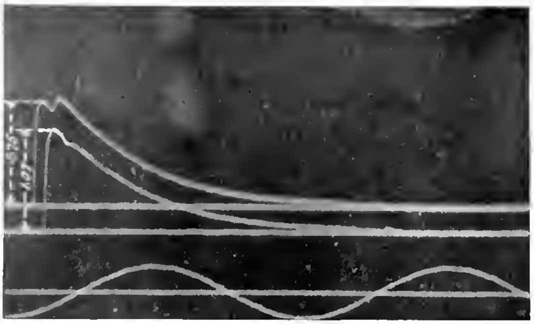


Fig. 8. Refraction of Impulse from One Circuit into Another. Upper curve, current at generator end of line; middle curve, current at transition point; lower curve, 60 cycle timing wave.

up an artificial line to various kinds of apparatus and to the oscillograph. Again many of the disturbances on a large power line take place at such a time and under such conditions that it is not possible to obtain records of them, and hence the only means of judging their nature and magnitude is by the tangible effects they produce, such as spilling over of spark gaps, puncture records, destruction of apparatus, etc. In some cases it has been possible to carry on investigations on one of two duplicate circuits of a power system, but here there is always the difficulty of risk of damage involving costly equipment and the time available is usually limited. Hence the artificial transmission line becomes a valuable device in increasing the available knowledge of transmission line phenomena.

REVIEW OF GRAPHICAL AND ANALYTICAL METHODS FOR PREDETERMINING OPERATING CHARACTERISTICS OF INDUCTION MOTORS

Part III

By Prof. C. R. Moore

School of Electrical Engineering, Purdue University

In Part II of this paper Prof. Moore described in detail the various methods, analytical and graphical, for predetermining the motor's characteristics. In this month's instalment these methods are applied to the case of a 12 h.p. motor, and a comparison made of the characteristics of the machines when estimated in all these different ways. It will be seen that there is considerable discrepancy in the results. In view of the fact that the analytical methods, while more accurate than the graphical, are usually less easy to apply, the author evolves a combination of the two principles, in which he is able to determine both the radius of the true current locus circle and the true position of its center directly from experimental data, and thereby render unnecessary any approximation in the graphical process which follows.—Editor.

APPLICATION OF METHODS

By way of illustration the foregoing methods have been applied to a 12-pole, 52 h.p. 440-volt three-phase motor operating at 600 r.p.m. This motor is of standard construction and presents no new or novel problems in its treatment. Results of this work will be found in curves shown in Figs. 20, 20a, 20b, 20c and 20d. Inspection of these curves shows that all methods give curves of practically the same general shape but agreement is close only at certain points not common to all curves.

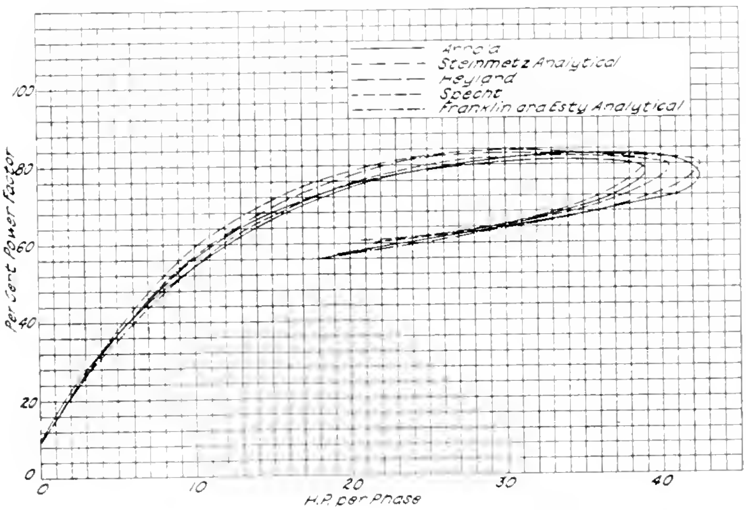


Fig. 20. Power-factor Plotted Against Horse Power Output Per Phase

A difference of some 4 per cent is noted in the efficiency curves at 5 h.p. output (per phase); while at full load (17 h.p. per phase) the difference is about 1 per cent. A difference of about $3\frac{1}{2}$ h.p. per phase exists at the break-down point. The power-factor curves show a difference of about 3 per cent, this difference existing over a wide range of outputs. The greatest difference exists at rated output per phase. The current curves also show a practically constant difference of about 10 amperes over a wide range of output, the difference increasing with the output. The slip and torque curves also show a difference which increases with the slip, a greater discrepancy occurring in the slip.

The differences in all characteristic curves as noted above may at first thought appear slight; but, as pointed out earlier in this paper, firms will often guarantee results on a given motor within one or two per cent of their estimated value—a difference less than that shown by the application of the various methods. It is easy, therefore, for different engineers, starting with the same tests and preliminary calculations, to get results which differ from each other by a percentage larger than the factor of safety, so to speak, of the manufacturers.

In point of time required to work up the results herein shown, it should be stated that the analytical methods require longer than the graphical, which of course is what one would expect. It seems evident, however, that some method should be adopted as standard for motors of a given class.

Modification of Existing Methods

In view of the fact that the analytical methods, while more accurate than the graphical processes, are less easy to apply

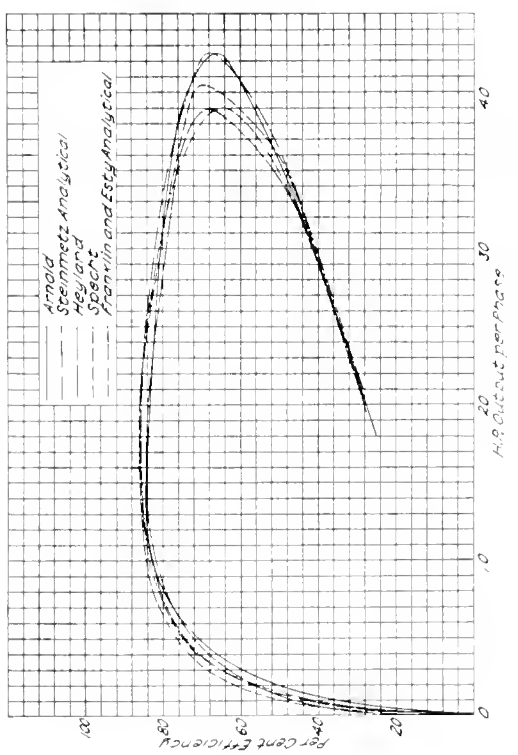


Fig. 20a. Efficiency Plotted Against Horse Power Output Per Phase

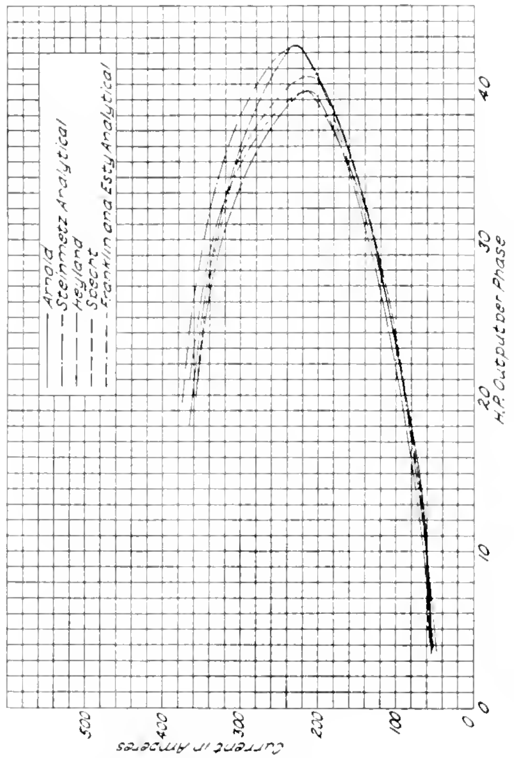


Fig. 20b. Current Input Plotted Against Horse Power Output Per Phase

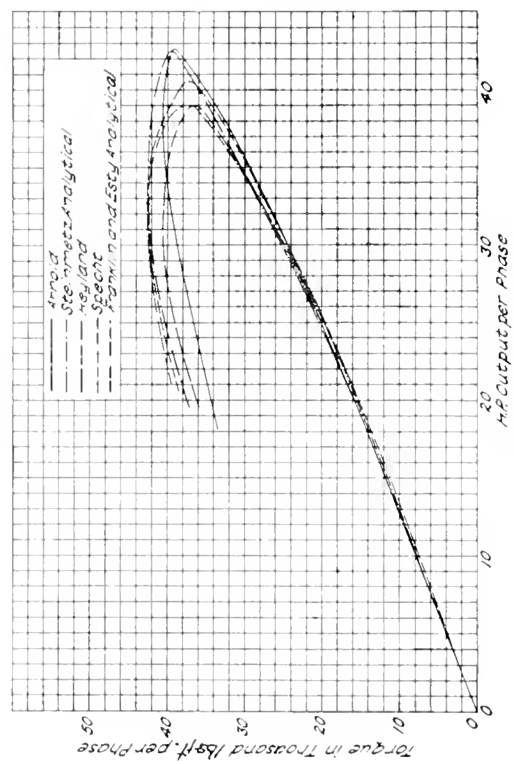


Fig. 20c. Torque Plotted Against Horse Power Output Per Phase

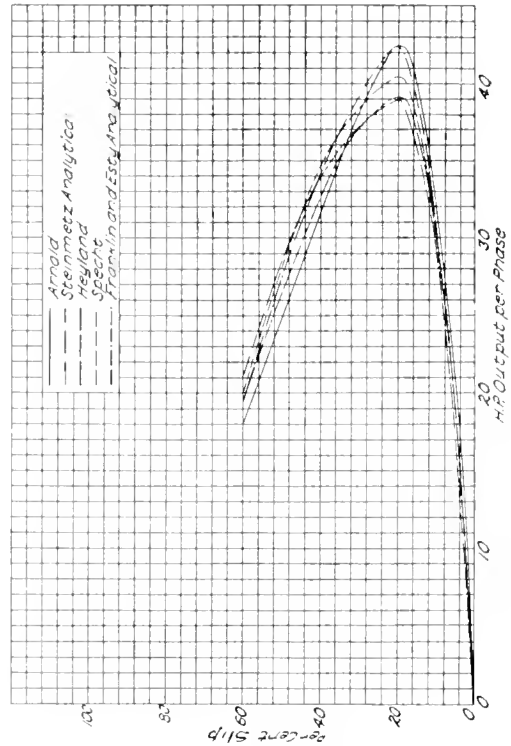


Fig. 20d. Slip Plotted Against Horse Power Output Per Phase

the writer has endeavored to combine these two general schemes.

Reference to Fig. 16 would seem to indicate that the position of the center of the final admittance circle could be found by direct calculation, since all the quantities involved are at hand from the preliminary tests, calculations, etc. Furthermore the diagram

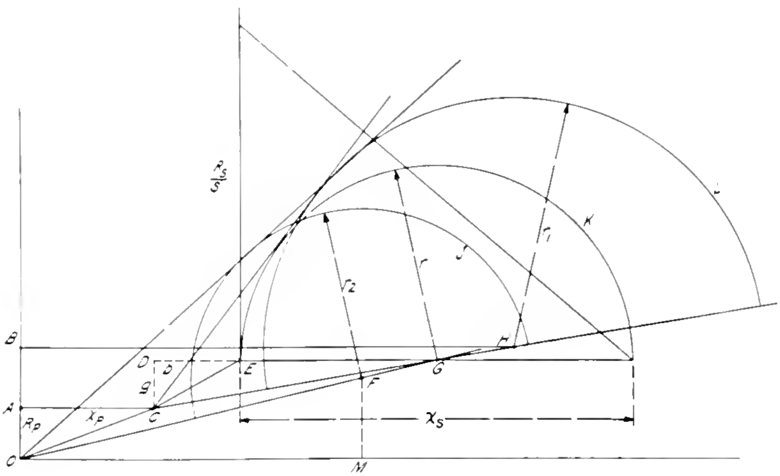


Fig. 21. Inversion Diagram

shown in this figure represents the true solution of the circuit generally accepted as representative of induction motor performance; so that equations deduced therefrom, based on the principle of inversion, should give the true position of the true circle. If the true position of the center of the circle and its radius be known the results given by it should check closely with those given by the mathematical analysis.

These equations are easily deduced as follows:

In Fig. 21 choose radius $r=\frac{1}{2X}$, which fixes the scale such that, if the values given by the resulting formulae be multiplied by the voltage per phase, the diagram will read directly in amperes. The circle K results, the center being at G. As shown under Theory of Graphical Methods, the equation of the inverse circle is

$$\left(x_1-\frac{a}{a^2-r^2}\right)^2+y_1^2=\frac{r^2}{(a^2-r^2)^2} \quad \text{(see Fig. 15)}$$

where a is distance of first circle from origin, and r its radius. From this equation it is evident that the distance from the origin to the center of the inverse circle is $\frac{a}{a^2-r^2}$, and the radius is $\frac{r}{a^2-r^2}$

From Fig. 21,

$\overline{CG}=\sqrt{(b+r)^2+g^2}=a_1 \therefore \overline{CH}=\frac{a_1}{a_1^2-r^2}=a_2$, and $\gamma_1=\frac{r}{a_1^2-r^2}$. Designating the vertical and horizontal distances between H and C as s and t respectively we have

$s=\frac{ga_2}{a_1}$ and $t=\frac{a_2(b+r)}{a_1}$. Also $OH=\sqrt{(s+R_p)^2+(X_p+t)^2}$ $=A_2$ from which it follows that $OF=\frac{A_2}{A_2^2-r_1^2}=a_3$ and $r_2=\frac{r_1}{A_2^2-r_1^2}$. Again $\frac{FM}{s+R_p}$ $=\frac{a_3}{A_2}$ or $\overline{FM}=\frac{a_3(s+R_p)}{A_2}$

It will be noted that the last four equations completely define the true circle representing the exact solution of circuit A Fig. 5 (see Part I of the series). These equations will therefore hold for any three-phase motor regardless of output. In their development, however, certain quantities are involved which, when compared with other values, especially in the case of large motors, are practically negligible. For instance, the true distance between O_1 and M_1 (Fig. 16) is represented by the square root of the sum of the squares of the horizontal and vertical differences of their co-ordinates. In this case the vertical difference is the conductance, g, which is small compared with the horizontal difference, i.e., if g were neglected and the distance between O_1 and M_1 were taken as the difference of their abscissæ the error would indeed be small.

On this basis equations have been developed which place the center of the final admittance circle very close indeed to its true position, and require somewhat less calculation than the preceding method. The error involved is smaller than that observable in slide rule calculations. This development follows:

Taking $\overline{CG}=b+r$, and regarding C for the

RESULTANT VALUES FOR 12-POLE 3-PHASE INDUCTION MOTOR, 52 H.P., 440 VOLT, 600 R.P.M. VALUES PLOTTED IN FIGS. 20, 20a, 20b, 20c, and 20d

SLIP	OUTPUT					EFFICIENCY					POWER-FACTOR					INPUT					TORQUE				
	Steinmetz	Franklin Esty	Arnold	Heyland	Specht	Steinmetz	Franklin Esty	Arnold	Heyland	Specht	Steinmetz	Franklin Esty	Arnold	Heyland	Specht	Steinmetz	Franklin Esty	Arnold	Heyland	Specht	Steinmetz	Franklin Esty	Arnold	Heyland	Specht
0.01	11.7	10.54	12.6	10.23	10.35	71	68.8	67	66	71.5	30.9	30.6	34.2	29	29	53	48.7	52	54	52	3130	2840	3180	28100	3050
0.02	23.58	21.45	18.6	23.65	21.5	81	79.8	81.5	79	81	48.7	47.8	51.5	49.5	14	58.5	51	59.5	60	56.5	6185	5635	7250	6100	5350
0.03	35.6	31.65	40.8	35.7	31.74	81.6	81.5	84	83	84.5	61.6	61	63.1	62	56.5	66.2	59	68	69	63	9140	8320	10650	9250	8000
0.07	76.5	67.5	76.8	68.5	67.5	84	84.8	83.5	82.5	85	81.2	80.7	79.5	77.5	77.5	104	96.5	111.5	105	97	19450	17400	20100	18500	17500
0.13	108.5	101.24	112.5	102.3	103.5	77.8	77.6	76.3	76.5	77	82	83.2	82.9	81.5	82	167.3	153	171.5	160	153.5	31400	29100	32000	29200	29000
0.20	127.5	117	127.5	117.5	121.5	68.7	67.3	65.5	68.5	70	80.5	81	77.1	79	80	277.5	211.5	234	216	207	39700	36600	39000	36600	37000
0.40	101.7	101.7	94.6	97.2	104	45.8	47.3	43	45.5	47.5	66.4	68.2	65.6	67.2	68	327	309.5	324.5	312	309	42300	42450	39400	40400	42600
0.60	58.3	63	54	58.5	61.2	27.3	28.2	25	27.5	28.5	56.4	60.5	56.4	57.5	57.5	374	364.5	366	358	357	37100	39350	33200	36000	38000
1.00	0	0	0	0	0	0	0	0	0	0	45	46.1	46.3	46.3	46.3	410	398	398	398	398	26700		2360	26900	28700

moment as the origin, we have $b+r=a$. We may therefore write

$$r_1 = \frac{r}{(b+r)^2 - r^2}$$

$$= \frac{r}{b^2 + 2\,b\,r}$$

$$= \frac{r}{k}. \quad (k = b^2 + 2\,br)$$

and

$$\overline{CH} = \frac{b+r}{(b+r) - r^2}$$

$$= \frac{b+r}{b^2 + 2\,br}$$

$$= \frac{b+r}{k}. \quad (k = b^2 + 2\,br)$$

Adding at C the quantities X_r and R_r as shown, and regarding O as the origin, and taking

$$OH = CH + X_r = \frac{X_r k + b + r}{k}$$

$$= \frac{q}{k} \; (q = X_r k + b + r)$$

we have

$$r_2 = \frac{\frac{r}{k}}{\left(\frac{q}{k}\right)^2 - \left(\frac{r}{k}\right)^2} = \frac{rk}{q^2 - r^2}$$

also

$$OF = \frac{\frac{q}{k}}{\left(\frac{q}{k}\right)^2 - \left(\frac{r}{k}\right)^2} = \frac{qk}{q^2 - r^2}$$

From similar triangles,

$$\frac{AB}{g} = \frac{CH}{CG};$$

from which, after substituting for CH and CG values $\frac{b+r}{k}$ and $b+r$ respectively, we have

$$AB = \frac{g}{k}$$

Further

$$\frac{FM}{OB} = \frac{OF}{OH}$$

$$FM = OB\frac{OF}{OH}$$

$$= \left[R_r + \frac{g}{k}\right]\left[\frac{qk}{q^2 - r^2}\right]\left[\frac{k}{q}\right]$$

$$= k\left(\frac{R_r k + g}{q^2 - r^2}\right)$$

Summarizing we have:

Radius of final admittance circle

$$r_2 = \frac{rk}{q^2 - r^2}$$

Distance of center from origin

$$\overline{OF} = \frac{qk}{q^2 - r^2}$$

Height of center above X axis

$$\overline{FM} = k\left(\frac{R_r k + g}{q^2 - r^2}\right)$$

The values given by these three equations (and those derived by the preceding method) are in terms of admittance, and must be multiplied by the impressed voltage per phase to give values in terms of current. The diagram may now be completed graphically in a manner similar to that given by Specht, or the circle only may be drawn, measurements therefrom giving data from which the desired quantities may be calculated. In using these methods it should be borne in mind that their accuracy depends upon the accuracy with which the fundamental quantities involved have been determined. They differ from other methods in two important respects, i.e., the position of the current locus circle and the radius of such circle are both determined. This being true the no-load and short-circuit current values, as found by test, should fall on the circle as the measured power-factor. Obviously it is a decided advantage to be able to determine the radius of the true current locus circle, and the true position of the center, directly from experimental data, since no approximations are then necessary in the graphical processes following.

In view of the fact that the end leakage has been shown to be large even when the lock-test voltage is only one-fourth to one-third of full rated voltage, it is likely that, as the teeth reach saturation (as will be the case when the voltage is brought to normal value) the leakage reactance will change giving a change of power-factor. The lock test should therefore be made at as high a voltage as conditions will permit. Furthermore the exact position of the calculated short-circuit current (at full voltage) is of little importance since the position of the center of the locus circle and the radius are readily determined. Further, the fact that the rotor resistance increases with slip also goes to show that the problem of finding a method which will fit a given case exactly is a very complex one. About the best that can be done is to adopt an equivalent circuit most nearly representative of the conditions, and then develop a method for solving the same.

This paper has made an attempt to show the differences between various methods of solution rather than to try to find out which method checks a given performance test best. It seems pertinent to suggest that some method of solution be agreed upon, in order that different engineers may check each other more closely in the predetermination of operating characteristics than the use of so many different schemes seems to allow.

In closing, the writer wishes to express his appreciation of the assistance rendered by Messrs. C. C. Dash, D. P. Wright, W. Moon and T. Inomata, who assisted in making experiments and working up curves. Particular thanks are due to Mr. P. W. Robinson, who performed valuable work in the development of the last method given.

ADVANCED COURSE IN ELECTRICAL ENGINEERING

Part VI

By Ernst J. Berg

Professor of Electrical Engineering, University of Illinois

Circuits of Resistance and Variable Inductance

In the discussions given so far it has been assumed that the inductance L has been constant. In almost all cases of interest to engineers this is, however, not the case because almost all magnetic circuits contain iron, and the permeability of iron is not constant but depends upon the magnetization. In other words the flux produced by a given current or, what is equivalent, m.m.f. is not proportional to the current. Fig. 22 gives the saturation curve of an entirely-closed iron magnetic circuit, as shown in Fig. 23. It is the familiar hysteresis loop, which shows how the magnetism lags behind the m.m.f. producing it.

This particular sample has a remnant magnetism of 7600 lines per cm.^{2}, so that this density corresponds to an exciting current of 0 amperes. The maximum density is 10,000, which corresponds to an exciting current of 4.5 amperes. If, after the maximum density is reached, the current is gradually reduced the relation between existing current and density is found in curve a. The flux does not disappear until the current is 2.6 amperes in opposite direction to the original 4.5 amperes.

If, instead of being entirely of iron, the magnetic circuit consisted partly of air circuit and partly iron (Fig. 24), the influence of the air circuit would as a rule be so much greater than that of the iron that the shape of the saturation curve would become materially modified. Thus the saturation curve of a dynamo, having a magnetic circuit largely of iron but also of at least a small air-gap, can be represented by a set of curves similar to those in Fig. 25. If the air circuit is very small the two curves corresponding to a and b in Fig. 22 can be observed. If the gap is reasonably large the two curves merge into one as shown in the dotted line.

Frolich evolved an equation of such a saturation curve for a magnetic circuit consisting partly of iron and partly of an air gap; which, modified by Kenelly, can be written thus

$$\phi = \frac{Ki}{1+K_1 i}$$

where ϕ is the flux corresponding to an exciting current of i amperes.

If the number of turns of the exciting winding is known then the inductance for any particular value of current i can be determined. It is

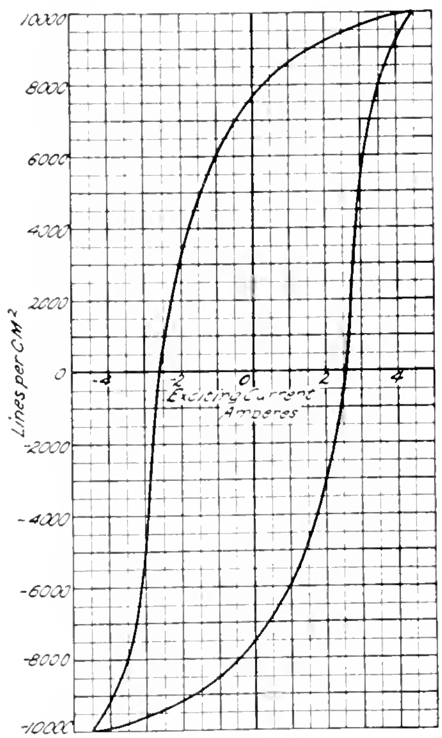


Fig. 22

$$L = \frac{N\phi}{10^8 i}, \text{ where } N = \text{number of turns.}$$

$$\therefore \; L = \frac{Nk\ 10^{-8}}{1+k_1 i}$$

The general equation thus becomes

$$e = ir + L\frac{di}{dt} = ir + \frac{Nk\ 10^{-8} di}{1+k_1 i\ \ dt} \qquad (112)$$

Separating the variables

$$(e-ir)(1+k_1 i)dt = Nk\ 10^{-8}\ di$$

or

$$\frac{Nk10^{-8}di}{(e-ir)\ (1+k_1 i)} = dt$$

or

$$\int \frac{di}{(e-ir)\ (1+k_1 i)} = \frac{10^8 t}{Nk} + Const \qquad (113)$$

This integral is solved in any book on Integral Calculus, or may be found in any of the standard tables of integrals. For instance: It is

$$\int \frac{dx}{(a+bx)(a^1+b^1x)} = \frac{1}{ab^1-a^1b} \log \frac{a^1+b^1x}{a+bx}$$

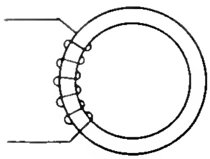


Fig. 23

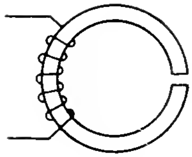


Fig. 24

$$\therefore \int \frac{di}{(e-ir)(1+k_1 i)} = \frac{1}{ek_1+r} \log \frac{1+k_1 i}{e-ir}$$

$$\therefore \log \frac{1+k_1 i}{e-ir} = \frac{10^8 t(ek_1+r)}{Nk} + c$$

and

$$\frac{1+k_1 i}{e-ir} = C\epsilon^{\frac{10^8 t\,(ek_1+r)}{Nk}}$$

C the integration constant is determined by the problem.

Example. Find the relation between field current and time, in starting a current in such an inductive circuit.

Then for $t=0 \quad i=0$

$$\therefore \; c = \frac{1}{e}$$

$$\therefore \frac{1+k_1 i}{e-ir} = \frac{1}{e}\epsilon^{\frac{10^8 t\,(ek_1+r)}{Nk}} \qquad (114)$$

Curve a in Fig. 26 gives the relation between the exciting current and time for the field current of a direct current generator having the following constants:

$e = 100$ volts = voltage impressed on the field.

$r = 100$ ohms = field resistance.

$N = 4000$ = total number of field turns in series.

$\phi_1 = 1$ megaline with 1 ampere excitation.

$\phi_2 = 0.6$ megaline with 0.5 ampere excitation.

It is instructive to verify this curve.

Curve b gives the corresponding values if the saturation curve had been a straight line, i.e., if the flux were 1 megaline for 1 ampere excitation, and 0.5 megaline for 0.5 ampere excitation.

In that case the inductance L would be constant and would be

$$L = \frac{4000 \times 1{,}000{,}000}{10^8 \times 1} = 40 \text{ henrys}$$

and the equation $e = ir + L\frac{di}{dt}$ would be $100 = 100\,i + 40\,\frac{di}{dt}$ in which case $i = 1 - \epsilon^{-2.5t}$ (115)

It is interesting to see that the field builds up considerably slower than would have been the case if L had been constant. The reason for this is that, while at the final value $i=1$, the inductance is the same in both cases, for all smaller values of current the inductance is greater because the flux is greater for the same current. When the saturation cannot be expressed by a simple equation, there is no better method than to calculate step by step.

Let Fig. 27 represent such a saturation curve. Determine the rise of current if a constant impressed e.m.f. of 100 volts is impressed on a coil 4000 turns with a resistance of 100 ohms.

Thus

$$e = ir + \frac{N}{10^8}\frac{d\phi}{dt}$$

Using differences instead of differentials it is:

$$e = ir = \frac{N}{10^8}\frac{\triangle\phi}{\triangle t} \qquad (116)$$

or

$$\triangle\phi = \frac{10^8(e-ir)\triangle t}{N}$$

$$= 0.25 \times 10^7(1-i)\triangle t \qquad (117)$$

If the values of current are determined every tenth second $\triangle t = 0.10$.

$\therefore \; \triangle\phi = 0.25 \times 10^6(1-i)$

The actual flux at any time is of course $\epsilon\triangle\phi$

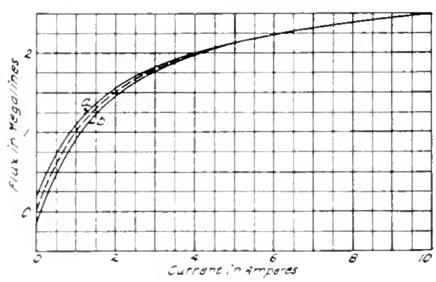


Fig. 25

The result of this calculation is given in full drawn lines in Fig. 28.

As the saturation happens to have been chosen the same as in the previous example the accuracy of this approximate method can be readily seen by comparing the full drawn lines with the dotted lines which give the corresponding relation as obtained by the use of the differential equation.

The starting of an alternating current in an inductive circuit containing iron is of special interest since almost all electrical devices used with alternating current have iron. Unfortunately the equations are very complex and are not subject to solution, even with long and elaborate treatment by series. Even in the simplest case, when the saturation curve can be represented by Frolich's equation, an accurate solution is not possible, although to be sure it is not difficult to bring the relation into the form of a linear differential equation. The problem in that case can be solved as far as a mathematician is interested; but the engineer, and indeed the mathematician, cannot use the solution for any practical purpose.

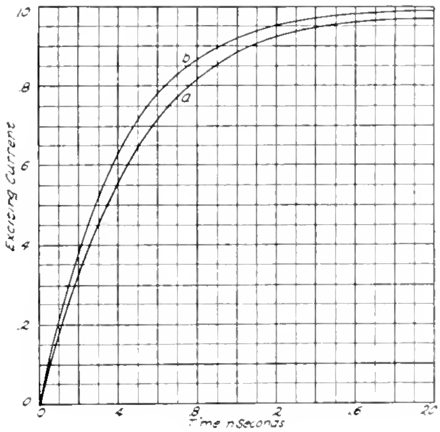


Fig. 26

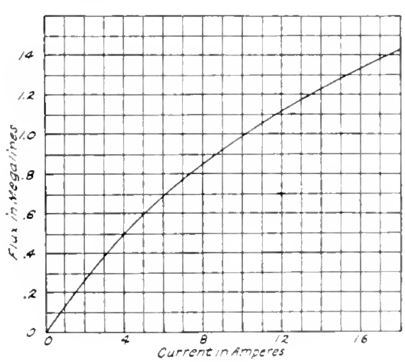


Fig. 27

To illustrate this assume that an alternating current e.m.f. is impressed on a magnetic circuit having N effective turns per phase, and a saturation curve represented by $\phi=\frac{ki}{1+k_1 i}$. Assume that the resistance of the winding is r ohms, and that the impressed e.m.f. is a sine wave. At any instant the following relation exists:

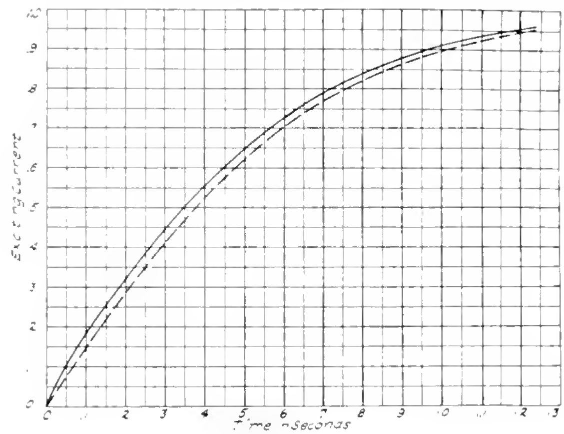


Fig. 28

$$E \sin \omega t = ir + L\frac{di}{dt}.$$

But $L=\frac{N\phi}{10^8 i}$ where N = number of turns

$$\therefore\ E \sin \omega t = ir + \frac{Nk10^{-8}}{1+k_1 i}\frac{di}{dt}$$

$$= ir + \frac{a}{1+k_1 i}\frac{di}{dt} \qquad (118)$$

where $a = N\ K\ 10^{-8}$

substituting for $1+k_1 i = \frac{1}{y}$;

$$\therefore\ i=\frac{1}{k_1}\left(\frac{1}{y}-1\right) \qquad (119)$$

$$\frac{di}{dt} = -\frac{1}{ky^2}\frac{dy}{dt}$$

$$\therefore\ E \sin \omega t = \frac{1-y}{yk_1}r - \frac{ay}{k_1 y^2}\frac{dy}{dt}$$

$$= \frac{r}{k_1 y} - \frac{r}{k_1} - \frac{a}{k_1 y}\frac{dy}{dt}$$

$$k_1 y\ E \sin \omega t = r - ry - a\frac{dy}{dt}$$

$$\frac{dy}{dt} + y\frac{(r+k_1\ E \sin \omega t)}{a} = \frac{r}{a} \qquad (120)$$

$$y = \epsilon^{-\int \frac{r+k_1 E \sin \omega t}{a} dt}$$

$$\left[\frac{r}{a}\int \epsilon^{+\int \frac{r+k_1 E \sin \omega t}{a} dt} dt + c\right] \qquad (121)$$

Since $i = \frac{1}{k_1}\left(\frac{1}{y} - 1\right)$

the solution for i is found by a simple substitution.

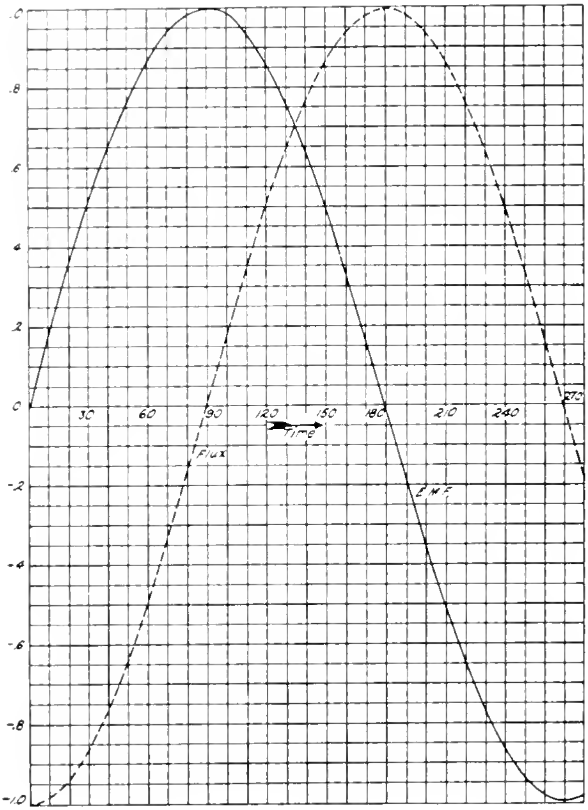


Fig. 29

Unfortunately, however, the solution is not in a simple form and cannot be simplified; and thus, while mathematically the problem is solved, practically it is unsolved. In cases like this it is necessary to proceed by a step-by-step method.

Consider then the case of an alternating current impressed upon a magnetic structure having a saturation curve represented by

$$\varphi = \frac{ki}{1+k_1 i}$$

The following relation exists at any instant:

$$E \sin \omega t = ir + \frac{N}{10^8}\frac{d\phi}{dt}$$

where r is the resistance (123)

$$\therefore \; E \sin \omega t \, dt = ir dt + \frac{N}{10^8} d\phi \qquad (124)$$

$$\therefore \; d\phi = \frac{E \times 10^8}{N} \sin \omega t \, dt - \frac{ir \, 10^8}{N} dt \qquad (125)$$

If, with full load current I, the resistance drop is p per cent. of the rated voltage, then $Ir = \frac{p}{100}\frac{E}{\sqrt{2}}$; and for any other value of I as i,

$$ir = \frac{p}{100}\frac{iE}{\sqrt{2}} \qquad (126)$$

$$\therefore \; d\phi = \frac{E \times 10^8}{N}\left[\sin \omega t \, dt - \frac{i}{I}\frac{p}{100\sqrt{2}} dt\right] \qquad (127)$$

or since $d\frac{\cos \omega t}{\omega} = -\sin \omega t \, dt$

$$d\phi = \frac{E \times 10^8}{N}\left[\frac{-d \cos \omega t}{\omega} - \frac{pi \, dt}{100 \, I\sqrt{2}}\right]$$

It is usually more convenient in alternating current problems to introduce θ, the phase angle, instead of ωt.

In that case $\theta = \omega t$ and $dt = \frac{d\theta}{\omega}$

Referring to (127)

$$d\phi = \frac{E \times 10^8}{N}\left[\frac{\sin \theta \, d\theta}{\omega} - \frac{pi \, d\theta}{I 100 \sqrt{2}\omega}\right]$$

$$= \frac{E \times 10^8}{N\omega}\left[\sin \theta \, d\theta - \frac{pi \, d\theta}{I 100\sqrt{2}}\right]$$

$$= -\frac{E \times 10^8}{N\omega}\left[d \cos \theta + \frac{pi}{I 100\sqrt{2}} d\theta\right]$$

In most problems E, N, Φ_{max} and the frequency are known, so that numerical values can directly be substituted in the above equation. Since, however, there is a relation between them, one or more of the quantities may be unknown.

The most general aspect of the problem is given by eliminating the numerical value of the impressed voltage, turns and frequency, and specifying the maximum value of the density: ϕ maximum $= \Phi$

If the ohmic drop is very small then the counter e.m.f. is the same as the impressed; and the maximum value of the flux is:

$$d\phi = -\frac{E \times 10^8}{N\omega} d \cos \theta$$

Integrating the above

$$\phi = -\frac{E 10^8}{N\omega} \cos \theta + K$$

with sine wave of impressed e.m.f. The flux wave is zero when the e.m.f. has reached its maximum.

It has its maximum when the e.m.f. has advanced 180 deg.

Thus

$$O = -\frac{E10^8}{N\omega}\cos 90° + K \quad \therefore K = O$$

and

$$\phi = \max. = \Phi$$

$$= -\frac{E10^8}{N\omega}\cos 180°$$

$$= \frac{E10^8}{N\omega}$$

Substituting this value in (127)

$$d\phi = -\Phi\left[d\cos\theta + \frac{pi}{I100\sqrt{2}}d\theta\right]$$

Substituting differences $\triangle\phi$, $\triangle \cos\theta$ and $\triangle\theta$ instead of differentials, the equation becomes:

$$\triangle\phi = -\Phi\left[\triangle\cos\theta + \frac{pi}{I100\sqrt{2}}\triangle\theta\right]$$

If the ratio between flux, current and phase angle θ is determined every 10 deg. then $\triangle\theta = 10$ deg. $= 0.175$ radians.

$$\triangle\phi = -\Phi\left[\triangle\cos\theta + 0.00121\, p\frac{i}{I}\right]$$

Numerical Example. Determine by "step-by-step" method the current in an iron-clad inductive circuit when an alternating current e.m.f. is impressed thereon. Assume that the saturation curve of the magnetic circuit is represented by Fig. 27 and equation:

$$\phi = \frac{1.5i}{1+0.5i}\text{megalines.}$$

Assume that before the switch is closed the remanent magnetism is zero as is practically the case when the magnetic circuit contains an air-gap. Assume further that under normal conditions of operation the maximum flux is 1.4 megalines, that normal current is 1.7 amperes, and that the resistance drop is 3.91 per cent. Then

$$\triangle\phi = -1.4\,[\triangle\cos\theta + 0.00286\,i]$$
$$= -1.4\,\triangle\cos\theta - 0.004\,i$$

The total flux is obviously $\Sigma\triangle\phi$. If the switch is closed when the e.m.f. passes through zero and is rising, the normal flux at that

	FIRST APPROXIMATION				SECOND APPROXIMATION		
	for $i=0$ $\triangle\phi$	$\Sigma\triangle\phi$	i	$1-i$	$\triangle\phi$	$\Sigma\triangle\phi$	i
0.1	0.25	0.25	0.182	0.818	0.205	0.205	0.146
0.2	0.205	0.41	0.316	0.684	0.171	0.376	0.286
0.3	0.171	0.547	0.447	0.553	0.138	0.514	0.413
0.4	0.138	0.652	0.555	0.445	0.111	0.625	0.525
0.5	0.111	0.736	0.65	0.35	0.087	0.712	0.622
0.6	0.087	0.799	0.726	0.274	0.068	0.78	0.705
0.7	0.068	0.848	0.788	0.212	0.053	0.833	0.768
0.8	0.053	0.886	0.838	0.162	0.040	0.873	0.82
0.9	0.040	0.913	0.875	0.125	0.031	0.904	0.86
1.6	0.031	0.935	0.905	0.095	0.024	0.928	0.896

No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9
θ	$Cos\ \theta$	$\triangle Cos\ \theta$	$-1.4\ \triangle Cos\ \theta$	$\Sigma\triangle\phi$	i	$0.004\ i$	$\Sigma\triangle\phi$	i
0	1.0	0	0	0	0	0	0	0
10	0.98	—0.02	0.028	0.028	0.01884	0.000075	0.027925	0.01875
20	0.94	—0.04	0.056	0.0839	0.0576	0.00023	0.08367	0.0573
30	0.87	—0.07	0.098	0.18167	0.1289	0.000516	0.1811	0.1288
40	0.77	—0.10	0.14	0.32115	0.2398	0.000959	0.3202	0.2395
50	0.64	—0.13	0.182	0.5020	0.402	0.001608	0.5004	0.4010
60	0.50	—0.14	0.196	0.6960	0.604	0.002416	0.6935	0.6020
70	0.34	—0.16	0.224	0.9175	0.881	0.00352	0.9139	0.8740
80	0.17	—0.17	0.238	1.1519	1.247	0.00497	1.1469	1.238
90	0.00	—0.17	0.238	1.385	1.712	0.00684	1.3781	1.699

Column No. 1, phase angle; No. 2, the cosine of the phase angle, No. 3, difference in the value of the cosine between two successive steps, for instance *cos* 20°—*cos* 10°; No. 4 is self-explanatory, No. 5, first approximation of the flux (sum of No. 8 of the preceding line and No. 4 on the line under consideration); No. 6, current as obtained from the saturation curve or the equation if such is given, No. 7, ohmic drop; No. 8, second approximation to the flux which takes into consideration the ohmic drop (the algebraic sum of No. 5 and No. 7) No. 9, current corresponding to the last approximation of the flux column, No. 8.

instant would be a maximum in the negative direction as shown in Fig. 29. As it has been assumed that the flux really is zero it is evident that there is a transient stage in the magnetization before permanent condition is reached. It is evident also that if the switch were closed when the e.m.f. was a maximum no transient condition would result, because the condition then demands zero flux, and the flux is assumed to be zero. In the numerical example it is assumed that the switch is closed when the e.m.f. wave passes through zero.

The method of using the above equation is best shown by the following tabulation.

(To be Continued)

VENTILATION OF STEAM TURBINE-DRIVEN ALTERNATORS

By E. Knowlton

Turbine Engine Department, General Electric Company

The purpose of this short article is to suggest methods of ventilation for steam turbine-driven alternators of different types and capacities in order that station engineers may operate them most efficiently. The exact arrangement here shown may not be applicable to all cases but will give desirable results where they can be properly applied.

The object of the arrangements shown is to ensure an ample supply of cool, clean air, and to remove the heated air so that it cannot surround, or immediately re-enter the machine. The illustrations and descriptive matter clearly show the arrangement of ducts, and the paths of the air through the machine.

Vertical Machines

Referring to Fig. 1, the movement of air is produced both by fans and by the blower action of the field. Air is admitted at the top of the machine; and, after thoroughly circulating through the parts to be cooled, is discharged at the lower end of the armature frame into the space between the generator and turbine. From here a duct may be run to the boiler room or to a point outside the building.

Horizontal Machines

Referring to Fig. 2, air is drawn into the bottom of the base by fans on the rotor. After thoroughly circulating through the parts to be cooled it enters the armature frame, where it flows circumferentially to the point where the outlet duct is attached.

Air Supply: Quantity

The quantity of air for ventilating such apparatus averages about 4 cu. ft. per minute per kilowatt capacity. In the smaller machines it has been found desirable to use about 5 sq. ft. of duct area per thousand kilowatts, and in the larger sizes, about 3 sq. ft. of duct area per thousand kilowatts. The resistance of the ducts to the passage of air is largely influenced by the number and shape of bends and elbows, and such obstructions should be avoided as much as possible.

Quality of Air Supply

The capacity of the generator is directly dependent on the air conditions; and an ample supply of cool, clean air is therefore of great importance. Dust or soot in the air soon collects in the air-spaces, and greatly reduces the quantity and efficiency of the air as a cooling medium. Such accumulation is particularly rapid where any oil vapor can accompany the ventilating air. It is, there-

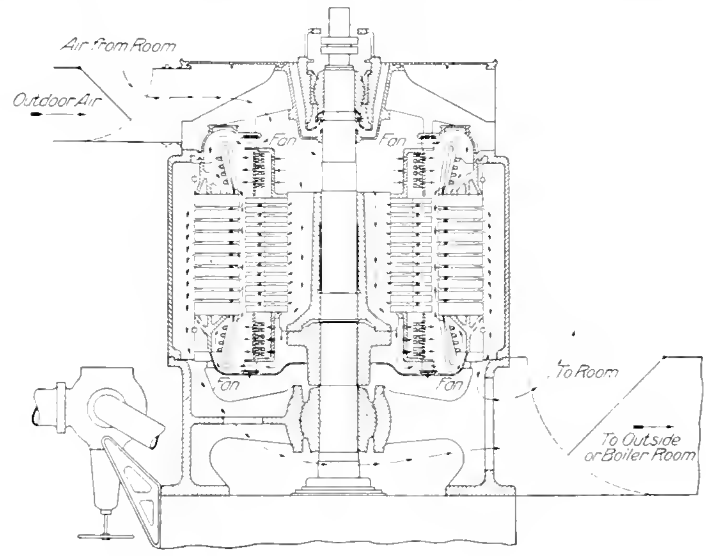


Fig. 1. Ventilation of Vertical Steam Turbine Alternator

fore, desirable to exercise great care to avoid any admission of oil to the ventilating spaces.

Cleaning

For controlling the humidity of air in cotton mills and public buildings there have been developed several varieties of humidifiers. These also remove most of the dirt in the air, and to some extent control the temperature. The principle of this apparatus is the passing of the air through a spray of water and then through bafflers which remove the entrained water and the dirt in the air. The temperature of the air after leaving the humidifier will not vary greatly from the temperature of the water used.

In Europe both air-filters are extensively used in connection with the ventilating apparatus. Where air is being successfully filtered through cloth, about 0.2 sq. ft. of a cloth similar to canton flannel has been used for each cubic foot of air per minute, the cloth being spread on frames of wood or metal in such a manner as to expose a maximum surface with the minimum amount of space. It should also be easily removable for cleaning. This cloth is usually rendered non-combustible by a chemical process; since accidental ignition of a filter would possibly destroy the generator, owing to the flames being drawn in by the ventilating air. The advantages of carrying out these suggestions are:

Reduction of Noise. The armature frames enclose these generators in such a manner that the noise existing in all high-speed machinery is greatly reduced. However, the use of ducts to carry the exhaust air outside the engine room will result in a still greater reduction of noise; allowing conversation to be easily heard, and avoiding the confusion and discomfort which often exist. If it is desirable to take air from the interior of the station it can usually be taken from the basement without objectionable noise; although the supplying of cool, clean air to the basement should not be overlooked.

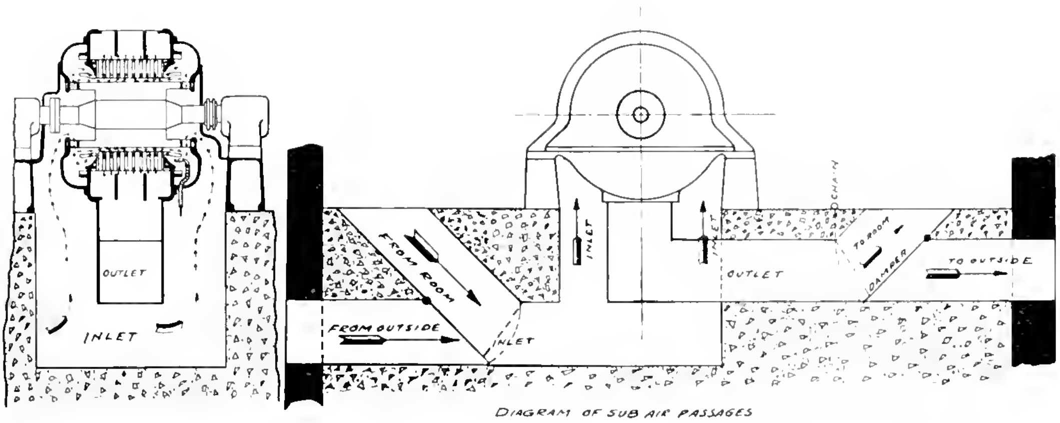


Fig. 2. Diagram Showing Air Passage and Direction of Air Flow

Control of Station Temperature. With an arrangement by which all ventilating air is admitted and discharged outside of the building it is possible that the room would not be sufficiently heated by radiation from the surfaces of the turbines and the other apparatus. To overcome this objection dampers may be placed in inlet and outlet pipes as shown in the illustrations, and the amount of heated air circulating in the station be easily controlled.

Economy. When heated air is taken away from the apparatus by ducts, as shown, it will often be possible to convey this heated air to a point where it will supplement the draft of the boilers. Such a method, if properly applied, might effect an appreciable saving in fuel; since all, or nearly all, losses of the engine room could thus be delivered in the form of heat to the furnaces.

CORE LOSS, FRICTION AND WINDAGE TESTS ON A 7500 KW. WATER-TURBINE GENERATOR

This short article includes the description of an interesting application of the deceleration method of testing to the case of a 7500 kw., 11,000 volt generator. The theory used in applying the deceleration principle for estimating losses are clearly given, although this theory, we are aware, has often been expounded in general terms elsewhere. The test connections used for obtaining input readings when the generator was motoring off the bus are of interest, and are shown in the diagram of connections.—EDITOR.

In the January, 1912, issue of the REVIEW, we published an account of tests which were carried out at the Holtwood, Pennsylvania, station of the Pennsylvania Water and Power Company, to determine the efficiency of the 13,500 h.p. water turbines installed in that station. With regard to the 7500 kw. generators to which these turbines are coupled, the electrical tests possess many features of interest, chiefly owing to the size of the machines. It is not the purpose of these notes to describe all these tests in detail, as they were for the most part carried out along standard lines; but a short account of those which were made to determine the friction, windage and core losses may prove of considerable interest, since the methods, in some respects at least, possess features which are certainly not encountered in every day test practice.

Fig. 1. Generator Room

Fig. 1 is a view of the main floor of the generator room. From the cross-sectional view through the power house shown with the article to which we have already referred, it may be seen that each generator is coupled to two waterwheels placed one above the other. The generators are three-phase, 25 cycle, 11,000 volt machines running at a speed of 94 r.p.m. It is important to note the mechanical arrangement of the units. There is one main roller bearing situated directly below the generator, supporting the entire revolving element; while, in addition, the generator has two guide bearings and there is a guide bearing to each waterwheel runner. The shaft is in three pieces which are connected together by two couplings. It is possible, therefore, to disconnect the lower waterwheel runner, and lower it away from the revolving element, thus enabling the generator to be run as a motor with either one or two waterwheel runners connected to the shaft.

To determine the efficiency of generators by the "segregation-of-losses" method, it is necessary to know the copper loss, core loss, load loss, and friction and windage of the machine under normal full load conditions. The first of these quantities may be found by calculation from the full load armature and field currents and the resistance (hot) of the windings. A determination of the total loss in the generator is, of course, not essential to a calculation of the overall efficiency of the combination, but is necessary if the independent efficiency of either the waterwheel end or the electrical end is to be computed.

The first method for obtaining core loss, friction and windage was by a deceleration test; while a check upon these results was obtained by a second method, which consisted in running the generator under test as a synchronous motor from one of the other machines, and deducting the calculated armature copper losses from the power input as measured by special testing meters wired in for the purpose.

Deceleration Test

This method of testing electrical generators has already been fully described in the GENERAL ELECTRIC REVIEW (December, 1909) in the series of articles by Mr. E. F. Collins on "Commercial Electrical Testing." Briefly, in applying the deceleration method, it is necessary to run the machine under test up above normal speed and then disconnect it entirely from the source of power. By virtue of its inertia, the rotating mass then has kinetic energy stored in it, in amount depending on its moment of inertia and its angular velocity. When the machine is disconnected from the source of power, the rate at which the speed falls is a measure of the rate at which the rotating mass is giving up its energy, and, hence, a measure of the losses. If the field of the machine is unexcited at the time, the losses will be caused by friction and windage only; if the fields are excited, the losses will include the core loss. In making the test, frequent readings of the falling speed are taken at intervals of, say, 10 or 20 seconds, from which the amount of energy given out in a given time may be calculated. If these intervals of time are made very small, it is possible to calculate the amount of power which is going to waste as friction and windage at any desired point on the speed curve, the most important point being, of course, the normal speed at which the machine runs.

At the time T_1 and the speed S_1, the energy stored in the rotating mass is $0.00017\ Wr^2\ S_1^2$, while at the time T_2 and speed S_2, the energy is $0.00017\ Wr^2\ S_2^2$; and the difference between these two quantities represents the energy given out in $T_2 - T_1$ seconds. S_1 and S_2 we already know, while Wr^2 is the flywheel effect, i.e., total weight in pounds multiplied by the square of the radius of gyration in feet. From the calculated energy loss, the mean power loss during this interval of time may be found.

It was stated above that as a check on the deceleration test, the machine was run as a motor and the power input measured. The switchboard instruments were unsuitable to this purpose, as the quantities to be measured were far below their normal range. Special testing instruments of the proper capacity were therefore connected in on a temporary circuit, shown dotted in the diagram of connections (Fig. 2), the full

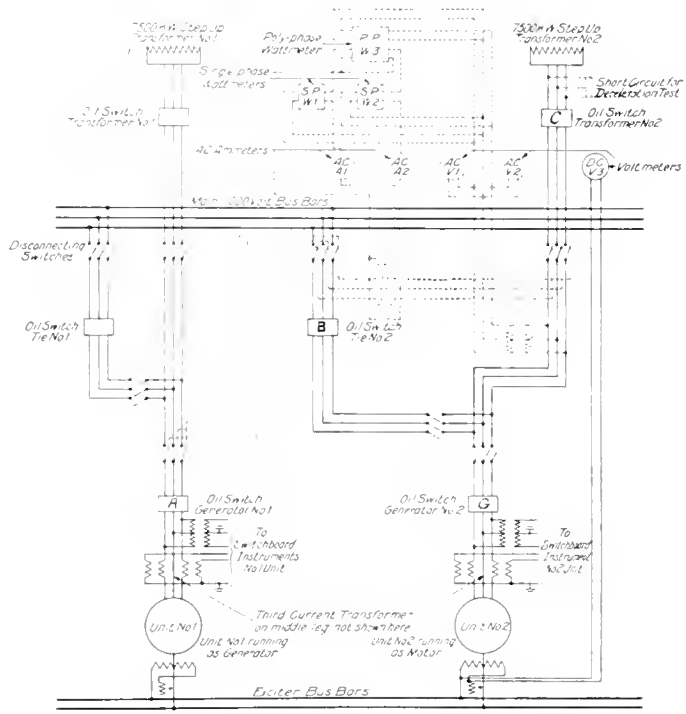


Fig. 2. Diagram of Connections. Dotted Lines show Circuits of Special Testing Instruments

lines indicating the permanent station connections. In starting up the generator under test as a motor, there would naturally be a rush of current far beyond the capacity of these instruments; and at starting they were therefore short-circuited by the switch B. When the motor was up to speed, B was opened, thus allowing the current to pass through the measuring circuit. The method of starting up the generator as a motor is interesting. Both units being at standstill, the switches were closed, and a small excitation applied to both fields. The wicket gates of No. 1 turbine were then gradually opened by hand control of the governor, and the generator very slowly brought up to speed, the motor meanwhile keeping in synchronism with it.

For the deceleration test, the motor was brought up to speed in the usual manner, and disconnected from the circuit by opening oil switch G. A set of deceleration tests was made with the armature short-circuited and the field excited to give full load current in the armature circuit. This determines the short-circuit core loss, from which the load losses are calculated. These tests were made in the following manner: No. 2 turbine having been brought up to about 10 per cent. above normal speed, oil switch A was opened. The field excitation of No. 2 was then adjusted to the value necessary to produce full-load current through the armature on short circuit. Oil switch C was then closed, and its three terminals on the transformer side having been previously connected together by three short lengths of heavy cables, the short-circuit of No. 2 armature was completed.

The following is a summary of the test:

First series: Generator running as a motor with both turbine runners coupled to the shaft. Power input was measured for three values of motor field excitation and also at three frequencies.

Second series: The same tests as the above were repeated with only one turbine runner coupled to the shaft. By this means it was enabled to separate out friction and windage caused by each waterwheel runner. The tests at the different speeds also enabled the eddy current losses to be segregated. The resistance of the windings having been measured and the armature currents in each case being known, it was possible to separate out the copper losses. It might be noted here, though obvious, that the copper losses in the revolving field did not, of course, enter into any of these measurements, although this loss has to be taken into consideration in computing the efficiency of the generator.

Third series: Deceleration test with field unexcited, first with two and then with only one turbine runner coupled to the shaft.

Fourth series: Deceleration test with field excited to the same values as in the first and second series, the armature being on open-circuit. These tests were taken with two runners coupled to the shaft, enabling the core losses to be segregated.

Fifth series: Deceleration test with two runners coupled to shaft, armature on short-circuit and full load current flowing in the short-circuit. This test gave the short-circuit core loss, one-third of which is, in accordance with the A.I.E.E. standardizing rules, taken to be the load loss.

ANNUAL OUTING OF THE SONS OF JOVE

It certainly was a day of rejuvenation for the Sons of Jove who held their annual outing in Saratoga on the 8th of September. Over 200 members headed by the General Electric band arrived in special cars over the Schenectady Railway; and from the time of their arrival until their departure they owned the place. The Jovians marched through Broadway, with the Red Cross hospital corps. A. M. Jackson; who acted as official announcer and general master of ceremonies, informed the party that the first event would be the ball game. This contest between the Watts and the Wattless was brimful of comedy. The Wattless, or unrejuvenated, surprised the Watts by winning the game, 16 to 5, in four innings.

The track and field events then took place. The first was a cigarette race. The contestants had to go to one station to get a paper, another station for the tobacco, and the third station for the match. They were to roll the cigarette, and the first one across the line with it lighted was declared the winner. John Hemphill was the winner. The 50-yard dash was won by A. D. Cameron with G. M. Harris second. The time was 7.1 seconds. A special 50-yard dash was put on for four contestants who finished as follows: E. P. Waller, first; G. L. Emmons, second; Mark Atuesta, third, and C. W. Gray, fourth. Time 7.7 seconds.

The next was the potato race, and owing (possibly) to the high price of potatoes turnips were substituted. The contestants had to carry the turnip to the finish line on a spoon without dropping the vegetable. Holding with the finger and jabbing the turnip on a spoon were barred. In the first heat A. B. Cooper won, and D. C. Estell came second. The second heat went to H. M. Jacobs, with E. P. Waller second. In the final heat Cooper defeated Jacobs. The backward race proved an easy victory for A. M. Jackson. The fat man's race caused the officials a lot of trouble. A score of entrants presented themselves; but the tape was put to work, and those who were under 36 inches girth were rejected. J. P. Jones won, J. J. Farrell was second and Blodgett third.

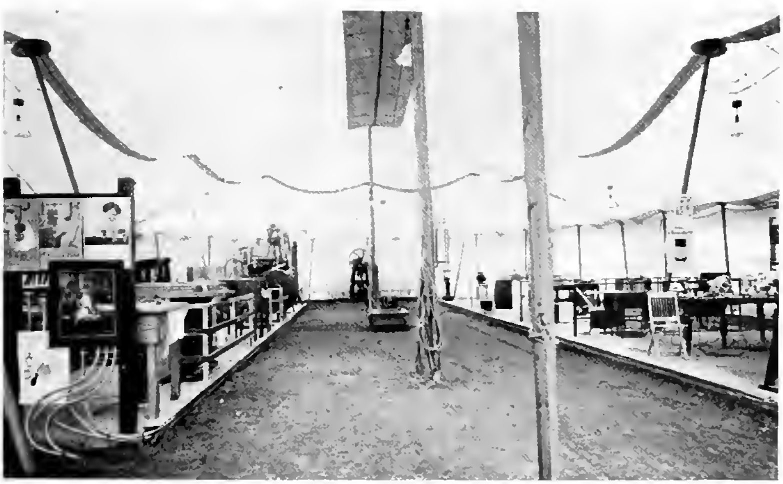
The concluding event was the tug-of-war, in which the Watts defeated the Wattless. The teams were: Watts—Farrell, Bliss, Kline, Crawford, Blodgett and Sneed; Wattless—Jones, Mayo, Niven, Pentecost, Carpenter and Cole. The Jovians then fell in behind the band and marched to the Casino, where a dinner awaited them. During the dinner the Glee Club led the singing, in which all the members joined. C. A. S. Howlett distributed some special prizes. F. W. Shackelford, a statesman of the Sons of Jove, who has been transferred to the Philadelphia office to become assistant supply sales manager, was presented with a mahogany tray. The presentation speech was made by M. O. Troy. Mr. Shackelford responded.

After the dinner a class of 45 was rejuvenated in due form. The Jovians then departed for home, well satisfied with the first annual outing.

THE MISSIONARY FARM OF THE BOSTON EDISON COMPANY

Exhibits, more or less incomplete, have been made from time to time of electrical apparatus available for farm use; but it has remained, we believe, for the Edison Electric Illuminating Company of Boston to get together what may be regarded as a complete and practical exhibit of appliances available for use on the farm, in all phases of farm activity.

Eight months ago, Mr. W. H. Atkins, General Superintendent of the Boston Edison Company, convinced his associates of the practicability of this enterprise. Some five months later the farm was opened to visitors, and the attendance of interested people has averaged about one hundred a day, excluding children and people obviously attracted out of curiosity. The farm consists in the grouping of some forty large pieces of apparatus and farming tools, together with thirty or forty of the ordinary and smaller appliances, in a big tent, 60 by 106 ft. in size. All the apparatus is practical for use and for economic service on the average farm. Each appliance is plainly marked with its name, manufacturer, price, and the cost of operation. The price is retail and includes the machine, its motor and everything ready for actual service on the farm. Some machines and tools have been omitted from the exhibition because they have been regarded as unpracticable, at least for use in New England territory. Others are not shown because it has not been possible to standardize them, i.e. furnish them to the purchaser with "every-thing-all-on" ready for operation. For the first five weeks the farm was located on the old Middlesex south Fair Grounds in suburban South Framingham. In front of the main entrance have been placed three large display signs employing striking colors to add some of the "drawing" effect of a high-class circus. The two cuts shown on this page give exterior and interior views of farm marquee. A broad, main passageway extends down the center of the tent from end to end. On either side are the working exhibits protected from the visiting throng by railings. Two electric trucks, one of two-ton capacity (General Motors Truck Company), and another of 700-lb. capacity (Walker Vehicle Company), are used in connection with the farm for hauling material to and fro. Wherever the farmers have shown interest in the truck proposition



the vehicle suited to the service has been sent out to haul loads around on the farm. From time to time material has been carried from farms into town, or vice versa.

A partial list of the apparatus shown on the Farm includes: cider mill, vegetable cutter, electrobator, electric brooder and bone-cutter, milk tester, milking machine and vacuum cleaner outfit, butter churn, cream-separator, bottle-washing machine, grindstone, horse-clipper, forge-blower, circular saw, wood saw, wood-splitter, portable breast drill, furnace-blower, meat-chopper, oat-crusher, electric pump for farm storage supply system and irrigation, pumping jack for attachment to windmill outfits, motor-operated sewing machine, vegetable-peeler, battery-charging rectifier outfit, ice-cream freezer, corn-sheller, clover-cutter, feed-grinder, friction windlass, ensilage-cutter, hay-unloader, electric kitchenette, washing machine, flatirons, and all electric household utensils, as well as buffing and grinding outfits, and all electric appliances for use in a carpenter or repair shop.

The farm is equipped with a motor on a portable truck, which can be moved from place to place and connected up with any piece of apparatus. The milking tests prove very attractive for the people and there is always a crowd at the evening milking time. Practical milking demonstrations have been given at large nearby dairy farms, to the great satisfaction of dairymen.

BOOK NOTICES

ENGINEERING VALUATION OF PUBLIC UTILITIES AND FACTORIES

By Horatio A. Foster

D. Van Nostrand Co.

361 pages 50 Blank Forms $3.00 net

The importance of the subject with which this book deals is coming to be more generally recognized every year. The responsibility resting upon consulting engineers in making appraisals is a heavy one, and the demand for specific information on the matter has become urgent. The supply of such information has hitherto been so meagre as to cause great weight to attach to the very few books which have actually been published. For this reason alone, apart from its intrinsic value, Mr. Foster's treatise will be bought and studied by all engineers whose business brings them into touch with appraisal matters, as well as by numbers of others who realize the necessity of broadening their general engineering education, by acquiring at least some knowledge of what is becoming one of its most important departments. The book is quite elementary, and provides easy reading for any engineer acquainted with the commonest legal terms. Its scope is wide and a nice sense of proportion is evidenced in the distribution of space for the various sections into which the book is divided. Depreciation, concerning which there is an urgent need for standardization of method, is thus accorded something over 100 pages and is dealt with very lucidly and thoroughly. This section of the book is particularly valuable. In a very short notice of Mr. Henry Floy's book "The Valuation of Public Utility Properties," in the September REVIEW, the writer referred to the aptness and copiousness of the references to various judicial authorities with which that book abounded. Mr. Foster makes no excuse for adopting a similar plan. At the present time, indeed, a book upon this subject could hardly have any value without such references; and a good instance of their effective introduction may be found in the author's discussion of the word "value." Lexicographers, consultants, judges, and commissions are all quoted in presenting to the reader the facts upon which he must form his conception of its meaning. Those interested may perhaps obtain a more clear idea of the scope and nature of this valuable work by glancing over the table of contents given occasionally in our advertising columns under Messrs. Van Nostrand's announcement.

STRENGTH OF MATERIALS

By Mansfield Merriman

John Wiley & Sons

169 pages 54 Illustrations $1.00 net

This work, which is now in its sixth edition, has been written with the intention of presenting the subject of the strength of materials—beams, columns and shafts—without the employment of the calculus. The only mathematical training essential to a ready understanding of the text is that regularly included as a part of the average high school course, embracing arithmetic, algebra, and geometry. In those cases where the formulæ are best arrived at through the aid of the calculus, such as the deductions for the deflections of beams, they are given without proof, accompanied by a carefully prepared explanation of their significance which should enable the student to apply them without difficulty to the solution of practical problems. Special effort has been made to convey a correct conception of the mechanical ideas involved, which, to the average individual, are by far the most difficult part of the subject, and yet, for the solution of problems somewhat out of the ordinary, must be thoroughly understood. All important principles and methods ordinarily employed in calculating the strength of materials are given, as well as a large number of examples; as it is only by the solution of numerous numerical problems that the full meaning of the text and the theory of the subject may be acquired.

The sixth edition contains a new chapter on combined stresses, several changes in the original text, four new cuts, and 70 new problems. There are in all 91 articles and 230 problems. A list of chapters follows: Chap. 1, Elastic and Ultimate Strength. Chap. 2, General Properties. Chap. 3, Moments for Beams. Chap. 4, Cantilever and Simple Beams. Chap. 5, Columns or Struts. Chap. 6, The Torsion of Shafts. Chap. 7, Elastic Deformations. Chap. 8, Miscellaneous Applications. Chap. 9, Reinforced Concrete. Chap. 10, Combined Stresses. Chap. 11, Resilience of Materials.

ELEMENTS OF ELECTRICITY

By W. H. Timbie

John Wiley & Sons

556 pages 411 Illustrations $2.00 net.

This volume may confidently be recommended to all those looking for a textbook on the fundamental principles upon which modern electrical engineering, the industry of the generation, transmission and utilization of direct and alternating current, is based. In some respects it seems to follow the vogue of books on the elements which were published ten or fifteen years ago, before technical schools and colleges were providing the student with the advanced engineering course which is customary today. Prof. Timbie's book is, indeed, exceedingly elementary, and in its reading calls for no special preparation beyond a knowledge of simple arithmetic and the simplest algebra.

The volume cannot be recommended to college students as their only handbook, although it will serve them as an admirable standby for elementary matters which are possibly omitted from the usual college handbook on elementary electricity. It is excellently suited to accompany the short practical courses in electricity given in apprenticeship departments, industrial trade schools, and the like. The matter is necessarily similar to much which has been previously published in standard elementary handbooks; but the manner of treatment and the sequence in which the new ideas are laid before the reader (which, of course, are the all-important considerations) are eminently logical and sound. This is not surprising, since the scheme adopted is the natural outcome of an extensive experience in starting young engineers on their path. Men who have progressed further on their road and have perhaps become rusty on some of their fundamentals will be wasting no time if they go over the summaries which are placed at the end of each chapter, and in which the salient ideas of the course are collected and succinctly expounded.

THE MATHEMATICS OF APPLIED ELECTRICITY

By E. H. Koch, Jr.

John Wiley and Sons

651 pages   316 Figures $3.00 net

This book contains an abundance of information on engineering mathematics; and while the text was primarily intended for the instruction of college students, the volume may also be used for reference or for self-study. For this latter purpose it would have been much more valuable if the answers had been given to the various examples, since a knowledge of the answer is generally the only thing that will show whether the mathematics has been properly applied and the problem correctly solved. The work is graded, and arranged in a logical sequence. It is so written that it may be presented in any order, irrespective of chapter divisions. The first chapters are of a very elementary character, but should nevertheless prove useful to men who are occupied in various electrical industries, and who find their progress in electrical matters retarded owing to their deficient knowledge of elementary practical mathematics. The book, however, contains considerable material of a more advanced character which may be omitted on a first perusal, and used later for reference or in further preparation for more advanced study. The text contains a limited amount of information concerning electrical phenomena, so as to reduce the necessary references to supplementary electrical texts.

ANNUAL MIDSUMMER CONVENTION OF THE EASTERN NEW YORK SECTION OF THE N.E.L.A.

The third annual convention of the Eastern New York Section of the National Electric Light Association, was held on Saturday, August 10, 1912, at Trenton Falls, at the site of the 8000 horse power hydro-electric plant of the Utica Gas & Electric Company, a locality of interest to the many delegates who attended. This section has a total membership of 363, including consulting engineers, manufacturers, operators and various employees, and there are 56 Class A members. There were over 60 in the party which came to Trenton Falls on the Black River train, arriving there shortly after 10 o'clock A.M., and during the morning and early afternoon the number was increased to 100.

The convention headquarters was the Hotel Trenton. The business session opened at 10:30, President Throop presiding, and R. H. Carlton of Schenectady filling his office as secretary. The president made the opening address and gave the announcements for the day. Mayor Frank J. Baker of Utica welcomed the delegates. M. O. Troy of the General Electric Company, and one of the organizers of the Eastern Section, gave a fine report of the purpose and progress of that body. F. H. Gale, also of the General Electric Company, gave a most interesting account of the national convention held in Seattle recently, describing the trip and the advance made in electrical work, as brought out by the addresses, and by observation. Dr. William B. Coolidge, assistant director of the research laboratory, Schenectady, delivered a very interesting address on "Some Contributions of the Research Laboratory to the Development of the Electric Industry."

The secretary next gave the report of the nominating committee, which was composed of Bryce Morrow, Glens Falls, chairman; H. W. Peck, Schenectady; Lee Hagood, Schenectady; L. W. Emerich, Fulton; O. F. Webster, Syracuse; W. J. Reagan, Utica; and J. A. Anderson, Albany. Mr. Throop, the president, who was serving out the unexpired term of M. Webb Offut, was re-elected to that office, and the other officers were chosen as follows: Vice president, A. Anderson of the Municipal Gas Company, Albany; secretary, R. E. Russell, General Electric Company; treasurer, F. W. McRae, Adirondack Power Corporation, Glens Falls. The executive committee is composed of the officers and the following additional members; H. W. Peck, Schenectady Illuminating Company; L. W. Emerich, Trenton Light, Heat & Power Company; O. F. Webster, Westinghouse Manufacturing Company, Syracuse; Mr. Schreck of the Central-Hudson Gas & Electric Company; J. T. Mange of the Ithaca Electric Light & Power Company, and C. W. Stone of the General Electric Company.

Luncheon was served at 1 o'clock, and afterwards a program of games and contests was run off, while a clambake was enjoyed on the hotel grounds. At 8 o'clock the company reassembled for some excellent papers, one written by W. B. Underwood, on "Heating for Increasing Central Station Load," and another by E. P. Edwards on "Electricity as a Factor in Progressive Agriculture." After some dancing the party left Trenton Falls on the 11:40 Black River train, which made a special stop.

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Dr. Louis Bell

Dr. Bell, for many years one of the foremost authorities in this country on matters pertaining to electric lighting, contributes an article to this issue of the REVIEW on the Illumination of the Boston Electrical Show of 1912. See page 676.

GENERAL ELECTRIC REVIEW

NIAGARA FALLS CONVENTION OF THE ILLUMINATING ENGINEERING SOCIETY

The recent Niagara Falls convention of the Illuminating Engineering Society was probably the most successful in the history of the association. The registration may seem somewhat low (fewer than 150 names appear on the record); but it must be noted that the percentage of out-of-town delegates was very high, and also that those who did attend the meeting were there with a great enthusiasm for the purposes of the Society and were bent on business, as is indeed testified by the high proportion of attendance-at-sessions to total registration.

The Illuminating Engineering Society is primarily a scientific body, and at Niagara Falls the bulk of the business was concerned with questions of a scientific character. This is certainly as it should be; since the function of the illuminating engineer is to build up good illumination practice, based upon the correct application of the laws of the sciences of light and physiology, and even of psychology. Directly commercial questions received but little attention; and we find the majority of the papers dealing with such subjects as diffused reflection, natural and artificial distribution, reflecting power of opaque bodies, methods and means of determining the value of quantities used in illumination calculations, eye-comfort and discomfort, color values of different surfaces, standards of light, and so on. Many of these papers are of interest to a great number of professional men outside the membership of the Illuminating Engineering Society; and it is not surprising to find that they are being accorded an extensive re-publication in various technical journals.

Apart from the actual contents of the papers, many points of interest may be noticed in a study of these contributions. The report of the Committee on Progress is a valuable document, although reference to one or two recent developments of importance seems to have been omitted. The value of the annual report of the N.E.L.A. Committee on Progress is well-known. It is like no other publication, and provides a better history-in-instalments of the electrical industry than can be obtained anywhere else. The N.E.L.A. is a commercial organization; the Illuminating Engineering Society is a scientific body. But the work of a Committee on Progress can be just as valuable to the latter as to the former; and members of the new profession will, as time goes on, find an increasing value in these annual broad outlines of the year's achievement.

The report of the Illuminating Committee of the Association of Iron and Steel Electrical Engineers is of great value in itself, and of interest because of that of which it is symbolical—co-operation between professional associations having some community of interest. It must be of advantage to the Iron and Steel electrical men to have their views on illumination discussed by specialists in the applied science of illumination. It must be of advantage to the Illuminating Engineers to have their discussions of specialized fields of illumination enriched by men who spend all their time in these specialized fields. Friendly relations frequently exist between various bodies; here is a case of the good feeling finding expression in a practical manner. This session of the convention may be placed in the same category as the joint session of the Illuminating Engineering Society and the American Institute of Electrical Engineers, held at Boston last June during the 1912 convention of the latter body. The Illuminating Engineering Society gained enormously in prestige through this intimate official association with the older institution.

The practice of including, in the proceedings of a young and increasingly important professional body, papers of the nature of that which was presented by Dr. Hyde on "Methods of Research," is entirely to be commended. The doctrines expounded in this scholarly essay have certainly a bearing upon other applied sciences besides that of illumination. In a code of ethics drawn up for the guidance of independent investigators in this and other fields, Dr Hyde's paper would deserve a prominent place. His argument throughout is lucid and concise; and his forceful, yet restrained, warning, as delivered in his concluding paragraphs, is a model of its kind in substance as in diction. Dr. Hyde is disposed to take no lenient view of the offense of the broad speculator, who, making wide generalizations from the results of an investigation very limited in scope, accepts (whether willingly or not) the responsibility for leading and misleading other seekers after the truth in the same field. Dr. Hyde's paper may be of great value to all such investigators; but of equal significance is the fact that the essay itself was prepared for a purpose, was the outcome of the desire of the Council of the Society that some code of rules, at least some suggestions as to procedure, be drawn up for the guidance of the men who are today searching for the laws of illumination upon which practice is going to be based. This sense of responsibility is indicated elsewhere in the Niagara Falls proceedings, notably in the report of the Association of Iron and Steel Electrical Engineers already referred to, in which a strong plea is made for a full statement of authenticity on all illumination test results which are intended for practical use. [This same matter, by the way, is also referred to by Mr. G. H. Stickney, in his article on the interpretation of photometric curves appearing in this issue.]

It is worthy of note that, although the finances of the Society are in anything but a flourishing condition, there was nothing that could be described as approaching dejection in the attitude of the members assembled to discuss these money matters. The tone of the conversations was distinctly optimistic; and it may be presumed that some satisfactory specific will soon be discovered whereby the financial affairs may be put in order, expenditure curtailed, receipts increased, and a favorable balance in hand assured. Various ways and means were discussed, the most promising solution appearing to lie in the direction of roping into the membership of the Society a greater number of lighting men from all the smaller central stations in the country.

SOME NOTES ON THE GROWTH OF THE ELECTRIC LIGHTING BUSINESS

This issue of the Review includes Part II of Mr. Lee Hagood's article on "The Operation of Synchronous Machines in Multiple," the first part of a new paper by Mr. D. Basch on "Storage Batteries in Modern Electrical Engineering," which will be continued in later issues of the magazine, and a further instalment of Dr. E. J. Berg's papers on transients. The remainder of our space this month we have given over to the publication of an important group of articles on lighting by electric lamps; and these will probably be found of considerable interest to all those engaged in the engineering of lighting, whether in the operation of the systems which furnish the energy for electric lighting, in the design of the lamps, or in the adoption of the correct scheme and arrangement for obtaining a maximum of useful illumination for the energy expended at the lamp.

Electric lighting practice is a very broad term, and covers more than the mere current-consuming devices by which electric energy is converted into light, and light again into useful illumination. The millions of tungsten lamps (to name only one unit) which are sold in a year in this country alone certainly represent an extraordinary fact; and the steady improvement in arc lighting practice, as illustrated in many recent installations of the street-lighting magnetite lamp, is equally significant of an enormous amount of specialization in these departments of the lighting field. But it must be remembered that these things *are* specialization; and there is just as great a cause for wonder in the extent of refinement which has today been reached in the other phases of the engineering of lighting—in the power house, in the transmission line, and in the substation. Progress in the lamp would have been useless by itself. The lamp is a vital link in the chain; but the machinery for the generation, transmission and distribution of energy is just as vital as the machinery for consumption.

Quite early in the history of the industry, the full truth of this was realized. At some of the early meetings of the National Electric Light Association way back in the eighties, as much time was given to the discussion of methods of station economies as to house wiring and lamp breakage. At the time when Boston, quoted as possessing the greatest electrical transmission system in the world, boasted a lighting load of not more than 10,000 lamps, and a power load of but a few hundred horse power, station engineers were already closely watching their coal and oil bills, studying ways and means for their reduction, and looking about for fresh revenue-producing applications of electricity upon which their station service could be expended. Indeed, it would almost appear that, for a time, their labors in these directions were so thorough as to withdraw from the consuming devices, the lamps, all that attention which was their due; with the result that for some years the lamp itself, judging by results only, seemed to have passed through a period of suspended activity. Prof. Elihu Thomson, writing in the General Electric Review, December, 1911, says: "It seems at first somewhat singular that the carbon arc, open and enclosed, continuous current and alternating, held its place for so long a period. It is probably to be explained by the attention of engineers being diverted into such fields as electric railways, alternating current distribution, motor applications, and the many others which opened up one after the other in a more or less unbroken series." But these other details were so closely connected with the details of the lighting business, and were so often even common to the lighting business, that none of the time spent upon them was wasted, even from the purely lighting standpoint. Quite early it was realized that a central station, the instrument of an Edison Illuminating Company, would hardly flourish if it had to depend purely on its illumination load; but that it must do all that lay in its power to assist in the increased application of electric motive power to the industries, and to urban, suburban, interurban and even main line railways.

A full realization of this would render unnecessary many of the questions which are asked as to the appropriateness of the name of our great National Electric Light Association. Maybe, as has been frequently mooted during the last few years, that body may change its name to a title which would be more truly indicative of the wide range of its activities; but, taking this broad view of electric lighting, it is easy to see how the name, for many years at least, was strictly appropriate and a truthful index of the character of the work performed by the Association. This broader scope, embracing branches of engineering regarded by some as extraneous, does after all represent a range of activity which had to be covered by the electric lighting companies if the life of the electric lighting business, strictly as such, was to be preserved. Thus, in many respects at least, the history of electric lighting is a history of the electrical industry. The existence of a lighting load forced the development of the station, of the line, and of all the detail apparatus pertaining thereto. Other loads were added as fresh proof was furnished of the wonderful flexibility of electric service; and indeed today a new residence lighting installation is welcomed by the central station not only because it becomes at once a source of revenue from lighting, but because the strong points of the lighting service may so commend the system to the consumer that a heating-and-cooking load, or a sewing-machine and flatiron load, will follow as a matter of course, as a result of the missionary lighting work. Sometimes, as we have seen, attention was apparently diverted from lighting matters to other matters, co-related and just as important. But progress was steadily made, while history was also made; and the modern electric supply system came gradually into being. The changes have been so gradual, and withal so radical and quickly accomplished, that it would be the height of folly to hint that any great degree of finality had been reached as regards either general system or apparatus.

Before leaving this point, and to show how the lighting companies realized what the other directions were in which they had to apply their energies, it may be of interest to quote from the Minutes of the Association of Edison Illuminating Companies in the earliest days. In a report on the subject of electric motors in February, 1887, Mr. H. McL. Harding, of the Sprague Electric Railway and Motor Company, gave some interesting facts and made some prescient suggestions. "The motor is absolutely automatic . . . . . non-sparking at the commutator . . . . . . They all work satisfactorily, and no money has been expended in repairs . . . . . . There need be no trouble in selling motors. All the illuminating companies should take hold of the electric power and electric railway business. There is going to be more electricity used for power than for lighting . . . . . . If the storage battery business proves successful, they can charge the batteries for running street car motors." *That was 25 years ago.* The last sentence is pregnant with suggestion; and is of extraordinary interest when we reflect upon latter-day energy in the electric vehicle publicity campaign, as waged by, say the Boston Edison Company under its present enlightened and progressive management; and upon recent successful applications of the storage battery to electric railway service.

One is tempted to touch upon some of the principal steps in the history of the large lighting station as we know it today, but that is beyond the scope of these notes. We have now arrived safely at systems in which many hundreds of thousands of electrical horse power are distributed through miles and miles of a network of conductors. Twenty-five years ago "the principal system in the world" had a few thousand glow lamps connected. Today the output of tungsten lamps from the Harrison factory alone represents a sale of nine and one-half million dollars per annum. This is remarkable; but it means that the engineering problems which confront the men who have to design and operate the apparatus for supplying this enormous load are almost bewildering in their magnitude and their variety. Electrical engineers are well acquainted with their nature. Leaving aside all details of the design of apparatus, we have to acquire the fullest scientific knowledge of the nature of line disturbances, whether arising from external sources (such as lightning) or internal sources (such as an arcing cable gone to ground). We have to obtain a much fuller understanding of the nature of corona than we possess at present, since upon such understanding depends a great deal of transmission development at present barely feasible. We have to bring about the fullest co-operation of operating engineers and designing engineers to decide such questions as the successful practical handling of the short-circuit of a 25,000 kw. alternator, so as to limit the amount of damage which can result therefrom; and there are many other questions of a similar nature, altogether too numerous to mention, upon the successful solution of which further progress in the development of the big electric lighting system depends.

Returning to matters connected simply with the lamps, it may be well to call particular attention to the lighting articles published in this issue of the REVIEW. A year ago we were describing the new magnetite lamp for ornamental street lighting. It was proposed to publish a book on modern arc lighting shortly after the issuance of the December, 1911, REVIEW; but progress was moving so rapidly on this luminous lamp that little could be said definitely from month to month, and preparation of the volume was not proceeded with. Mr. Halvorson now collects into a supplementary article some of the principal results of the year's work; and in view of the extent to which this lamp has already been marketed, and the inevitable extent to which it will, during the next few years, be installed on the streets of the principal cities in this country, his paper should be of the greatest interest.

With the present widespread interest in the general subject of illuminating engineering, and with very active advertising on the part of all the different manufacturers of competitive illuminants, it is not surprising that the man who has not specialized in the lighting field should find some difficulty in understanding just what is the province of the various lamps (arc and incandescent) now on the market. Those in doubt on these matters can do no better than consult Dr. Steinmetz's classic paper on lighting by electric arcs which appeared in the December, 1911, REVIEW, towards the end of which he categorically considered seven main fields of exterior lighting, and gave his judgment as to the type of illuminant with which the needs of each should be met. Dr. Steinmetz also contributes to the present issue of the REVIEW and gives a very clear exposition of the relative importance of the various characteristics of artificial illuminants, such as efficiency, distribution, color, etc. Prof. Elihu Thomson has a valuable article in this number on "Vision and the Measurement of Light and Illumination," in which he shows very clearly the urgent need for standardization of the nomenclature used in the practice of illumination, which need the Illuminating Engineering Society of America is now doing all in its power to fill. Other articles included in this issue deal with series and multiple enclosed flame arc lamps, the interpretation of photometric curves, and present-day practice in regard to the use of reflectors with tungsten lamps; and the REVIEW is also particularly fortunate in being able to publish a paper from Dr. Louis Bell, who takes as his subject the illumination of the Boston Electric Show. Perhaps the most interesting feature of this elaborate scheme of display electric lighting is the use, for the first time, of deliberated colored flame arc lamps in very great profusion for the spectacular decoration of Huntington Avenue, Boston, the street on which the exhibition building is located.

EFFICIENCY OF ILLUMINANTS

By Charles P. Steinmetz

Chief Consulting Engineer, General Electric Company

This article gives a clear exposition of the relative importance of the various characteristics of an illuminant as affecting its suitability for different purposes. The efficiency is of greatest importance, since the others (distribution, color, brilliance) can always be corrected for by sacrifice of efficiency. For any proposed lighting installation, the efficiency of light production and that of distribution vary in opposite directions with a change in the size of the lighting units, and hence in the number. The function of the illuminating expert is therefore to effect such a compromise between the two as will give a maximum resultant efficiency. The article includes a curve-sheet of efficiencies of electric lamps, the values of quantity of light referring to the candles of the beam proper, no deduction being made for the loss which is nearly always incurred due to correction of the distribution curve or reduction of intrinsic brilliancy.—Editor.

Of foremost importance in the study of illumination are:

The total amount of light produced by the illuminant;

The distribution curve of the light;

The quality of the light; that is, diffusion and intrinsic brilliancy, color, etc.

As the problem of illumination is to supply the proper amount of light at the places to be illuminated, it is obvious that the illuminant must produce sufficient light for the purpose; and, no matter how perfectly the distribution curve of the lamp fits the requirement, how well diffused and of low brilliancy and perfect color the light is, if the amount of light given by the lamp is insufficient, the illumination is unsatisfactory.

Of first consideration therefore is the quantity of light given by the illuminant, or the total light flux. This is usually measured in *mean spherical candles*. Occasionally as measure of the light the *lumen* is used, which is the theoretically more correct unit of light quantity. One mean spherical candle equals 4π lumens.

However, the quantity of light of the lamp is not sufficient, but its distribution curve also is essential for proper illumination. An illuminant may give ample light for the most perfect illumination, and still the illumination be unsatisfactory. For instance, in the usual street illumination, with arc lamps spaced about 200 ft. apart, the flame lamp with converging carbons, as it has been extensively used for decorative lighting, would be unsatisfactory; it gives more than enough light, but the distribution curve is such that most of the light is thrown downwards, only little in the horizontal; and the result would be that, midway between the lamps, the illumination would be insufficient, while near the lamp an equally unsatisfactory excessive intensity of illumination would give a blinding glare. The magnetite lamp, on the other hand, although giving much less light than the above flame lamp, gives a satisfactory street illumination, as it sends most of its light out 10 to 20 deg. below the horizontal, only little downwards, and thereby distributes it fairly uniformly over the street surface. On the other hand, an attempt to use the series magnetite lamp for indoor illumination would give a bright illumination of the upper parts of the side walls of the room, but only little light below the lamp, where it is desired in indoor illumination. In the latter case, the distribution curve of the converging carbon flame lamp, with most of the light thrown downwards, would be more satisfactory. Thus, with a sufficient light quantity given, the next important feature is a distribution curve of the light suited to the requirements of the illumination —indoor lighting, street lighting, etc.

It must be realized, however, that practically any distribution curve can be produced by suitable shades, reflectors, diffusing or diffracting globes, etc., at a greater or lesser loss of light; that is, sacrifice of efficiency by absorption. As the result hereof, high efficiency may make up for unsatisfactory distribution curve. For instance, the flame arc with vertical carbons gives a distribution curve which is unsatisfactory for indoor illumination, as most of the light is sent out in the horizontal. On the other hand, the quartz mercury lamp gives a distribution curve essentially suited for indoor illumination. However, the efficiency of the yellow flame arc may be as high as 4 mean spherical candles per watt, while that of the mercury lamp is from 2 to 2.5 candles per watt. If then, by suitable reflectors, etc., we correct the distribution curve of the flame lamp and thereby sacrifice 25 per cent of its light, we still have an efficiency of 3 candles per watt, or higher than the mercury lamp. Thus, while a distribution curve suitable for the purpose is of importance, it is so within limits only; and no distribution curve can compensate for any great inferiority in efficiency, as a moderate sacrifice of efficiency usually permits producing any desired distribution curve.

Similar considerations hold regarding the quality of the light, more particularly the intrinsic brilliancy. A high intrinsic brilliancy is objectionable and not permissible in good illumination; and such illuminants as the mercury lamp and the Moore tube, which have a low intrinsic brilliancy, are superior. However, the intrinsic brilliancy of an illuminant can be lowered in any desired degree by diffusion and diffraction, by various kinds of globes, such as opal, alabaster, alba, frosted, etched, sandblasted, etc. This however involves a loss of efficiency, of from 10 to 30 per cent; and the illuminant which intrinsically has a low brilliancy, therefore has the advantage by the percentage which would have to be wasted in lowering the brilliancy of a high brilliancy illuminant, approximately 20 per cent, but no more.

The color of the light is directly of essential importance in those cases where certain classes of work have to be performed, as color matching, etc. It is a physiological and psychological phenomenon, and as such can not well be expressed numerically, except, in general, that, where low intensity illumination is contemplated, as in most of the street lighting, the white color has a material advantage in physiological efficiency. The bluish green probably is still better, but the orange yellow materially inferior.

This brings us back then to the question of efficiency of light production, as the most important feature, since all other features, if unsatisfactory, can be made satisfactory by a sacrifice of efficiency, and thereby are compensated for by a higher efficiency.

In considering the efficiency of light production, it has to be realized that the efficiency of most illuminants is a function of their power consumption, and the efficiency practically always increases with increasing power consumption, as seen on attached curve sheet. That is, larger lighting units are more efficient light producers than smaller units. On the other hand, in most cases the efficiency of illumination, that is, the efficiency of distributing the light in the manner as desired, decreases with decreasing number, and therefore with increasing size of the light units; and the two factors, efficiency of light production and efficiency of light distribution, thus vary in opposite direction with the change of the size and thereby number of the light units. The problem of illuminating engineering therefore is to choose such a compromise between the decrease of efficiency of light production resulting from the use of more numerous smaller units, and the decrease of efficiency of light distribution, resulting from the use of fewer large units, as to give the maximum resultant efficiency—with due consideration of the economic side of the cost of installation and maintenance. This however is beyond the scope of the present discussion.

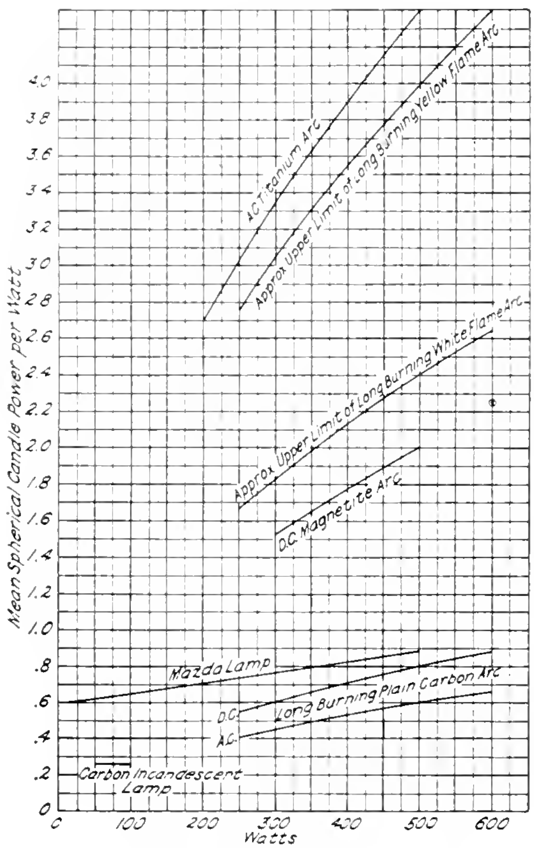
Furthermore, when comparing efficiencies of illuminants on the basis of photometric tests of lamps, it must be taken into consideration whether the distribution curve of the illuminant has already been corrected in the lamp, and the loss of efficiency incident to this correction incurred, or whether this is not the case; and in order to use the illuminant for the particular purpose contemplated, some of its tested efficiency would have to be sacrificed for producing the desired distribution curve. For instance, the 300-watt magnetite lamp gives an efficiency of 0.95 mean spherical candle per watt, the tungsten incandescent lamp an efficiency of 0.84 mean spherical candle per watt, i.e., only 11.5 per cent lower. However, the 300-watt magnetite arc gives about 1.3 candle per watt of a distribution curve practically the same as that of the tungsten lamp, and to make this distribution curve suitable for street illumination, by sending most of the light out under an angle of 10 to 20 deg. below the horizontal, 0.35 candles per watt are sacrificed by absorption in the reflector, etc. Approximately the same loss of efficiency would have to occur in correcting the distribution curve of the tungsten lamp for street lighting, and this would drop its efficiency from 0.84 candles to about 0.63 candles per watt. Thus, direct comparison of photometric data without consideration of the distribution curve, and the loss which would result in correcting it, would be misleading.

In the accompanying curves are given approximate efficiencies of various more important illuminants, with the power consumption as abscissae, and as ordinates the light, in mean spherical candles per watt, given by the radiator proper, that is, the raw material, as we may say. The light given by the completed illuminant, as installed for any particular purpose, then is lower than the values given in the table, by the loss in controlling the distribution curve, the loss in producing a sufficiently low brilliancy, etc. Where therefore the distribution curve of the radiator has to be modified to suit the requirements, either by external appliances, as usual with incandescent lamps, or by reflectors, etc., which constitute a part of the lamp, as usual with arc lamps, the efficiency is lowered, usually from 20 to 30 per cent, so that in average we may assume *a loss of 25 per cent efficiency in controlling the distribution curve.* Where the intrinsic brilliancy has to be lowered by diffusing globes, etc., this again involves a loss varying usually from 10 to 30 per cent and more, depending on the density of the globe, or an average of *20 per cent loss in lowering the intrinsic brilliancy.*

For instance, the 500-watt magnetite arc gives an efficiency of 2.0 candles per watt. The production of a distribution curve suited for street lighting, by reflecting the light of the upper hemisphere into the horizontal, may be assumed to cause a loss of 25 per cent, to 1.5 candles per watt. The use of a diffusing globe, to lower the brilliancy, may involve another 20 per cent loss, to 1.2 candles per watt, so that the lamp, as used in Boston, may be expected to give an efficiency of 1.2 candles per watt. Or, considering the 100-watt Mazda lamp for indoor illumination. Its efficiency, from the table, is 0.65 mean spherical candles per watt. By a suitable reflector, to throw the light of the upper hemisphere downwards, a loss of 25 per cent—more or less—would lower the efficiency to 0.48 candles per watt. On the other hand, where the requirements are such as to permit the use of the illuminant without change of distribution curve or diffusing globe, the full efficiency would be available.

It must be understood that the loss of efficiency resulting from the correction of the distribution curve, etc., still permits a materially higher efficiency in the illuminated area. For instance, if in the Mazda lamp, by throwing the light of the upper hemisphere downwards, a loss of 25 per cent occurred, this means that only half of the light of the upper hemisphere is thrown downwards. But it also means, that in the lower hemisphere an increase of 50 per cent in light is secured. Or, in the 500-watt magnetite lamp, the loss in efficiency, from 2.0 to 1.5 candles per watt, is accompanied by an increase in light, 10 deg. below the horizontal, from 2.5 to 3.25.

The curves given for the yellow and the white flame arcs constitute the approximate upper limits of efficiency reached with long burning flame carbons; no definite efficiency can obviously be given for the flame carbon in general, as, depending on the



Light plotted against energy consumption for the more important illuminants

amount of impregnating material, any efficiency can be secured, from the low efficiency of the long-burning plain carbon arc up to the curves given in the curve sheet. There is, however, an additional limitation at the highest efficiencies of the flame carbon arc, and that is the increasing danger of slagging and consequent failure to start, or going out of the lamp, so that the upper limit is rather indefinite.

VISION AND THE MEASUREMENT OF LIGHT AND ILLUMINATION

By Elihu Thomson

In treating of the theory of vision in this article, Professor Thomson gives considerable attention to the ability of the human eye to perceive color contrasts. Light possesses no color in itself, but depends on the visual organ and the nervous mechanism back of it for the interpretation of color. If all eyes were alike in sensitiveness, both as regards luminosity and color vision, the problem of the measurement of light would be simpler than it is. In practice sufficiently satisfactory results are obtained from measurements based on a comparison of lights or surfaces one with the other, as by some form of photometer, it being assumed that the observer's vision, though subject to variation, will be affected alike by both lights compared. From a very lucid introduction on these lines the author then defines some of the terms most frequently employed in illumination measurements; and shows that a great advance will be made in placing such measurement upon a secure and scientific basis if the recommendations of the I.E.S. Committee on Nomenclature are adopted internationally. A study of this article may with advantage be followed by a study of Mr. Stickney's paper on "Interpretation of Photometric Curves," on page 725.—Editor.

Were there no living creatures in the universe provided with eyes there would of course be no distinction between so-called visual rays and non-luminous or invisible rays. There would still exist the possibility and probability of the generation of that vast series of electric waves beginning with the lowest frequencies and ranging upward through rates of several hundred thousand waves per second as used in wireless telegraphy—through many millions per second—as in the waves investigated by Hertz, reaching at last the high frequencies characteristic of radiant energy given out by hot bodies such as the sun, and including those frequencies which correspond to visible light and even the ultra-violet rays, themselves invisible. All this range of wave frequencies are equally entitled to be called radiant heat waves, for they all represent energy which when the rays are absorbed in a body result in raising its temperature. Too much emphasis cannot be laid upon the fact that not only the dark heat waves, the ultra-red so-called, as well as those which excite the sensation of light in our eyes, are all heat waves in the same sense, as are also those finer waves extending many octaves beyond the violet end of the spectrum. They all represent radiated energy, but the lower waves not only require more energy to produce them but give a correspondingly larger amount of heat when absorbed. The visual rays are limited approximately to only one octave and range from a frequency of about 400 millions of millions per second for the red rays up to about double that for the violet end of the visible spectrum.

Why, it may be asked, are not our eyes adapted to recognize a greater range of wave lengths than a single octave? The answer to this question doubtless is that the organ of vision is a product of a long evolution during which unsuitable departures have been eliminated. It is probable that if our range of vision extended to lower wave lengths or higher frequencies than those now concerned in vision it might only lead to confusion instead of benefit, as some substances are transparent to ultra-red rays that are opaque to ordinary light, and others opaque to ultra-violet rays that are quite transparent to ordinary light waves. Again it is probable that, following the results of Prof. R. W. Wood in photographing with ultra-red and ultra-violet, similar contradictions to those found by him in the photographic effects, might equally exist in vision, which indeed may depend upon an effect upon the retina of the eye akin to photography. Just as the fire-fly has, by an exceedingly long process of evolution and elimination of the inefficient, become capable of producing light at the least cost, or waves confined to the visible spectrum without low or so-called heat waves and without ultra-violet, which would be useless for its purposes, the eye has been evolved for each animal to recognize most sharply those wave lengths most suitable to its life needs. A creature which always lived in a medium of a single color would evidently have no need of color vision for other colors. This condition must be approached by some of the deep sea fishes. Such fish are probably color blind to red, which is absorbed by moderate depths of sea water. Many of the insects, however, which seek the flowers must have a lively sense of color differences.

The birds, whose plumage is often highly colored and is different for the two sexes, must also have a highly developed color sense. The belligerent bull must likewise have an intense sense of red,—which causes him to charge a red cloth as if it were a wounded and bleeding enemy of his own species. The Spanish bull fight utilizes this blind instinct.

Even in man the faculty of color distinction varies widely. A considerable number of men are color blind, generally to the red rays, which involves the loss of its complementary, the green, since their white light is light green. It is said that some of the black races fail in being able to distinguish purple or violet from blue. Many years ago the writer found that a pupil of his was entirely color blind, seeing all objects in shades of yellow which was to him his only light, a very restricted range of wave length. He saw as if objects were illuminated by yellow light only, and they must have appeared as they do to persons of normal vision when illuminated by the yellow sodium flame. Color as such was absent.

The retina of the human eye is apparently capable of at least four distinct sensations aside from their intensity. These sensations differ, moreover, in their relative intensity over different portions of the retina itself. The simplest of these sensations is that of luminosity without color distinction, and this seems to be located in the so-called "rods" which are found microsopically in the retinal membrane. The other three sensations concern color vision, and possibly belong to the so-called "cones" which with the rods make up the retinal sensitive surface. We apparently see in three colors only, the intermediate shades being recognized by the varying degrees in which these three fundamental sensations are affected by any particular wave length of light

In a very faint light though we may see objects, the rods only are assumed to be affected and color vision is substantially absent. This fact is impressed when one tries to distinguish by the eye which is the red end of the spectrum when a faint star is observed in a star spectroscope. No color is seen but merely a faint band of luminosity; and it is quite impossible without other means of testing, as by photography, to distinguish one end of the spectrum from the other. A slightly brighter star may give a faint color effect in the band, and of course the spectrum of a bright star has the characteristic range of colors as in the solar spectrum. Unlike vision, the effect on a photographic plate with low intensities easily distinguishes the red from the violet end of the spectrum of even the faintest light sources, and indeed the sensitive film is capable of depicting objects where the luminous intensity is many thousands of times less than would affect the eye. Exposures of seven to ten or more hours with the largest telescopes are not unusual in recording the faint nebulous masses in the sky, the light effect being cumulative with the time. With the eye the effect is quite different. In the dark the eye gains in sensitiveness, but long gazing in an effort to see a faint object is of little use; though curiously, faint objects such as minute points of feeble light may frequently be seen by averted vision instead of direct vision. Averted vision is made use of when the axis of the eye is directed not directly towards the object to be distinguished, but to a position at one side. This superior sensitiveness of the eye to light just outside of the axis, or *fovea centralis*, is sometimes explained by the "rods," being more numerous there, crowded out of the central area, as it were, by the less sensitive "cones," so necessary to distinguish colors.

The assumed difference of function of the "rods" and "cones," while largely hypothetical, seems to accord with the facts. In brief the way we see colors is explained as follows. Lights of wave lengths from the lowest red up to the green affect the red sensation most intensely below the orange fading upwards and at last ceasing in the green or thereabouts. The green sensation begins to be feebly affected by waves as low as where the orange joins the red, and its intensity reaches a maximum in the green and fades away beyond the blue. The purple sensation has a similar range beginning in the green, perhaps reaching a maximum towards the violet and fading out in the lavender. It must be remembered that we are here dealing with wave lengths of electric waves that affect these three sensations of the nervous organism of the eye, and not with colors or colored light. The light possesses no color in itself, but depends on the visual organ which receives it and the nervous mechanism back of that for the interpretation of color. Different visual organs and different nervous mechanism will result in different interpretations of these wave lengths.

When we see the yellow in a spectrum, at least two sensations, the red and green, are affected simultaneously and to a certain relative degree; and we interpret the combination as yellow, which is a luminous or bright color (near-white) because two sensations are at the same time about equally and rather strongly affected. With orange the red sensation is affected but the green less so. With yellow-green the reverse is true.

Blue is a luminous or bright color for the same reason that yellow is. The green and purple sensations are affected simultaneously and nearly equally. But the purple sensation is on the whole less strong or intense than the others; and blue of the spectrum, though a light color, is not so near-white in luminosity as the yellow.

May we not be permitted to guess that the purple sensation has been the last to be evolved in the race, since it is more feeble than the others and is believed to be more feeble in some of the more primitive races? The modern processes of color photography are based on the ideas of color vision just pointed out.

Measurement of Light and Illumination

If all eyes were alike in sensitiveness both as regards luminosity and color vision, or if all light sources, or surfaces illuminated thereby produced the same relative effect in all eyes, whether the intensity of such effect was equal or not, the problem of measurement of light would be simpler than it is. Evidently, however, we cannot expect a person who is color blind or partly so, say to red, to evaluate light intensities containing red, in comparison with other tints. The sensitiveness of our eyes varies in accordance with conditions. The iris opens or contracts as an automatic diaphragm. The retinal surface in bright light dulls its sensibility automatically, and in feeble light the reverse. This very action, tending to annul too great contrasts, assists us to see into dark corners in the presence of brightly lighted areas. In this respect the eye is far superior to the photographic plate, in which the difficulty is to record any detail in the shadows without extinguishing the high lights by over-exposure. On the other hand the photographic plate can be used directly to measure radiation in terms of its action on the plate—a manifest impossibility with the eye. Hence all our light measurements must be based upon comparing lights or surfaces together, one with the other, as by some form of photometer, it being assumed that the observer's vision, though subject to variation, will be affected alike by both lights compared. Practically this results in sufficiently satisfactory values except where the color contrasts are great. In the latter case resort is to be had to special instruments such as spectro-photometers for comparing intensities of the colors in the spectra of the lights concerned.

If vision or visual power were constant it would be possible to find what proportion of the radiation energy was utilized in producing the light or luminous flux as it has been called. It is indeed hoped that some basis for such a determination may be found. For practical purposes, however, it suffices to establish a suitable unit of intensity of light to which other sources may be compared. The unit which has been adopted in many countries is the "international candle," a standard which has been established by the U. S. Bureau of Standards working in conjunction with similar bodies in other countries. Hence candle-power now means the rating of a light source in "international candles."

The luminous rays emitted by a distant star reach us as parallel rays, and the rays from the sun, on account of its great distance, are substantially parallel. But manifestly the density of the light flux is with the sun enormously greater than in the case of the star. We might find the relative values of these fluxes falling upon a unit of surface normal to its direction, and obtain a figure for the star in terms of the solar light flux or for the sun in terms of the star's flux density. The figures would give us the relative intensities of the light sources. But for practical purposes we cannot avail ourselves of parallel rays as in the case noted.

Our ordinary sources of light being nearby, give out diverging light, generally in all directions. If the source be a luminous point the density will, for a given surface across the path, diminish as the inverse square of the distance from the point emitting light, but the flux for any given solid angle will remain the same. Hence we may establish a unit of luminous flux by assuming a unit solid angle filled with light from a point equal to one standard candle as our basis of comparison. The unit solid angle is the solid radian or steradian, and the unit of light flux so taken is the "lumen." The total light emission of a point equal to one candle, considering the radiation equal in all directions from it, is then equal to 4π lumens, as the surface of a sphere covers 4π steradians.

Since the practical value of a light source is for illumination, it is useful to possess a measure of the illumination of a surface, such as the light flux which reaches it for each unit of its area. The natural c.g.s. unit would be one lumen per square centimeter. A practical unit of illumination is one lumen per square meter, called the lux. If the square foot be taken it becomes a foot-candle, or an illumination of one lumen per square foot.

In the excellent report of the Committee on Nomenclature and Standards of the Illuminating Engineering Society given at the Niagara Falls convention, September 16-19, a number of proposed definitions, including the quantities and ratios just mentioned are given, and reference is here made to such report for many additional matters connected with this subject of light measurement and for typical formulae concerning them. *Specific luminous intensity* of any element of a luminous or illuminated surface is taken as the ratio of the luminous intensity of such element in a normal direction to it, to the area of the element in centimeters. It is expressed in candles per square centimeter. The *brightness* or *apparent specific intensity* of any such element of a surface taken from a given position, as in a direction of sight at an angle to the surface, or even normal to it, is its luminous intensity per unit of area of the surface considered as projected on a plane at right angles to the line of sight. The surface included must be small in comparison with the distance of the observer. The greater the obliquity of the surface to the line of sight the smaller will be its projection or apparent surface in the imaginary plane perpendicular to the line of sight. The brightness is measured in candles per square centimeter of the apparent area or surface in the said imaginary plane. The brightness varies inversely with the cosine of the angle of the line of sight from the normal, with such surfaces as those for which the cosine law of emission is found to hold true. When the luminous emission of a surface is expressed in lumens per square centimeter it is designated in the proposals of the report as the *specific luminous radiation.*

It has been usual to express the reflecting power of a mirror surface in percentage of light returned to that incident on the reflecting surface. The number expressing this percentage as ratio is designated the *co-efficient of specular reflection.* In like manner the *co-efficient of diffuse reflection,* or *diffusion co-efficient,* of a surface is the proportion of the incident light which is returned from it by diffusion.

It may be mentioned that finely ground surfaces, as of glass, for normal incidence of rays will diffusely reflect, while as the angle of incidence is increased or is made more oblique to the surface the reflection becomes more and more specular or mirror like, until at grazing incidences very little light is diffused. Moreover, as the specular reflection begins to develop during this change of incident angle, it is the red rays which are most affected, the higher rays continuing to be diffused.

In the report of the committee to which attention is directed, the distinctions between the various practical embodiments of standards of light for use in measurement are succinctly given, such as fundamental luminous standard, primary and secondary luminous standards, reference standard, working standard, comparison lamp, test lamp, etc. The terms are well chosen and of course some are already in use.

There is no need to consider here such terms as mean horizontal candle-power, mean spherical candle-power, mean hemispherical candle-power, which are widely used and understood. *Mean zonal candle-power* is not so common, but is evidently applicable to certain cases of zonal distribution of light emission.

The *spherical reduction factor* of a lamp is given as the ratio of the mean spherical to the mean horizontal candle-power of the lamp. It is particularly important in the rating of incandescent lamps in which the disposition of the filament sections control the direction of emission. An ordinary candle flame approaches the case of a uniformly radiating source, while a single vertical cylindrical filament would give a mean horizontal candle-power requiring to be multiplied by the factor $\frac{\pi}{4}$ to obtain the mean spherical power, assuming the cosine law of emission to hold as before referred to.

It will be seen from the above, that if the recommendations of the committee be adopted internationally a great advance will be made in placing light measurement upon a secure and scientific basis. It is indeed singular that this work should have been so long delayed in view of the age of the art of artificial illumination.

THE LIGHTING OF THE BOSTON ELECTRICAL SHOW

By Dr. Louis Bell

Boston, Mass.

By the time this article appears the great Boston Electrical Show of 1912 will be nearing its end. The exhibition has attained a nation-wide importance by virtue of the magnificent scale upon which it has been laid out, the completeness of its exhibits, and the thoroughness of its publicity. Dr. Bell, the consulting engineer in charge of the lighting plans, interior and exterior, was up against a very stiff proposition when he endeavored to frame a suitable scheme for the spectacular illumination of the building, on a commensurately grand scale, and to fulfill its prime function of attracting vast crowds to the hall. In this article Dr. Bell indicates the nature of some of the difficulties and how they were successfully overcome. The scheme finally adopted was on a scale quite beyond anything hitherto attempted in an enterprise of this sort, and presented some novel and delightful effects.—Editor.

Exposition lighting is a stunt quite by itself in the art of illumination, since many things have to be considered beside the actual light delivered for useful purposes, and particularly because all the effects produced have to be planned in relation to the architectural and artistic features of the show. The Mechanics Building, in which the Boston Electric Show has been held, is in some respects about the most unpromising subject for decorative lighting which could well be imagined. It is raw and barn-like inside, defaced by a multitude of girders and a tangle of piping, crudely piped for gas with uncompromising ugly fixtures, which the owners of the building absolutely refuse to move, take down, or modify in any manner whatsoever. In addition the owners regard the outside of the building, ugly enough at best, as sacrosanct, so that no spike or nail should be driven into its holy brick work, even for the purpose of removing some of its pristine bad looks. The front of the building is providentially partly concealed by a heavy growth of ivy, which however renders the support of decorative lighting without injury to the foliage a still more troublesome matter. The most glaring interior failings of the building were remedied by a lavish expenditure for decoration, but no practical amount of decorating could entirely remove the structural inconveniences.

The main scheme of decoration carried out was the outlining of the entire façade, 600 feet long, running from near Irvington Street to West Newton Street; together with the ornamentation of the entrances and the chief architectural features by means of close-wrought mosaics worked out in colored lamps. The free use of color for decorative purposes has been the keynote of the design from the very beginning. The western entrance, as will be seen from Fig. 6, night photograph, was elaborately decorated, the chief feature being the mosaics worked into spandrels and pediment. These were conventionalized flower patterns carried out in dark and light green, dark and light red, and amber lamps, the dark being 8 c-p. and the light 4 c-p., placed as closely as the sockets could be arranged. The support of these heavy pieces without a free hand in spiking was an extremely difficult matter, but finally a sufficient number of attachment points were granted to make it possible to carry out the plan. The broad spaces, 5 by 10 feet, at the sides of the main door, were converted into fluted pilasters, worked out in light and carried by false work reaching to the ground and forming a suitable base. These pilasters had capitals in color supporting a frieze studded with lamps above which rose the decorations of the arch. The outlining of the windows was very ingeniously accomplished by the contractor by springing into the window space the necessary strips bearing the lamp sockets. The small gables in the roof were also decorated in red and green mosaic work. The central entrance of the building, never an important one, was ornamented in similar manner, as shown in Fig. 7, while the tower, Fig. 8, was outlined, decorated with lines and patterns in color, and provided with a flasher for the roof decorations. Approximately 24,300 lamps were installed on the front of the building. The shape of Mechanics Building is triangular, the tower being at the apex, so that the long rear and a comparatively short end on West Newton Street remained to be lighted. Here the work was carried out wholly with festooned Elblight cable. About two miles of Elblight double conductor was used for this work with lamps placed one foot apart, the crossings of the festoons being marked with knots of colored lamps.

Within the building, except in Grand Hall, a general scheme of decoration was adopted, consisting of reticulations of Elblight, suiting as closely as might be the architectural spaces available. At the center of each crossing of the Elblight, at the middle of each bay, the cable was pinned to the ceiling, as it were, by a Holophane globe containing a 250- or a 400-watt Mazda lamp.

In the light-well, over what was utilized during the Show as the automobile park, a six foot ring wound with Elblight cable was carried at the level of the roof girders, and from this twenty-four streamers of Elblight curved downwards to the balcony rail. These streamers were alternately studded with red and green lamps, and on each side of the light-well further illumination was furnished by a Holophane light globe containing a 400-watt Mazda lamp. In Grand Hall reticulations of Elblight covered the whole space under the balcony, the cables being pinned together at each crossing by a group of white lamps, while the cables themselves were alternately red and green. The main body of the hall was lighted entirely with lanterns. Ten of these, borne on two rows of pillars along the center of the hall, finished in bronze and glazed with a prismatic glass frosted inside and out, carried each a 500-watt frosted Mazda lamp placed just above the center of the lantern. Around the face of the balcony were looped electrically-lighted flowers; and borne on brackets there were fifty lanterns finished in bronze and glazed with prismatic glass, carrying alternately a very light red and a very light green, 250-watt Mazda lamp.

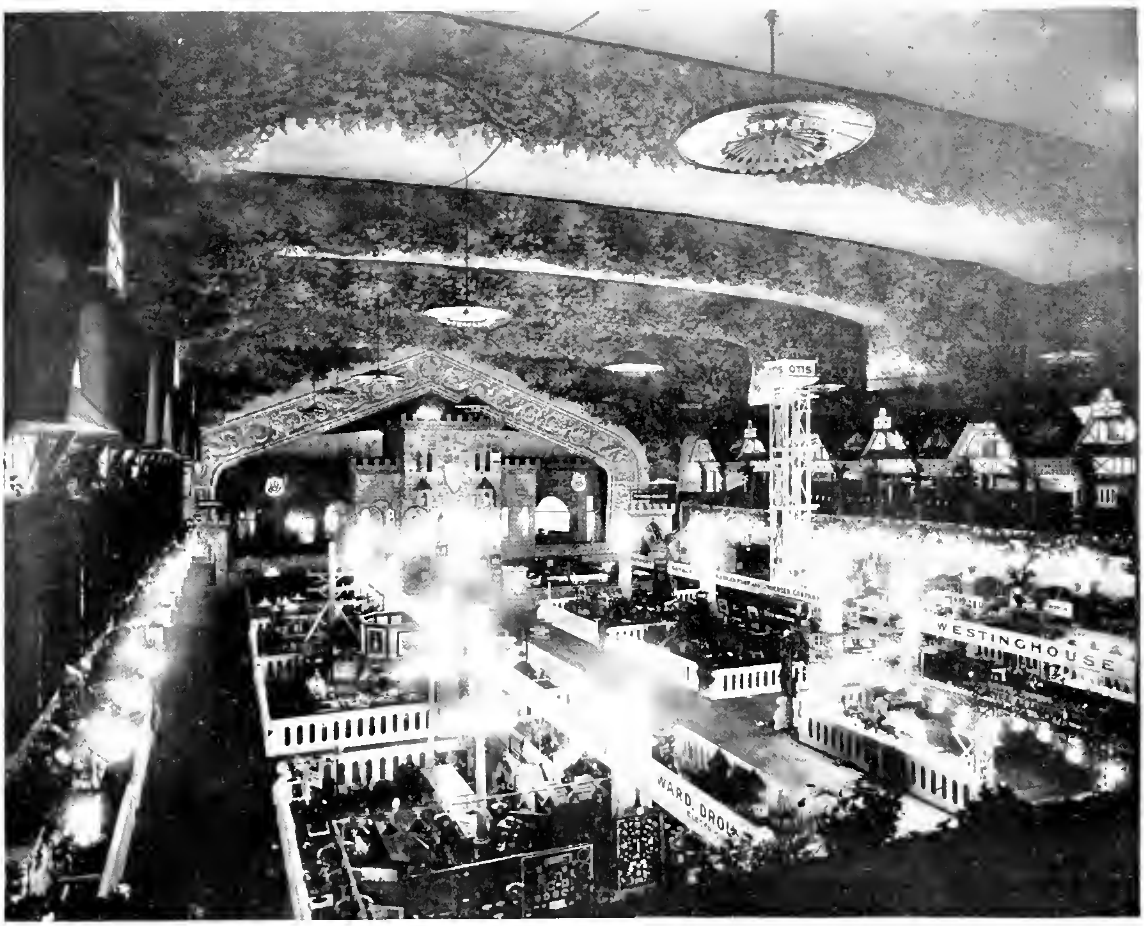


Fig. 1. Partial Interior View of Boston Electrical Show, Mechanics Building, Huntington Avenue

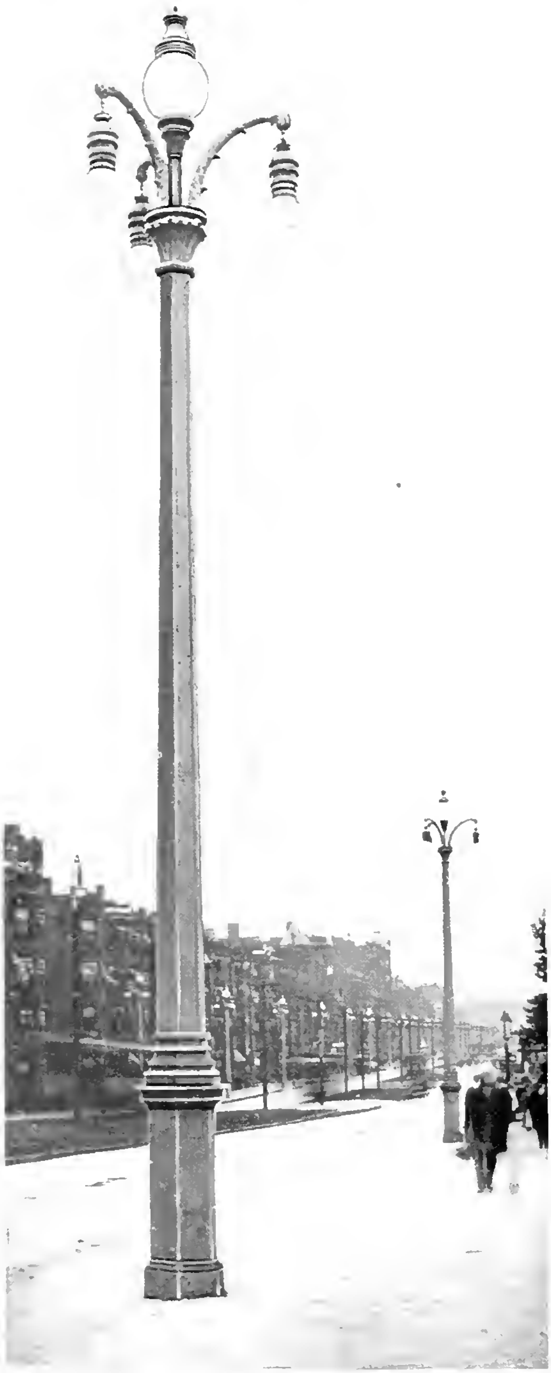
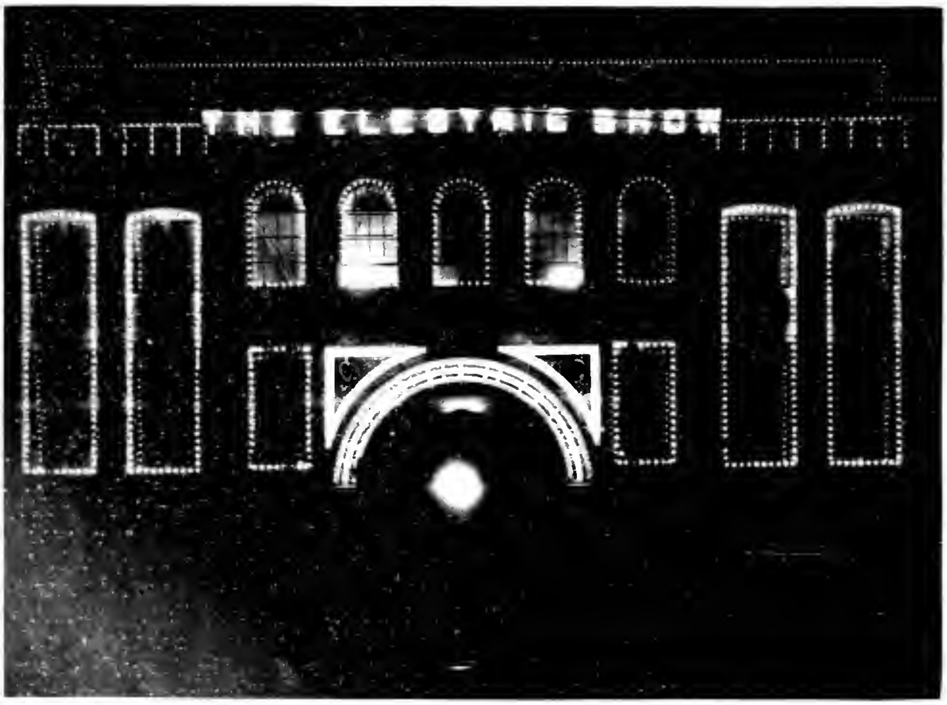


Fig. 2. One of the Poles Used for the Spectacular Illumination of Huntington Avenue, Carrying Four Colored Flame Arcs, the Upper One Pale Green, the Lower Three Light Rose Pink

Fig. 3. One of the Special Pylons Erected at the Ends of Huntington Avenue, 35 Feet High to the Upper Arc. Each Pylon Carries Thirteen Flame Arcs Colored Green and Pink

Figs. 4 and 5. Day and Night Views of Huntington Avenue During Boston Electrical Show. The Special Pylons of Gothic Design can be Seen in the Foreground, with the Standard Four Lamp Poles Trailing into the Distance



Figs. 6 and 7. The Upper View Shows the Illumination of the Main Entrance. The Lower Picture Shows the Illumination of the Center Entrance to Mechanics' Building

Figs. 8 and 9 The Upper Picture Shows the Scheme Followed in the Illumination of the Tower Entrance to Mechanics Building, in which Clear Lamps were Mainly Used, Enriched by the Use of Red, Green and Amber Lamps The Lower Picture is Another Night View of Huntington Avenue, Showing the Main and Center Entrance, with the Tower in the Distance

All the colored lamps used here and elsewhere, with the exception of a few of the Elblight lamps, were dipped lamps, those on the outside receiving a coat of spar varnish outside the color. It should here be remarked that dipping lamps to the right color is a very troublesome matter and it was particularly a difficult task to get a good green, most of the commercial green dips proving bluish in color rather than pure green.

Beside the lighting already referred to, the balcony, which was finished in booths, made after the semblance of old German tiled roofed houses, was provided with light on its own account by a 60-watt Mazda lamp in a frosted globe installed in the ceiling of each booth, while an additional lamp was put in the attic of each house to shine out through the stained glass window. The space behind the houses in the balcony was illuminated by long lozenges of Elblight pinned up by Nelite fixtures with 100-watt lamps.

The corridor leading to the east entrance and the lobby at the entrance were also decorated with reticulations of Elblight, and further light was secured by Mazda lamps in lanterns like those around the balcony. It should be noted that the fundamental idea in the decoration of Grand Hall was to carry out a night effect, the ceiling being a sky canopy with drops of painted foliage. Hence the hall was not lighted from above, but from below, the main mass of the light being about 14 feet up and turned downwards. From the floor the illumination therefore graded upwards leaving the ceiling fading into comparatively dim light. The Mazda Castle (Fig. 10), which occupied the stage, furnished an attractive addition to the decorations and the general effect in Grand Hall is well shown in Fig. 1 from a night photograph.

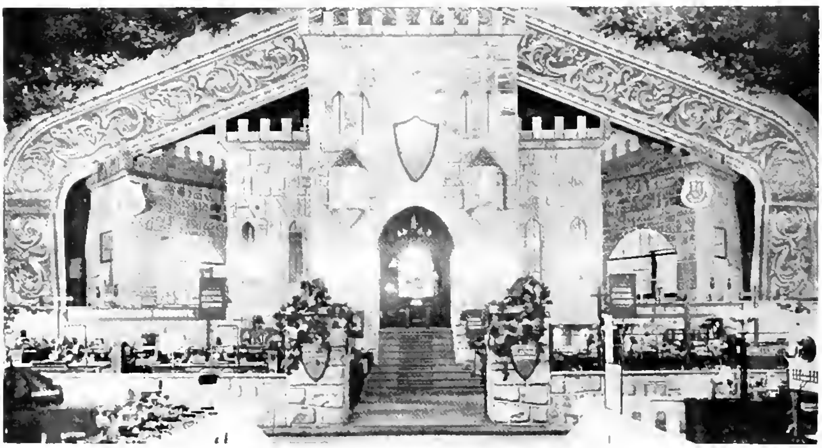


Fig. 10. Nearer View of Mazda Castle Seen at End of Exhibition Hall in Fig. 1

The exterior lighting extended along Huntington Avenue from Copley Square to Massachusetts Avenue, a distance of about 3000 feet. After successive study of a number of plans for this decorative work it was finally decided to use deliberately colored flame arcs, color being obtained by the composition of the carbons and not by any color in the globes, since the latter plan would inevitably lose most of the light. Special poles carrying each a group of four flaming arcs were therefore installed 125 feet apart on each side of Huntington Avenue, the poles on the two sides of the street being opposite each other. One of these poles is shown in Fig. 2. The upper lamp, in an 18-inch opal globe, is a flame lamp carrying carbons that burn a pale green; the three lower lamps, with 12-inch globes, were fitted with carbons burning light rose pink, presenting a very effective contrast. These lamps were an adaptation by the Lynn works of one of their intensified arcs, a plan adopted to secure a lamp of minimum length. Eight hours nightly was all the burning time that was required for the decorative work on Huntington Avenue, and this length of life could be secured with short carbons.

There was no objection to trimming the lamps every day if thereby a better effect could be obtained. The lamps were adjusted for six amperes and burned in multiple circuit. The standard poles were 30 feet to the upper arc and were of Gothic design painted *verde antique* in color.

At the two ends of Huntington Avenue, the entrance was marked by a pair of pylons 35 feet high to the upper arc, also of Gothic design and each carrying thirteen flame arcs, the uppermost lamp and the middle tier being green, and the others pink. One of these pylons is shown in Fig. 3. The effect of these colored lights blazing the whole length of the avenue and leading from either direction to the Mechanics Building as the center of interest was very striking, and the Copley Square entrance is excellently shown in Fig. 10, by a view taken at night. This is probably the first instance of using deliberately colored flame carbons as an element in decoration, and the result was so good as to encourage further efforts in this direction.

Two hundred twelve of these flame arcs were in use on Huntington Avenue. In efficiency they fell considerably below the yellow or white flames, as might be expected, but still compared favorably with the efficiency of the familiar carbon arcs and were immensely better and more brilliant in effect than anything which could have been devised in the way of an arc with a colored globe. Nearly seven miles of Elblight double conductors were used in the decorative work outside and inside, with the uniform spacing of lamps at one foot. Adding to this lighting material the lamps on the front of the building spaced at 8 inches, except in the mosaics, and the lights installed in the interior in other ways, one reaches a total of about 60,000 incandescent lamps in use, aggregating in c-p. somewhere about 300,000. Bearing in mind the fact that this estimate does not include the light of more than 200 arcs, it is safe to say that the illumination of the Boston Electric Show was on a scale quite beyond anything hitherto attempted in an enterprise of this sort, and it certainly presented some novel and beautiful effects.

OPERATION OF SYNCHRONOUS MACHINES IN PARALLEL

Part II

By Lee Hagood

Lighting Department, General Electric Company

This section of Mr. Hagood's paper takes up the problem of accomplishing both power-factor correction and automatic voltage control by means of synchronous machines, and shows the relations which exist between voltage and current as affected by the line factors and load factors in the electrical transmission of power. He takes up in detail the important question of what occurs when voltage is held constant at both the generating and receiving end of a transmission line, and his method of solving the problem is simple and easily applied. This is the first time to our knowledge that this method of analyzing the problem has been presented.—Editor.

Transmission of Power

In the transmission of power, wattless current is a matter of particular importance where the resistances and reactances involved are of any magnitude. Short transmission lines of 60 miles and below and of moderate voltages will first be considered, where the negative exciting current of the line is so small that it may be neglected. To further simplify the problem the exciting current required by the transformers in the line will also be disregarded. By studying out the problem in its simpler form, a solution can be obtained sufficiently accurate for most practical purposes.

Fig. 7 is a vector diagram showing the relation of the voltages and currents in a transmission line, where a certain amount of power is being delivered, it being assumed that the current and voltages are measured at the end of the line. The actual current, I, is out of phase with the receiver voltage by the angle θ, whose cosine is the power-factor: it causes a drop through the resistance, R, in phase with it; that is, IR must be parallel to I; and also causes a voltage through the reactance 90 deg. out of phase in the direction indicated, that is, IX is at right angles to IR, as shown. The vector E_g therefore represents the required voltage at the generator end of the line.

In Fig. 7,

$$V = AB + BC + CD$$

$$AB = IR \cos\theta = (I\cos\theta)R = I_e R$$

$$BC = IX \sin\theta = (I\sin\theta)X = I_w X$$

$$CD = \text{versine}\,\alpha\, E_g = (1-\cos\alpha)E_g.$$

$$(1)\quad \therefore V = I_e R + I_w X + (1-\cos\alpha)E_g.$$

Since $\cos\alpha$ will not likely exceed 0.98 for most transmission line problems, the last quantity in the above equation may be neglected, which introduces an error in voltage calculation in the magnitude of 2 per cent of the generator voltage and is too small for consideration. By dropping out this quantity, we have the following very useful practical formulas:

$$(2)\quad V = I_e R + I_w X$$

$$(3)\quad \text{Therefore}\quad I_w = \frac{V - I_e R}{X}$$

If V exceeds I_eR, I_w is positive, or lagging, and if V is less than I_eR, I_w is negative, or leading.

(4) $V = I_eR + I_e \tan\theta\, X = I_e\,(R + \tan\theta\, X)$

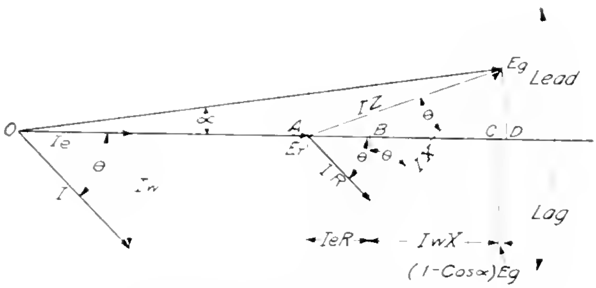


Fig. 7. Vector Diagram of a Transmission Line Illustrating the Relation Between Generator and Receiving Voltage for Different Loads and Power-factors

I = actual current.
I_e = energy component.
I_w = wattless component, positive if lagging and negative if leading.
$\cos\theta$ = power-factor of load at receiving end.
$\cos(\theta - \alpha)$ = power-factor of load at generating end.
α = angle between E_r and E_g.
E_r = receiving voltage.
E_g = generating voltage.
V = $E_g - E_r$ = the voltage difference in transmission.
X = Total three-phase reactance in transformers and transmission line.
R = Total three-phase resistance in transformers and transmission line.
Z = Total three-phase impedance in transformers and transmission line.
$\phi = \tan^{-1}\frac{R}{X}$

where $\tan\theta = \sqrt{\frac{1-\cos^2\theta}{\cos^2\theta}} = \sqrt{\frac{1-(\text{P-F.})^2}{(\text{P-F.})^2}}$

If W = power delivered (three-phase)
$W = 1.73\, I E_r \cos\theta =$
$1.73\,(I\cos\theta)\,E_r = 1.73\, I_e E_r$

(5) Therefore $I_e = \frac{W}{1.73\, E_r}$

Substituting in (4)

(6) $V = \frac{W}{1.73\, E_r}\left(R + X\sqrt{\frac{1-(\text{P-F.})^2}{(\text{P-F.})^2}}\right)$

From Fig. 7,

(7) $I = \sqrt{I_e^2 + I_w^2}$

The energy losses, (three-phase) = $1.73\, I^2R = 1.73\left(\frac{I_e}{\cos\theta}\right)^2 R = 1.73\frac{I_e^2R}{(\text{P-F.})^2}$

(8) Per cent energy losses $= \frac{1.73\, I_e^2R}{W(\text{P-F.})^2} \times 100 = \frac{\%\ \text{Losses at 1.00 P-F.}}{(\text{P-F.})^2}$

For convenience losses will be expressed in per cent of power received and voltage difference in per cent of voltage received. If the equivalent high tension voltage is lower at the receiving end than at the generating end it will be designated as "drop" and if higher as "rise."

It is evident that if we assume the receiving voltage and the energy transmitted to be constant, the generator voltage will vary with the power-factor. Since I_eR is constant, LL' represents (see Fig. 8) the locus of the terminals of the vectors IR.

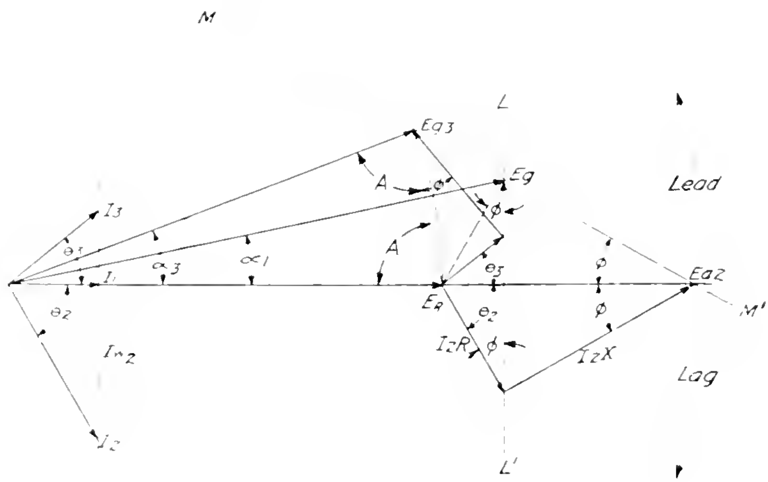


Fig. 8. Vector Diagram Showing Effect of Wattless Current on Generator Voltage if a Given Amount of Energy is Delivered at Constant Speed

When E_g takes the position E_{g2}, we have located one point in the line MM', and, since ϕ is known, we have determined its position.

By inspection of the graphical relations in the figure, it will be seen that all the terminals of the vectors for the generator voltage, E_g, for different wattless currents, fall in this line.

From Figs. 7 and 8, the following will appear, viz.:

$$tan\ \phi = \frac{IR}{IX} = \frac{R}{X}$$

$$versine\ \alpha = (1 - cos\ \alpha)E_g$$

When θ (lagging) $= 90° - \phi$, $\alpha = 0$

and $E_g = E_r + RI\ cos\ (90° - \phi) + XI\ cos\ \phi$.

In Fig. 8 this value of E_g is represented by E_{g2}.

When θ (leading) $= \phi + \frac{1}{2}\alpha$, $E_g = E_r$.

In Fig. 8 this value of E_g is represented by E_{g3}. This value of θ is derived by solving the following simultaneous equations, viz.:

$$180\ \text{deg.} = \alpha + 2A$$

$$190\ \text{deg.} = A + (90° - \phi) + \theta.$$

Since the magnitude of α is so small as compared with ϕ, it may be dropped for the purposes of this problem, hence:

$$\theta = \phi;$$

that is, when θ (leading) $= \phi_1$, $E_g = E_r$.

Therefore if the voltage of the receiving end is maintained the same as at the generating end, the power-factor, $cos\ \theta$, at the receiving end will* remain equal to $cos\ \phi$. Since the latter is a constant, the power-factor will be constant, which means that if the voltage at the receiving end is constant, that of the generating end will be constant, and, furthermore, since the energy delivered does not enter, this relation will maintain independent of variations in load. This is an important principle, which may be applied practically to great advantage as will be shown later.

Lines Paralleling Synchronous Machines

Thus it is seen that for delivering a certain amount of power over a given transmission line, the voltage difference between the generating and receiving station depends upon the wattless current. Now if a synchronous machine of suitable capacity is located at the load end of the line, as is shown in Fig. 9, the wattless current in the line is a matter of relative field excitations of the machines in the two stations. For example, we could raise the field excitation of the machine near the load until it carried part or all of the load's wattless current. In the latter case the power-factor at the receiving end of the line would be unity. By raising the field excitation still further the power-factor would lead, in which case not only would the machine carry the load's wattless current, but it would supply leading wattless current to excite the machine at the other end of the line. After each increase of excitation of the synchronous machine at the load end, assuming the field

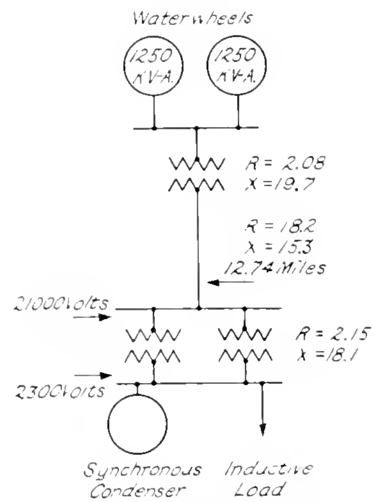


Fig. 9. One Line Diagram of a System Where Two Stations are in Parallel Connected Together by a Transmission Line

Total equivalent high tension reactance = 24.4 ohms.
Total equivalent high tension resistance = 53.1 ohms.
$Tan\ \phi = 0.42$. $Cos\ \phi = 0.92$.

current constant for the generators, the voltage will increase at both ends of the line. At the generating end the decrease in wattless lagging current would cause a voltage rise, not only due to its effect on the inherent reactance of the generators, but also to the change in the armature reaction tending to increase the total flux cut by the conductors. The voltage difference between the generating and receiving end of the line would decrease, due to the fact that the wattless lagging current flowing over the line reactance would be decreased. If the wattless current were made to lead to any extent, the voltage at the load end would exceed that at the generating end.

We have dealt with a simple case where one station is used to effect power-factor correction. If there were several stations containing synchronous machines, those used to supply corrective wattless current should be nearest the inductive loads, and the improvement in power-factor would occur in all the circuits having synchronous machines, except those effecting the correction.

*The accuracy of this assumption is discussed under "Accuracy of Method" on page 691.

Automatic Voltage Control

Power-factor and voltage have a very close relation. For the present the only voltage control which will be considered is that resulting from controlling the field excitation of a synchronous machine by means of an automatic voltage regulator. When there are several units in one station, it is assumed that they operate from a common exciter bus.

In any given station such a regulator equipment can be adjusted so that the excitation of each individual machine is such that all machines operate at approximately the same power-factor, that is, the station kv-a. required by the load is a minimum. This adjustment is made with the equalizing rheostats. In applying voltage regulators to two different stations in parallel, the voltage which may be maintained at each depends upon the resistance and reactance in the connecting lines, the load and its power-factor, and the size, etc., of the synchronous machines involved. The relations existing in a line connecting two points at which the voltage is regulated is best understood by examining a concrete case.

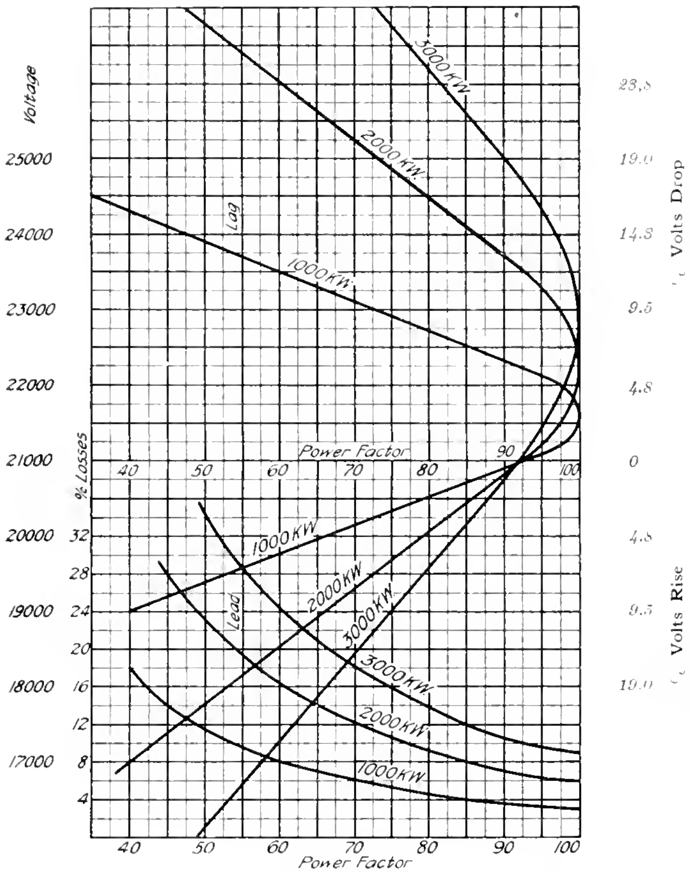


Fig. 10. The Above Curves Illustrate the Effect of Power-factor on the Generating Voltage at Different Loads for an Equivalent High Tension Receiving Voltage of 21,000 Volts. In the Lower Part of the Figure, Power-factor is Plotted Against the Per Cent of Energy Losses. Fig. 9 is the System for Which These Values Obtain

In Fig. 9, we have a one line diagram showing a generating station and a synchronous machine located near the load. A synchronous condenser is used for illustration as a matter of convenience, since the current it takes is wattless except for the very small amount of energy current required to supply its losses, and in such calculations as this, this energy current may be neglected. Should a synchronous motor or generator be used, these machines should be able to supply an equivalent amount of corrective wattless current and yet carry their energy loads. A voltage regulator on either a synchronous generator or synchronous motor operates when a tendency to change in voltage occurs; it can effect a voltage regulation within 2 per cent. In Fig. 9, the regulator may be adjusted on the synchronous condenser to maintain a voltage equal to, higher or lower than that of the generator. For whatever voltage setting a regulator may be adjusted, on either a synchronous motor or generator, it will tend to increase the field excitation of its machines when the voltage tends to drop and cause a decrease when the voltage tends to rise.

In Fig. 10, the effect of power-factor on voltage is illustrated for different loads. Fig. 9 represents the transmission line for which these values obtain. It is part of a system now in operation. Equation 6 justifies these curves, since, if the power delivered, receiving voltage, resistance and reactance are all constant, the voltage difference varies only with the power-factor. It should be noted that the power-factor is constant for all loads when it is approximately 0.92 leading P.F. This is the condition of θ being equal to ϕ, the voltage difference being zero. The curves showing losses are plotted from equation 8. The resistances and reactances given are three-phase values, that is, the actual values are multiplied by 1.73. The low tension resistances and reactances are reduced to their high tension equivalents. For example, to obtain the high tension equivalent resistance of a transformer, the low tension value is multiplied by the square of the transformer ratio and then added to the high tension value. The receiving voltage, in its high tension equivalent, is assumed constant at 21,000 volts.

Figs. 11, 12, 13 and 14 show the relation of power-factor, line current, line wattless current and synchronous condenser current, to the load for constant voltage drops 18.8, 8.8, 1.2 and 0 per cent respectively, from no load to full load; the constant voltage drop being accomplished by supplying automatic voltage regulators on both the generators and on the synchronous condenser. Figs. 15, 16 and 17 show a similar set of curves except for a different transmission line, the voltage drops being 10, 3.5 and 0 per cent respectively. For comparison two values of power-factor have been assumed for the load, one 0.80 and the other 0.60, this giving two sets of current values for the synchronous condensers. These curves are constructed as follows:

The curve designated "line amps. energy" is the energy component of the actual current. In other words, it is the current which would maintain if the kilowatt energy were received at unity power-factor. It is derived from equation 5, viz.:

$$I_e = \frac{W}{1.73\,E_R}.$$

This is evidently a straight line passing through the origin.

The curve designated "line amps. wattless" is the wattless current which must be maintained in the line at different loads to accomplish the required voltage control by means of the synchronous condenser. It is obtained from formula 3:

$$I_w = \frac{V - I_e R}{X}$$

Since V, R and X are all constants, I_w is therefore a straight line when plotted against the other variable I_e, or its equivalent, the kilowatts, since the voltage is constant. If V exceeds $I_e R$, I_w is positive or lagging, and, if V is less than $I_e R$, I_w is negative or leading. The slope of this line depends upon the relation of the resistance to the reactance. At zero load it is equal to the line current, and its value varies directly with the voltage drop and inversely with the reactance.

The curve "line amps." is obtained from formula 7:

$$I = \sqrt{I^2_e + I^2_w}.$$

and represents the current that an ammeter would indicate located in the transmission line. Since energy losses, due to resistance, vary with I^2, it is important to note the condition of its average minimum value from no load to full load. This would occur near the point where the voltage drop is zero. For practical requirements, it may be assumed to occur at this value. When we have the condition of zero voltage drop, I_e and I_w intersect at the origin, and, since their ratio will then be constant from no load to full load, the power-factor will also be constant through this range.

The curve "line power-factor" may be obtained from the relation of I_e to I, or I_w to I_e.

The curve marked "load amps. wattless" is a straight line passing through the origin, if it is assumed that the inductive load has constant power-factor from no load to full load. Its values are expressed by the following equations:

$$I_{W_L} = I_e \tan\,\theta_I = I_L \sin\,\theta_L = \sqrt{I^2_L - I^2_e},$$

where I_{W_L} is the wattless current of the inductive load. I_L is the actual current, and θ_L is the angle whose cosine is the power-factor.

The curve marked "syn. con. amps." gives the values of the corrective wattless current which must be supplied automatically by the synchronous machine on the assumption that the power-factor of the load is constant. Let I_s represent the synchronous condenser current; then $I_s = I_{WL} - I_W$.

I_W being the wattless current required in the transmission circuit for the required voltage control. In the curves, the values of the synchronous condenser current at different loads are plotted on the assumption that the inductive loads are constant in power-factor at all loads. Such does not obtain in practice, though with some mill loads the power-factor at the same corresponding periods from day to day is substantially equal. By using two values of assumed power-factor for the load, such as 0.60 and 0.80, we obtained the limits at which a synchronous condenser would likely operate. In general, the power-factor will always be found better on the heavier loads than on the lighter loads.

Minimum Corrective Wattless Current for Effecting Voltage Control

A practical problem arises as to what is the minimum size of synchronous condenser (or corrective wattless current), under control by a voltage regulator that will accomplish approximately constant receiving voltage from no load to full load for a given transmission line, such as is illustrated in Fig. 9, assuming approximately constant voltage at the generating end of the line. In this case the synchronous condenser amperes would be symmetrical about an axis vertical to the load ordinate and passing through half wattless. To simplify the problem it is assumed that the load's power-factor is constant from no load to full load. Let I'_{WL} be the full load wattless current and I'_e the full load energy current, substituting in formula 8 half of their values to obtain the quantities at half load, we have:

$$(9) \quad V = \frac{I'_{WL}X + I'_e R}{2}$$

We can therefore obtain V, the voltage drop, if we know the full load and its power-factor and have given the resistance and reactance. To obtain the full load synchronous condenser current $I's$, we have:

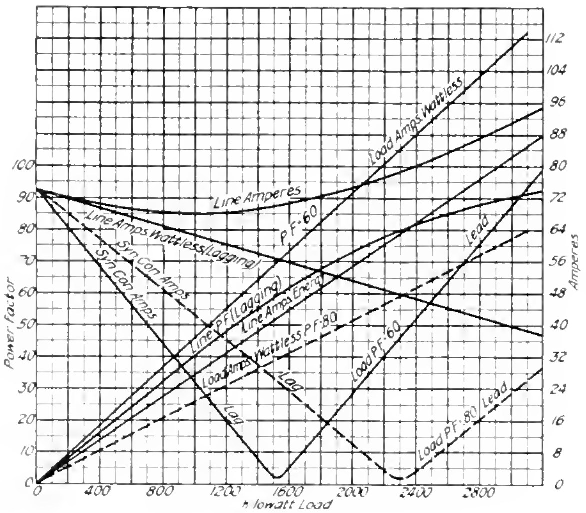


Fig. 11

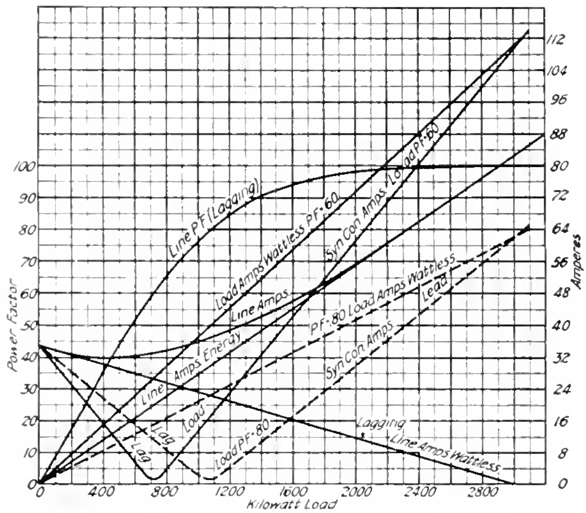


Fig. 12

The curves illustrate the relation of the kilowatt load to the line current, power-factor, and line wattless current, when the voltage drop is maintained constant. Two conditions of load are assumed, one at 0.60 p-f. and the other at 0.80 p-f., and the two corresponding curves of wattless current are given, these being designated "syn. con. amps."

Voltage drop = 18.8 per cent.
$R = 22.4$, $X = 53.1$, and $Cos\ \phi = 0.92$.
At 3000 kw. p-f. = 1.00.

Voltage drop = 8.8 per cent.
$R = 22.4$, $X = 53.1$, and $Cos\ \phi = 0.92$.
At 3000 kw. p-f. = 0.90 (Lag.)

load if the load's power-factor were constant. Fig. 11 illustrates such a condition for a full load of 3000 kw. at 0.60 power-factor, the voltage drop being 18.8 per cent.

At full load, the synchronous condenser's current is numerically equal to its value at no load. At full load it is leading, while at no load it is lagging, and at half load it is neutral. To obtain the current of the synchronous condenser at full load, it is necessary first to find the voltage drop, which is, according to our assumption, constant for all values of the load. At half load the line amperes wattless would equal the load amperes

$$(10) \quad I'_S = \frac{V}{X}$$

This comes about through formula 3, since $I_s = I_w$ at no load. Formula 9 is based on the assumption that the induction load's power-factor at half load is the same as at full load. This assumption is well within the accuracy of the requirements.

Fig. 19 is a graphical solution of the problem in this manner where 2500 kw. at 0.75 power-factor is the full load and is applied at the point marked inductive load. The voltage drop would be 11.5 per cent and the minimum size of the synchronous condenser should be capable of supplying 1700 wattless kv-a. The power-factor at full load would be about 0.96 power-factor lagging.

From an inspection of Figs. 11 to 17 and Fig. 19 and formulas 9 and 10, it will be seen that, for transmitting power at such a voltage drop as would accomplish the use of minimum corrective wattless current, the all-day I^2R losses might be excessive. The larger the ratio of resistance to reactance, the larger will be these losses.

Loaded synchronous motors or generators would be unsatisfactory for supplying corrective wattless current if the voltage setting of their regulators were such as to require minimum wattless kv-a. capacity, since at half load and below, the synchronous motors would operate on lagging power-factor, while the synchronous generators would operate leading; in both cases the weak fields might endanger their falling out of step.

If a synchronous condenser were used, a special scheme of excitation would have to be applied, since without it, the voltage regulator would not operate over the full range of the synchronous condensers' fields, unless the synchronous condenser is especially designed. To meet this special condition in design, or to supply a special exciter, would involve extra expense, and this extra money could better be applied to securing a larger synchronous condenser.

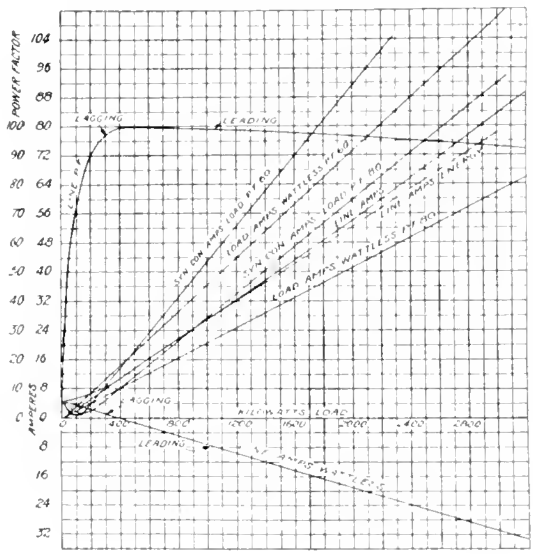


Fig. 13

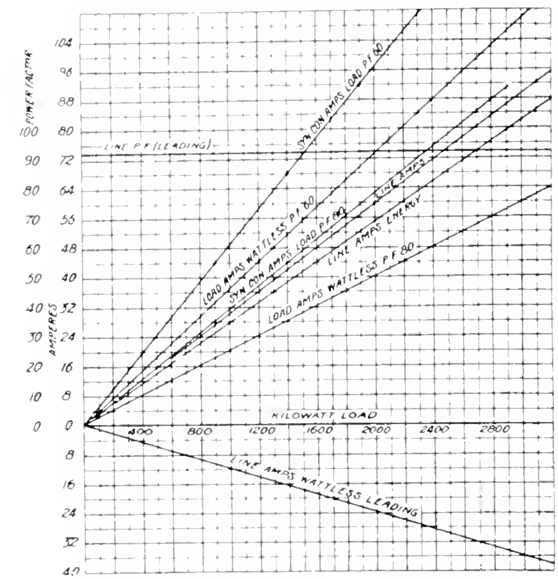


Fig. 14

These curves are similar to those in Figs. 11 and 12. They illustrate that when nearly zero voltage drop is maintained, the line current is approximately equal to its energy component from no load to full load, that is maximum power is delivered at minimum losses requiring minimum kv-a. capacity from the transmission lines, transformers and generators involved

Voltage drop = 1.2 per cent.
$R = 22.4$, $X = 53.1$, and $Cos\ \phi = 0.92$.
At 3000 kw. p-f. = 0.93.

Voltage drop = 0 per cent.
$R = 22.4$, $X = 53.1$, and $Cos\ \phi = 0.92$.
At 3000 kw. p-f. = 0.92 (Lead.)

Wattless Corrective Current for a Given Voltage Difference

The general equation that expresses the corrective wattless, or synchronous condenser current required for voltage regulation is:

$$I_s = I_{wL} - I_w$$

where $I_w = \frac{V - I_e R}{X}$

If V exceeds $I_e R$, I_w is positive, or lagging, and if V is less than $I_e R$, I_w is negative, or leading.

At full load, let I'_s be the synchronous condenser current, I'_{wL} the load's wattless current, I'_w the line wattless and I'_e the energy current, and let V be given voltage drop; then

$$I'_s = I'_{wL} - \frac{V - I'_e R}{X}. \qquad (11)$$

The given value of voltage difference should not be so large that the full load synchronous condenser current as calculated would fall below that which would occur at no load.

As an example, suppose the inductive load is 2500 kw. at 0.75 power-factor, the reactance 53.1 ohms, the resistance 22.4 ohms and the voltage difference 1850 volts (8.8 per cent of 21,000 volts).

At no load $I'_s = \frac{1850}{53.1} = 35$ amperes.

At full load $I'_s = 55.8 - \frac{1850 - 68.8 \times 22.4}{53.1} =$ 53 amperes.

Full load wattless kv-a. = 53×21000×1.73 = 1950 kv-a.

No load wattless kv-a. = 35×21000×1.73 = 1270 kv-a.

Wattless Corrective Current to Maintain Minimum Voltage Difference

If the voltage differences are to be a minimum, that is, zero, then formula 11 becomes:

$$(12) \quad I^1{}_S = I^1{}_{WL} + \frac{I^1{}_e R}{X}$$

Since $V = I_e R + I_w X$ and I_w is negative when $V = O$, we have

$$\frac{I_e}{I_w} = \frac{R}{X}$$

That is, the power-factor will be constant from no load to full load and its value will

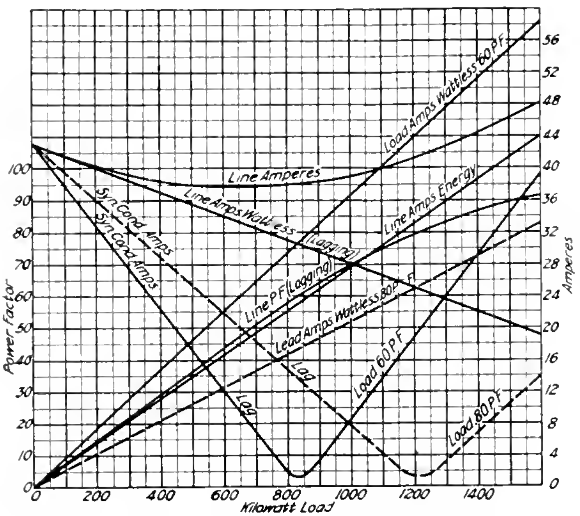


Fig. 15

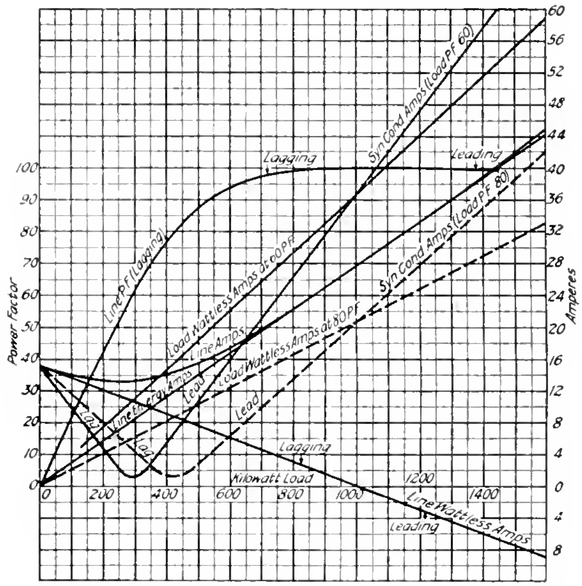


Fig. 16

These curves are similar to Figs. 11 to 14, but since the ratio of the resistance to reactance is greater, more wattless line current is required for the same loads, that is, the "line wattless amps." curve is steeper. The "line amps." and "line p-f." curves therefore assume a different character

Voltage drop = 10 per cent.
R = 26.6, X = 48.7, and $Cos\ \phi$ = 0.86.
At 1000 kw. p-f. = 0.70 (Lag.)

Voltage drop = 3.5 per cent.
R = 26.6, X = 48.7, and $Cos\ \phi$ = 0.86.
At 1000 kw. p-f. = 1.00.

The power-factor at full load would be lagging about 0.98. Fig. 12 illustrates the relation of the line current, line wattless current, and power-factor from no load to full load. If synchronous condensers or motors were used, they would operate leading at full load and lagging at no load. If generators were used, their power-factors would be lagging and leading instead. In using loaded synchronous motors or generators, care should be observed that the field excitation does not become so weak at light loads as to endanger their falling out of step.

depend upon the ratio of the resistance to the reactance. At no load, the wattless current will be zero. This condition is represented by Figs. 14 and 17.

If the load were 2500 kw. at 0.75 power-factor, the resistance 22.4 ohms, the reactance 53.1 ohms, and the voltage drop zero, the wattless current required would be:

At full load, $I_S = 55.8 + \frac{68.8 \times 22.4}{53.1} = 84.8$ lagging.

At no load, $I_S = 0$.

That is, at full load 3000 kv-a. wattless must be supplied, and none at no load. The power-factor would be 0.92 leading at all loads. Fig. 14 illustrates the relation of the line current, line wattless current, and power-factor at all values of the load.

There would be no difficulty in meeting this condition with loaded synchronous motors and generators, since their fields would never be sufficiently weakened to endanger their falling out of step. If generators were used to affect the power-factor correction, their power-factors would be lagging at full load and approximately unity at near no load. This method of operation offers the great advantage that maximum power is transmitted with minimum losses at approximately minimum kv-a. demand on the transformers, transmission line and generators, in the circuit wherein the power-factor is regulated. The convenience in having the voltage equal at the two stations would avoid the necessity of taps on the transformers. On a system having several stations in parallel and several distribution centers, we could locate synchronous condensers of proper size at the distribution centers and set all of their voltage regulators for the same potential. All the generators could then be adjusted by hand for this voltage, and without voltage regulators on the generators their voltages would hold approximately constant from no load to full load, provided the prime movers operate at speed regulations of the customary requirements. In other words, not only would the voltage regulators on the synchronous condensers hold constant voltage at the distribution centers, but the synchronous condensers would supply such exciting current to the generators as would compensate for variations in load, and slight variations in speed.

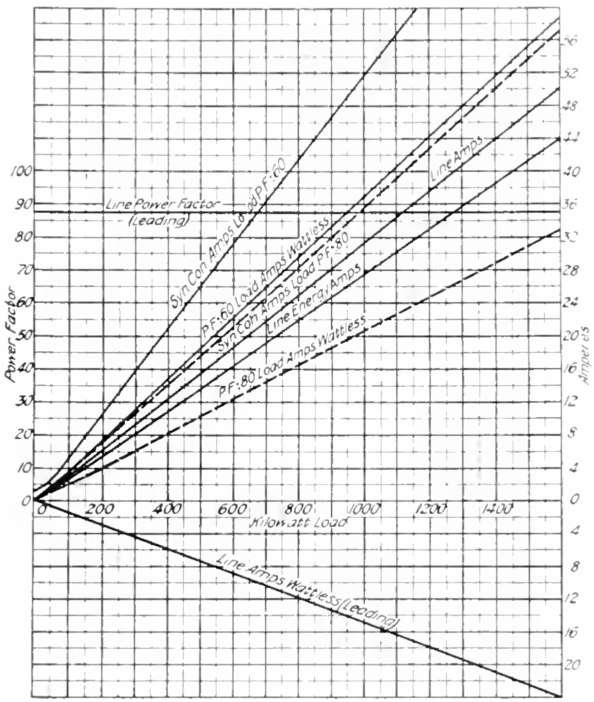


Fig. 17

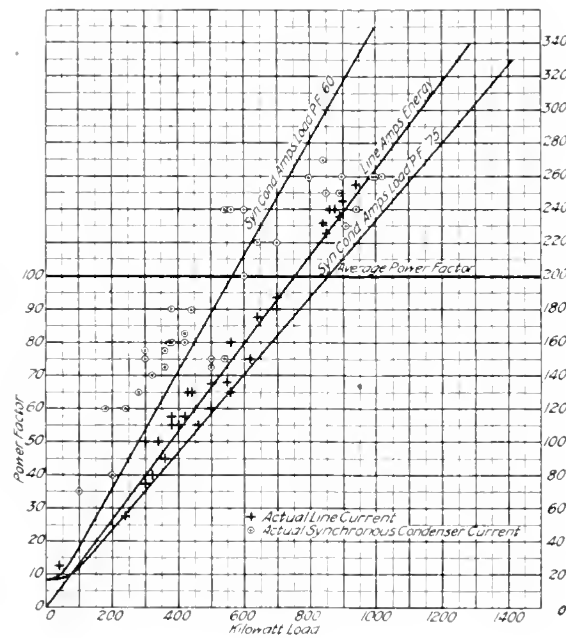


Fig. 18

Fig. 17 represents a theoretical calculation of the condition where zero voltage drop is maintained while Fig. 18 represents an actual case, the readings being taken with station meters and instruments. The constant voltage at the receiving end of the line was accomplished by means of a 1000 kv-a. synchronous condenser, the regulation being within 2 per cent. It is interesting to note that the power-factor maintained constant from no load to full load

Voltage drop = 0 per cent.
$R = 26.6$, $X = 48.7$, and $Cos\ \phi = 0.86$.
At 1000 kw. p-f. = 0.87.

Voltage drop = 0 per cent.
$R = 26.6$, $X = 48.7$, and $Cos\ \phi = 0.86$.
At 1000 kw. p-f. = 1.00.

Accuracy of Method

The above approximate method of calculation is sufficiently accurate for most practical requirements. The exact relation is expressed by equation 1, and for the approximated formula the quantity $(1\text{-}\cos\alpha)\,E_g$ has been dropped. The value of the angle α may be calculated from the following:

$$(13)\quad \tan\alpha = \frac{IR\sin\theta \mp IX\cos\theta}{E_R + IR\cos\theta \pm IX\sin\theta}$$

$$= \frac{I_wR \mp I_eX}{E_R + I_eR \pm I_wX}$$

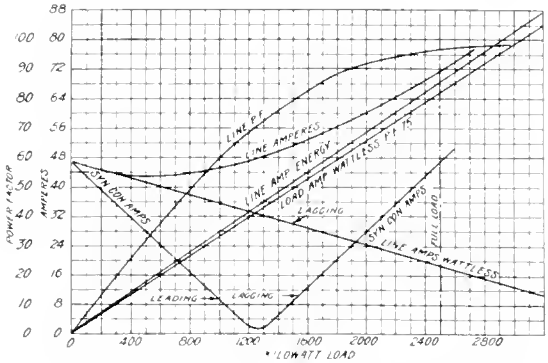


Fig. 19. This Figure Represents the Relation of Load to Line Current, Line Power-Factor and Wattless Line Current When the Voltage Drop is 11.5 Per Cent. This Value of Voltage Drop is that Which Would Occur if the Minimum Size of Synchronous Condenser were Used, when the Full Load was 2500 Kw. at 0.75 p-f., it Being Assumed that the Power-factor is Constant at All Loads

Voltage drop = 11.2 per cent.
$R = 22.4$ and $X = 53.1$.

Plus or minus depends upon whether the power-factor is lagging or leading.

Fig. 20 shows curves of voltage plotted against power-factor, the calculations being accomplished with the quantity $(1\text{-}\cos\ \alpha)$ E_g included, and without it. It is seen that the error is very slight in using the approximate method, except when the power-factor is leading considerably; at which values it would never be desirable to operate. After all, the requirements of the problem do not require any great refinement, and the results which can be obtained are well within the precision of the calculated resistance and reactance and the measurements that can be made with station instruments and meters.

Fig. 21 expresses graphically the actual relation which exists when the receiving voltage is held equal to the generating voltage, using the same constants, etc., as in Fig. 10. The vectors are drawn to scale and represent the full load condition. The value BD, adjusted to the proper scale, will represent the load, since it is actually the value of I_eR. This diagram will become clearer by referring to Fig. 8. It will be remembered that it was claimed that if the voltage E_R and E_G were held constant, the angle θ would equal ϕ from no load to full load. For such to occur, AB should be a straight line, since the following relation must hold; viz.:

$$\frac{BD}{DC} = \frac{BC}{CA}.$$

However, AB is an arc of a circle where E_R and E_G are radii. In the cases met in practice,

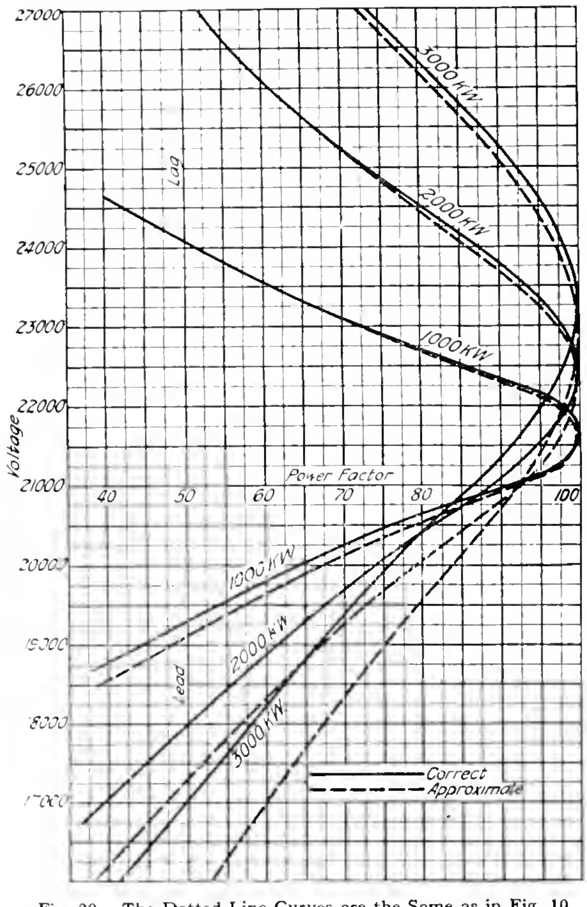


Fig. 20. The Dotted Line Curves are the Same as in Fig. 10, Being Calculated from Formula 2, While the Solid Line Curves are Calculated by Formula 1. It will be Noted that the Error in Using Formula 2 is Slight, Except on Power-factors Considerably Leading

$R = 22.4$ and $X = 53.1$.
$Tan\ \phi = 0.42$ $\qquad$ $Cos\ \phi = 0.92$.

E_G and E_R are so great relatively to the length of the arc AB, that AB is practically a straight line, and hence the assumption that θ will remain equal to ϕ at all loads, provided the voltages of E_R and E_G are constant, is well within the requirements of accuracy. The converse of this is true; that is, if the current were brought leading by the angle θ to a value equal to the angle ϕ the voltage at the generating station would remain constant from no load to full load, provided it were held constant at the receiving end.

Fig. 18 illustrates a set of readings at 2200 volts, the equivalent high tension value being 21,000 volts, taken on a transmission line when the voltage at the load end of the line was set the same as that at the generating station. The power-factor of the load varies considerably on light loads, because the readings were taken as the load was coming on.

We have here the condition of constant power-factor being established from no load to full load. Fig. 18 represents the calculations made by the approximate method. It will be noted that the power-factor should be, according to calculation, about 0.86 leading, whereas actually it was around 1.00. This difference was no doubt due largely to the effect of the negative magnetizing current or capacity effect, of the transmission line itself. By calculation the voltage drop should have been 10 per cent whereas by actual measurement it was found to be 12 per cent. But after all the actual data obtained checks close enough to the actual to show that this

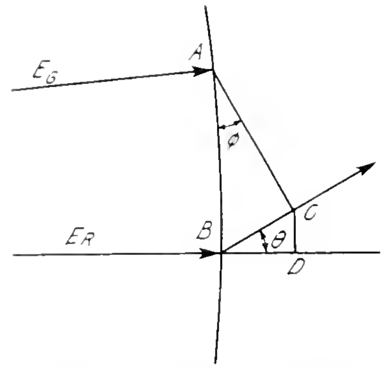


Fig. 21. Vector Diagram Showing the Condition of Constant Line Power-factor When the Voltage Drop is Maintained at Zero

$BC = IR$ $BD = I_c R$

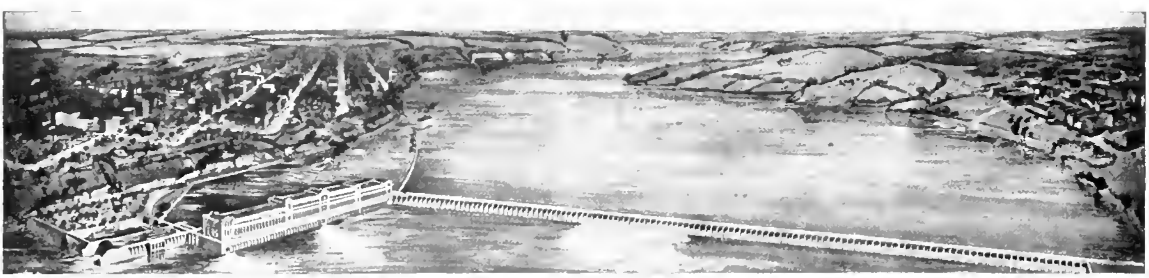
$CA = IX$ $tan\phi = \frac{R}{X}$

P-F of transmission line at receiving end $= cos\ \theta$.

Angle between E_G and $E_R = X$.

approximate method of calculation is sufficiently accurate for most practical purposes.

(To be Continued)



Bird's-eye View of Hydro-Electric Development by the Mississippi River Power Co. at Keokuk, Iowa

ADVANCED COURSE IN ELECTRICAL ENGINEERING

Part VII

By Ernst J. Berg

Professor of Electrical Engineering, University of Illinois

Characteristics of Condensers

The charge q of a condenser is proportional to the voltage; or $q=Ce$, where C is the capacity, depending upon the mechanical construction, dimensions, etc. of the condenser, and e is the voltage when q is the charge.

The charge q is measured in coulombs or ampere-seconds. Thus the charge dq given in a time dt when the current is i amperes is:

$$dq=idt$$

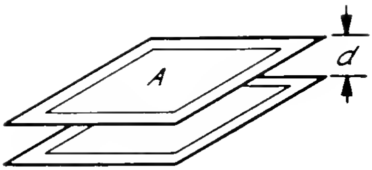


Fig. 30

The capacity is expressed in farads, a very large unit; so large indeed that in actual practice it is never used. The capacities of condensers are almost always given in microfarads, that is, in a unit which is one-millionth of a farad. Nevertheless, in all formulæ involving capacity, C stands for farads, not microfarads (m-f.) unless stated to the contrary.

To give an idea of the capacity of condensers used in engineering, it may be of interest to know that the ordinary paraffine paper and tinfoil 500 volt blocks of the size of the average textbook have a capacity from 1 to 2 microfarads. In a high potential transmission line the capacity of one wire against neutral is about 0.016 m-f. per mile. The capacity of underground cables is relatively high. Depending upon the voltage and type of cable, etc., it must obviously vary much. It is usually less than two m-f. per mile and more than one tenth of a microfarad. The capacity of an ordinary Leyden Jar is extremely small—a very small fraction of a microfarad.

The fundamental equations for the condenser are as stated above.

$$q=Ce \tag{128}$$

and

$$dq=idt \tag{129}$$

From these follow:

$$e=\frac{q}{C} \tag{130}$$

$$dq=Cde \tag{131}$$

and

$$i=\frac{dq}{dt} \tag{132}$$

Substituting (131) in (129)

$$Cde=idt \text{ or } i=C\frac{de}{dt} \tag{133}$$

or e, the voltage across the condenser $=\frac{1}{C}\int idt$ (134)

The rate of energy supply or power is ei

or from (133), $ei=e\frac{Cde}{dt}=Ce\frac{de}{dt}$ (135)

or from (130) and (132), $ei=\frac{q}{C}i=\frac{q}{C}\frac{dq}{dt}$ (136)

Thus the power supplied to a condenser at any time can be expressed either as $Ce\frac{de}{dt}$ or $\frac{dq}{dt}$. The energy stored in a condenser, which is the same as that required to charge a condenser to a voltage E or to a final charge Q, is therefore the rate of energy multiplied by the time. It is:

$$\int_0^E Ce\frac{de}{dt}dt=C\int_0^E \frac{ede dt}{dt}=C\Big|_0 \frac{e^2}{2}=\frac{CE^2}{2} \tag{137}$$

or

$$\int_0^Q \frac{q}{C}\frac{dq}{dt}dt=\frac{1}{C}\int q\frac{dq}{dt}dt=\frac{1}{C}\Big|_0^Q \frac{q^2}{2}=\frac{Q^2}{2C} \tag{138}$$

Equations (137) and (138) are obviously identical, since at any instant

$q=Ce$ thus for $e=E$ when $q=Q$

$Q=CE$, which, substituted in (138), gives

$$\frac{C^2E^2}{2C}=\frac{CE^2}{2} \qquad Q.E.D.$$

As in the case of inductance, the calculations of the capacity of any but the simplest circuits is difficult.

Of particular interest to engineers, however, are a few simple forms, the approximate capacity of which are given by equations which are well known.

Thus the capacity between parallel plates, Fig. 30 is:

$$Cmf = \frac{KA}{12.6d \times 10^6} \text{ microfarads}$$

where K, the specific inductive capacity is approximately 1 for air, 2 for paraffin paper, 3 for rubber, 5 for mica and 6 for glass.

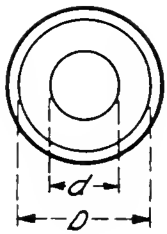


Fig. 31

A, the effective area is given in Cm^2 and d, the thickness of the dielectric, in centimeters.

The capacity between concentric conductors (Fig. 31) is:

$$Cmf = \frac{0.03861K}{\log_{10} \frac{D}{d}},$$

where the length l is given in miles of cable, K is the specific inductive capacity, D the inside diameter of the outside conductor, and d the diameter of the inside conductor. This is the capacity between the conductors, not the capacity to neutral or ground. The capacity of one conductor 1 mile long to neutral is twice as great.

The capacity between transmission lines is:

$$Cmf = \frac{.0386l}{\log_{10} \frac{D}{r}},$$

where l is expressed in miles and the capacity is that of one line against neutral D is the distance between wires, center to center, and r the radius of wire. The charging current is thus

$$i_c = \frac{2\pi fCe}{10^6}$$

where e is one half of the line voltage in the single-phase system and 58 per cent thereof in the three-phase system.

Circuits Containing Capacity and Resistance

Consider at first the case of a constant e.m.f. E impressed upon a circuit of resistance r and capacity C. After the circuit is established a current flows and energy is delivered to the resistance and the condenser. In the resistance heat is developed and in the condenser an electrostatic field is produced. The energy given by the source of supply of power is $\int Eidt$.

The energy supplied to the resistance is $\int i^2rdt$

and the energy supplied to the condenser

$$\int q\frac{dq}{Cdt}dt$$

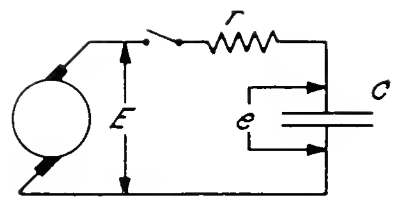


Fig. 32

Thus

$$\int Eidt = \int i^2rdt + \int q\frac{dq}{C} \qquad (139)$$

or

$$Eidt = i^2rdt + q\frac{dq}{C}$$

or

$$Ei = i^2r + \frac{q}{C}\frac{dq}{dt} \text{ which is the power equation} \qquad (140)$$

and

$$E = ir + \frac{q}{Ci}\frac{dq}{dt}$$

or substituting for $dq = idt$

$$E = ir + \frac{q}{C} \text{ which is the voltage equation} \qquad (141)$$

Obviously the voltage equation could have been derived directly, since ir is the e.m.f.

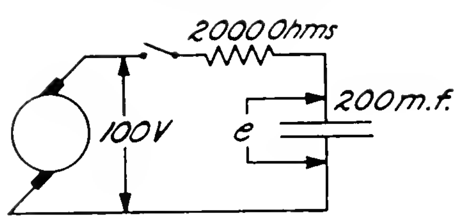


Fig. 33

consumed by the resistance and $\frac{q}{C}$ the voltage across the condenser.

The condenser voltage is thus $e_1 = E - ir$; but

$$i = C\frac{de_1}{dt} \therefore e_1 = E - Cr\frac{de_1}{dt}$$

or

$$\frac{de_1}{dt} + \frac{1}{Cr}e_1 = \frac{E}{Cr}$$

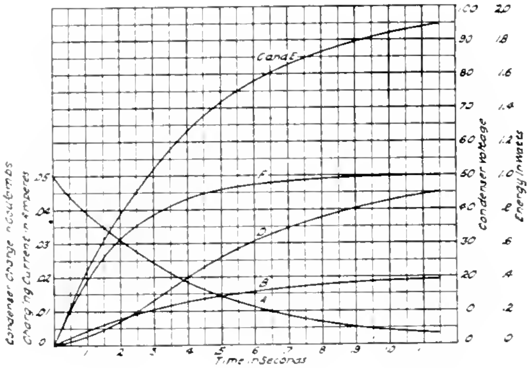


Fig. 34

Referring to equation $e_1 = A\epsilon^{-\frac{1}{Cr}t} + E$ (142) where A is the integration constant: The current is readily found, since $i = C\frac{de_1}{dt}$

$$\therefore i = -\frac{CA}{Cr}\epsilon^{-\frac{1}{Cr}t} = -\frac{A}{r}\epsilon^{-\frac{1}{Cr}t} \quad (143)$$

The charge q is $= Ce_1 = CA\epsilon^{-\frac{1}{Cr}t} + EC$ (144). (142), (143) and (144) are the fundamental equations.

Special cases:

(a) Condenser charge.

At time $t = O$ $e_1 = O$

$\therefore$ referring to equation (142), $O = A + E \therefore A = -E$

$$\therefore e_1 = E\left[1 - \epsilon^{-\frac{1}{Cr}t}\right] \quad (145)$$

Referring to equation (143)

$$i = \frac{E}{r}\epsilon^{-\frac{1}{Cr}t} \quad (146)$$

Referring to equation (144)

$$q = EC\left[1 - \epsilon^{-\frac{1}{Cr}t}\right] \quad (147)$$

(b) Condenser discharge.

In this case the impressed voltage $E = O$ for $t = O$, $e_1 = e_0$

Referring to equation (142)

$$e_1 = A\epsilon^{-\frac{1}{Cr}t} \quad \text{and } e_0 = A$$

$$\therefore e_1 = e_0\epsilon^{-\frac{1}{Cr}t} \quad (148)$$

$i = -\frac{e_0}{r}\epsilon^{-\frac{1}{Cr}t}$ that is in opposite direction to charging current (149)

$$q = Ce_0\epsilon^{-\frac{1}{Cr}t} \quad (150)$$

Referring to the e.m.f. of the condenser rather than to the impressed e.m.f., the current becomes positive since the discharge current

$$i = -\frac{dq}{dt} = -C\frac{de_1}{dt} \quad (151)$$

$$\therefore i = \frac{Cl_0}{Cr}\epsilon^{-\frac{1}{Cr}t} = \frac{e_0}{r}\epsilon^{-\frac{1}{Cr}t} \quad (152)$$

In order fully to understand the action of condensers it is not sufficient to follow the equations given above, but it is essential and indeed necessary to figure a number of numerical examples.

For this reason Fig. 34 is given. The curves shown there should be checked numerically by every student. They are calculated under the assumption that a constant impressed e.m.f. of 100 volts is impressed on a circuit of 2000 ohms resistance and 200 m-f. capacity, as shown in Fig. 33.

An interesting problem in connection with the charging and discharging of condensers, is to consider the flow of current between two leyden jars of different capacity and voltage (Fig. 35). The energy stored in condenser A at voltage E is $\frac{1}{2}$ CE^2. The energy stored in condenser A at voltage e

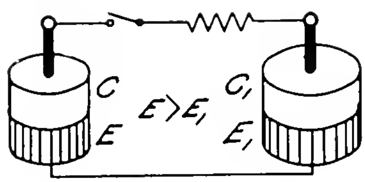


Fig. 35

is $\frac{1}{2}$ Ce^2. The energy stored in condenser B at voltage E_1 is $\frac{1}{2}$ $C_1 E_1^2$. The energy stored in condenser B at voltage e_1 is $\frac{1}{2}$ $C_1 e_1^2$. While current flows between the two condensers, a readjustment of energy takes place between the two condensers and energy is dissipated in heat in the resistance.

The energy equation is obviously:

$$0.5\ CE^2+0.5\ C_1E_1^2-0.5\ Ce^2-0.5\ C_1\ e_1^2=\int i^2rdt \qquad (153)$$

By differentiating this equation, the following results:

$$-Cede-C_1e_1de_1=i^2rdt \qquad (154)$$

As it is assumed that the voltage of A is higher than that of B, the latter is being charged; thus $i=C_1\frac{de_1}{dt}$ (155)

where e_1 is the voltage of B at any time. Equation (154) contains three variables, e, e_1, and i, which, however, are dependent upon each other.

At any instant the following relation exists between the e.m.f's.

$$e=ir+e_1$$

Thus

$$\frac{de}{dt}=r\frac{di}{dt}+\frac{de_1}{dt}=rC_1\frac{d^2e_1}{dt^2}+\frac{de_1}{dt}$$

Substituting in (154)

$$-C\left(C_1r\frac{de_1}{dt}+e_1\right)\left(C_1r\frac{d^2e_1}{dt^2}+\frac{de_1}{dt}\right)-C_1e_1\frac{de_1}{dt}$$
$$=C_1^2r\left(\frac{de_1}{dt}\right)^2 \qquad (156)$$

or

$$-C\left(C_1r\frac{de_1}{dt}+e_1\right)\left(C_1r\frac{d^1c}{dt^2}+\frac{de_1}{dt}\right)$$
$$-C_1\frac{de_1}{dt}\left(C_1r\frac{de_1}{dt}+e_1\right)=0$$

or

$$-\left(C_1r\frac{de_1}{dt}+e_1\right)\left(C_1\frac{de_1}{dt}+CC_1r\frac{d^2e_1}{dt^2}+C\frac{de_1}{dt}\right)=0$$

Since $C_1r\frac{de_1}{dt}+e_1$ cannot be zero

$$C_1\frac{de_1}{dt}+CC_1r\frac{d^1e_1}{dt^2}+C\frac{de_1}{dt}=0 \qquad (157)$$

Integrating (157)

$$C_1e_1+CC_1r\frac{de_1}{dt}+Ce_1=K$$

or

$$\frac{de_1}{dt}+e_1\frac{C+C_1}{CC_1r}=\frac{K}{CC_1r}=K_1 \qquad (158)$$

Referring to equation (4)

$$e_1=K_1+K_2\epsilon^{-\frac{1}{C_0r}t} \qquad (159)$$

where

$$C_0=\frac{CC_1}{C+C_1} \qquad (160)$$

The integration constants K_1 and K_2 are determined from the initial condition that for $t=o$, $e_1=E_1$ and $e=E$

$$\therefore E_1=K_1+K_2 \quad \text{or} \quad K_2=E_1-K_1$$

$$\therefore e_1=K_1+(E_1-K_1)\,\epsilon^{-\frac{1}{C_0r}t}$$

$$\therefore e_1=E_1+\frac{C}{C+C_1}(E-E_1)\left[1-\epsilon^{-\frac{1}{C_0r}t}\right] \qquad (161)$$

$$i=C_1\frac{de_1}{dt}=\frac{E-E_1}{r}\epsilon^{-\frac{1}{C_0r}t} \qquad (162)$$

$$e=E-\frac{C_1}{C+C_1}(E-E_1)\left[1-\epsilon^{-\frac{1}{C_0r}t}\right] \qquad (163)$$

The problem can be solved in a simpler way if it is realized that the total charge in the system is not changed after the switch is closed.

Thus

$$Q_0=EC+E_1\,C_1=q+q_1 \qquad (164)$$

Where q and q_1 are the charges at any time in jars A and B respectively.

In that case $e=ir+e_1$; or since $q=eC$ and $q_1=e_1C_1$ $\frac{q}{C}=ir+\frac{q_1}{C_1}=ir+\frac{Q_0}{C_1}-\frac{q}{C_1}$

Assuming $E>E_1$ then jar A is being discharged thus $i=-\frac{dq}{dt}$

$$\therefore\ \frac{q}{C}=-\frac{rdq}{dt}+\frac{Q_0}{C_1}-\frac{q}{C_1}$$

or

$$\frac{dq}{dt}+\frac{C+C_1}{CC_1r}q=\frac{Q_0}{C_1r}$$

$$\therefore q=\frac{Q_0C}{C+C_1}+K\epsilon^{-\frac{1}{C_0r}t}$$

$$\text{where } C_0=\frac{CC_1}{C+Cc_1}$$

for

$$t=o \quad q=EC$$

$$\therefore\ EC=\frac{Q_0C}{C+C_1}+K$$

Since condenser B is being charged $i=+C_1\frac{de_1}{dt}$

$$\therefore i=-\frac{C_1}{C_0r}(E_1-K)\epsilon^{-\frac{1}{C_0r}t}$$

but

$$e=ir+e_1 \quad \therefore e=-\frac{C_1}{C_0}(E_1-K_1)\,\epsilon^{-\frac{1}{C_0r}t}$$
$$+K_1+(E_1-K_1)\ \epsilon^{-\frac{1}{C_0r}t}$$

for $t=o$ $e=E$

$$\therefore =-\frac{C_1}{C_0}(E_1-K_1)+K_1+E_1-K_1$$

$$\therefore K_1=E_1+\frac{C_0}{C}(E=E_1)$$

and

$$K_2=-\frac{C_0}{C_1}(E-E_1)$$

or

$$K = EC - \frac{Q_0 C}{C+C_1} = C_0(E-E_1)$$

$$q = \frac{Q_0 C}{C+C_1} + C_0(E-E_1)\,\epsilon^{-\frac{1}{C_0 r}t}$$

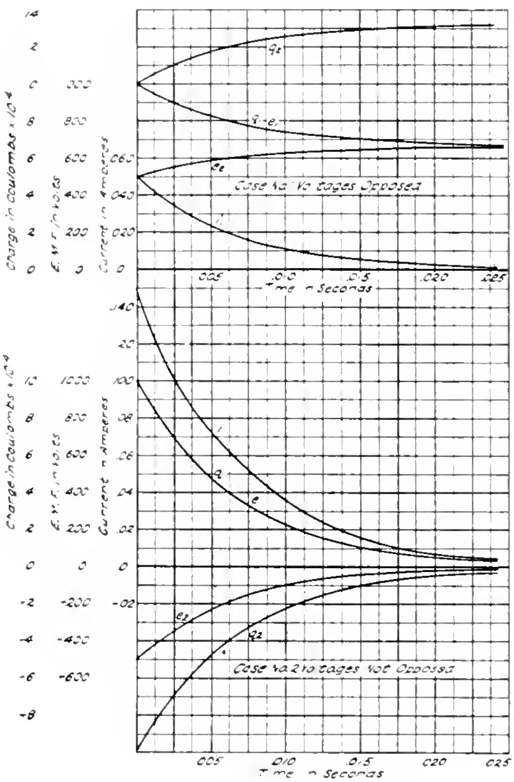


Fig. 36

Since condenser A is being discharged

$$i = -\frac{dq}{dt} = +\frac{E-E_1}{r}\,\epsilon^{-\frac{1}{C_0 r}t}$$

The voltage across condenser A, which is being discharged is

$$e = -\frac{1}{C}\int i dt = +\frac{1}{C}\left(\frac{E-E_1}{r}\right) C_0 r \epsilon^{-\frac{1}{C_0 r}t} + K_1$$

$$= \frac{C_1}{C+C_1}(E-E_1)\,\epsilon^{-\frac{1}{C_0 r}t} + K_1$$

for

$t = o \quad e = E$

$$\therefore K_1 = E - \frac{C_1}{C+C_1}(E-E_1)$$

$$\therefore e = E - \frac{C_1}{C+C_1}(E-E_1)\left[1-\epsilon^{-\frac{1}{C_0 r}t}\right]$$

$$q_1 = Q_0 - q = Q_0 - \frac{Q_0 C}{C+C_1} - C_0(E-E_1)\,\epsilon^{-\frac{1}{C_0 r}t}$$

$$= \frac{Q_0 C_1}{C+C_1} - C_0(E-E_1)\,\epsilon^{-\frac{1}{C_0 r}t}$$

$$e_1 = \frac{1}{C_1}\int i dt = -\frac{1}{C_1}\,\frac{E-E_1}{r}\,C_0 r\,\epsilon^{-\frac{1}{C_0 r}t} + K_2$$

$$= -\frac{C}{C+C_1}(E-E_1)\,\epsilon^{-\frac{1}{C_0 r}t} + K_2$$

for

$t = o \quad e_1 = E_1$

$$\therefore K_2 = E_1 + \frac{C}{C+C_1}(E-E_1)$$

and

$$e_1 = E + \frac{C}{C+C_1}(E-E_1) - \frac{C}{C+C_1}(E-E_1)\,\epsilon^{-\frac{1}{C_0 r}t}$$

$$e_1 = E_1 + \frac{C}{C+C_1}(E-E_1)\left[1-\epsilon^{-\frac{1}{C_0 r}t}\right]$$

With a slight modification of this equation it is seen that for $t = \infty$ the final voltage between the coatings of the leyden jars is

$$E_f = \frac{Q_0}{C+C_1}$$

Numerical example: condenser A has a capacity of 1 m-f. and is charged to 1000 volts; condenser B has a capacity of 2 m-f. and is charged to 500 volts; the resistance is 10,000 ohms. Find the current after the switch is closed.

The original charge in A is then $1000 \times \frac{1}{10^6}$ $= 0.001$ coulomb; the charge in B is $\frac{500\times 2}{10^6}$ $= 0.001$ coulomb also.

$E - E_1 = 500$

$$C_0 = \frac{2\times 10^6}{3\times 10^{12}} = \frac{2}{3\times 10^6}$$

and

$$\frac{1}{C_0 r} = 150$$

$$C + C_1 = 3\times 10^{-6} \quad \frac{C_1}{C+C_1} = .667 \quad \frac{C}{C+C_1} = .333$$

$$\therefore i = \frac{500}{10{,}000}\epsilon^{-150t} = 0.05\,\epsilon^{-150t}$$

$$e = 1000 - .667\times 500(1-\epsilon^{-150t})$$
$$= 500\,[2 - .667\,(1-\epsilon^{-150t})\,]$$
$$e_1 = 500 + .333\times 500\,(1-\epsilon^{-150t})$$
$$= 500\,[1 + .333\,(1-\epsilon^{-150t})\,]$$

For $t = \infty$ $e_0 = e_{01} = .667$ volts which is the final voltage of the two jars.

Fig. 36 gives the result of these calculations.

(To be Continued)

THE USE OF STORAGE BATTERIES IN MODERN ELECTRICAL ENGINEERING

Part I

By D. Basch

Switchboard Engineering Department, General Electric Company

In the March, 1911, issue of the Review we published an article by Mr. Basch on the uses of Storage Batteries in Switchboard Work. This constituted the first part of a more extended paper on all the various purposes to which the storage battery is applied at the present time, the full text of which is now in our possession. In order to place all the materials in the hands of our present subscribers we are reprinting the first section of the paper, with the author's revisions and additions, and shall continue it in further issues. The purpose of the paper, while explaining theory where necessary, is primarily to make definite recommendation as to what constitutes good practice in the installation, operation and maintenance of storage batteries. The paper will be divided under the following main headings: lead batteries; Edison batteries; charging sources; oil-switch and oil circuit-breaker batteries; batteries in small isolated lighting plants; vehicle battery switchboards; and ignition battery outfits with mercury arc rectifiers. The first instalment published this month covers the subject of lead batteries.—Editor.

Secondary or storage batteries are devices which, according to Volta's law, transform chemical energy into electrical, and whose energy can be restored again after having been spent. The unit of batteries is the cell, containing positive and negative electrodes, and an electrolyte. The voltage of the cell is a function of the electrochemical properties of the materials used for electrodes and electrolytes, and is independent of the size of the cell; the current capacity is approximately proportional to the surface of the electrodes that are submerged in the electrolyte.

LEAD BATTERIES

General

The oldest type of commercial storage battery is the lead battery. This battery contains as the positive electrode (anode) lead peroxide—a dark brown, chocolate-colored material, about as hard as soapstone; and as the negative electrode (cathode), sponge lead—which is light gray in color, and so soft that it can be cut with a fingernail. As electrolyte, diluted sulphuric acid is employed. The positive electrode is the portion of the battery from which the electric current passes into the load circuit; it returns to the cell through the negative. Inside of the cell the current starts from the negative electrode towards the positive. When a battery circuit is closed through outside load, it will give out, as the result of an electrochemical action between electrodes and electrolyte, a certain current, depending upon the battery voltage and the load resistance, and limited only by the internal virtual resistance of the battery.

This process is known as discharging the battery. When discharging, both electrodes are changed in part to lead sulphate (which is practically non-conductive) by taking the sulphuric acid component, or radical, out of the electrolyte. As more and more of this sulphuric acid radical is removed from the electrolyte, its chemical activity is reduced; and as the electrodes are covered more and more with lead sulphate, the e.m.f. of the battery gradually decreases.

When after discharge an external source is connected to the battery and current is forced through it in the opposite direction to that taken by the discharge current, the electrochemical process of the discharge is reversed; the lead sulphate formed on the electrodes is changed back to lead peroxide on the positive, and to sponge lead on the negative. The acid which, during the discharge, was taken out of the electrolyte for the formation of the lead sulphate, is returned to it, increasing its specific gravity; the battery voltage gradually rises and the battery is restored to the same state as before the discharge took place, i.e., it is charged. The input during charge must be somewhat greater than the output required at discharge, on account of losses due to heating and gassing, and also on account of the effect of polarization. Polarization is a phenomenon which occurs on the passage of current between two electrodes immersed in an electrolyte; and its effect is always to oppose the flow of current by creating a counter e.m.f. The discharge voltage is therefore equal to the voltaic cell potential *minus* internal resistance drop *minus* the polarized counter-e.m.f.; and the charge voltage is equal to the voltaic cell potential *plus* internal resistance drop *plus* the polarized counter-e.m.f. Lead storage batteries are rated in ampere-hour discharge. The rated capacity varies with the duration of the discharge, being greater for a slow discharge and *vice versa*. The slower the discharge, the greater the opportunity for diffusion of the electrolyte, and consequently the better the opportunity for the stronger acid to come into intimate contact with every particle of active material.

Stationary batteries are generally rated on the basis of an eight-hour discharge, and vehicle batteries on four- or five-hour discharge. With discharge current at eight hours as a unit, the discharge current of a stationary battery may be increased at five hours to 1.4, at three hours to 2, and at one hour to 4. The capacity of a stationary battery at one hour discharge is therefore only 50 per cent. of its eight-hour capacity.

Electrodes

The electrodes of lead batteries are made in two different types, one the so-called "formed" or *Planté* plate, and the other the "pasted" or *Faure* plate. In both, the body consists of lead, but in the formed plate the active material (lead peroxide and sponge lead) is formed electrochemically on the surface of the plate body; while in the pasted plate the active material, in the form of lead oxides, is first applied mechanically and afterwards subjected to the forming process.

The distinguishing operating features of the two types, determining their fields of usefulness, are the following: the *Planté* positive plates have a long life when not subjected to a state of partial or complete discharge over a great length of time. They may be charged and discharged several thousand times and retain their capacity and mechanical strength. The life of pasted positive plates is limited to a considerable extent by the number of charges they receive due to the great effect produced by the rapid generation of gases toward the end of the charge, but they will give more capacity for the same weight than the formed plate.

The negative plate is in general of the pasted type, although some companies furnish *Planté* negatives for stationary batteries and train lighting. Pasted positive plates are necessary where light weight is required, such as automobile batteries, or where space is an important item. The formed positive is used for the other fields of application. Of the two electrodes, the positive plate has ordinarily a shorter life than the negative. With negative plates there is, especially when subjected to abuse, a chance for a physical shrinkage of the material and a capacity decrease due to a gradual loss of porosity in the sponge lead; when, due to the contraction and expansion while charging and discharging, the thin walls of some of the pores collapse and stick together. The tendency to contract may be counteracted by the introduction of suitable ingredients into the negative material which have a tendency to keep this material in a porous condition.

Electrolyte

The specific gravity of the electrolyte depends upon the amount of acid present, and on the temperature. With proper allowance for temperature variation it is a direct indication of the state of charge and discharge. The level of the electrolyte must always be kept above the top of the plates. During the operation of the battery the level of the electrolyte will go down somewhat on account of the evaporation of water. This evaporation should be replaced by *water* and not by acid, except when the electrolyte has been spilled or has leaked. Specific instructions are given by the manufacturer for each battery, regarding the proper gravity of the electrolyte.

Retainers

Stationary batteries are generally assembled in glass jars. Lead-lined wooden tanks are used for elements that are too large for mounting in glass jars. Vehicle batteries are placed in rubber jars with suitable covers to prevent splashing and spilling of the electrolyte. Celluloid cells are sometimes used, the transparency of the celluloid making it possible to examine the condition of the element without removing it. Their disadvantage is their inflammability and liability to take fire and to burn with almost explosive-like rapidity.

Installation

Large stationary batteries must be installed in rooms which are well ventilated, dry and of moderate temperature. The floor should be covered with brick or asphalt. Cement floors are suitable only when kept clear of acid, as the action of sulphuric acid on even the best grade of cement is to dissolve it. Concrete floors can be improved by coating them with paraffine applied very hot and with a heavy brush to retain the heat. Wooden floors have a very limited life due to the disintegrating influence of the acid. Catch troughs of thin lead or asphalt placed under each row of cells will help somewhat. One objection to the use of asphalt is its tendency to flow at higher temperatures or under pressure. The best, though somewhat expensive, floor is made of concrete overlaid with a double thickness of waterproofing having a covering of vitrified brick or tile set with wide joints grouted with pitch, or preferably a high-grade pure asphalt.

Proper arrangements should be made for draining the battery room. Usually the floor is made to slope slightly downward to one or more points, at which an opening is made connecting with a drain or sewer, the hole being covered by a suitable acid-resisting metal cover. Drain pipes should be terra cotta or lead. For smaller batteries a cement floor may be used, which must have a smooth finish and be well drained. Care should be taken that the injurious acid vapors are withdrawn from the battery room. Where possible, ventilator openings should be placed at the floor level under the windows in the battery room arranged so that they can be closed or opened as desired. Along the peak of the roof ventilators of large area should be located, thus providing plenty of natural ventilation in conjunction with the wall ventilators. Where natural draft is not sufficient to produce circulation, or where it cannot be obtained, a bronze fan should be installed at the outlet to draw the air from the room. Excessive air circulation is not required, and is often objectionable since it tends to increase the evaporation of water from the cells. In order to maintain full capacity, the battery room should be maintained at a normal temperature of 70 deg., and if necessary a heating system should be supplied to maintain this temperature. All battery rooms should have a supply of pure water to fill up the cells from time to time, replacing the water which is evaporated.

Cells in glass jars are placed in sand trays to obtain even distribution of weight and to prevent the spreading of the electrolyte, one tray per cell for the larger types and one tray for 5 to 15 cells for the so called "two-plate" cells, i.e., those having only one positive and one negative plate. Sand trays are shallow trays made either of wood or glass. Glass trays have usually bosses on the underside to rest on and to serve as supports and insulators. Wooden trays are mounted on insulators. The cells in their trays are placed on wooden racks in one or more tiers, according to the size of battery and space available. Cells in wooden tanks do not require sand trays, being raised off the floor and insulated therefrom by means of oil insulators or wooden stringers and glass insulators. Glass covers are placed on top of the cells to prevent impurities, etc., from dropping into the cells, and to arrest acid spray produced by gassing. Adjoining cells of glass batteries are connected together (the positive terminal of one to the negative terminal of the next) by means of bolt connectors, each consisting of two lead-covered nuts and one brass stud. In tank batteries all plates are "lead-burned" to the busbars. Where connections must be made from one tier to another, or between cell groups that are separated from each other by a space, lead tape of suitable dimensions, or lead-coated copper bars, should be used in preference to copper cable. At the two ends of the battery end-terminals are furnished for the connections to the switchboard. Terminals should also be provided for any intermediate taps.

Fig. 1 shows a common form of stationary battery installation with all the individual parts. In general the racks should be so

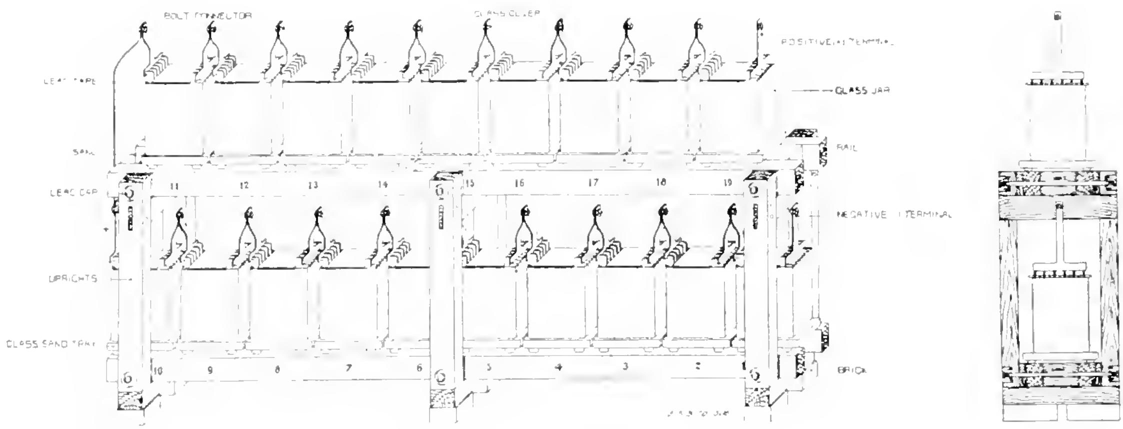


Fig. 1. Typical Installation of Storage Battery on Wood Rack

placed that they are easily accessible but not where direct sunlight will fall on the cells, as sunlight has a chemical effect on the plates. If this cannot be avoided, the windows must be painted with a semi-opaque paint or whitewashed. No bare iron or copper should be installed near the battery; and in cases where the use of these metals cannot be avoided, copper should have a heavy lead coating and iron should be painted with acid-resisting asphalt paint, as should also all woodwork.

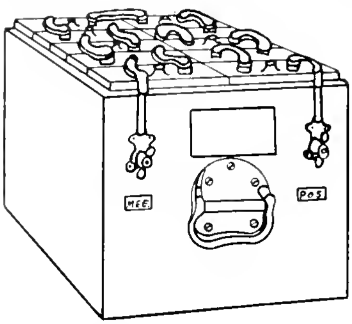


Fig. 2. Lead Battery for Electric Vehicle in Tray

In vehicle batteries the cell units, connected together in number and arrangement to suit the vehicles they are designed for, are assembled together in one or more hard wood trays, painted with acid-resisting paint and provided with suitable handles and terminals. The bottoms of the trays are provided with slots or holes for drainage in case of leaking or splashing of the electrolyte. (See Fig. 2.) Battery boxes for trucks are generally hung from the frame members or sills underneath the vehicle body and between the axles. There they occupy no useful space and are subjected to the least jolting and shaking, being spring-supported from the body and as far removed from each axle as possible. This is also the most convenient position for removal and replacement of the battery trays, the boxes opening on both sides. The boxes are made of a size to carry any of the principal battery makes. On pleasure vehicles the battery boxes are generally placed on extensions of the flooring in back and front.

Battery Readings

The condition of cells during charge or discharge may be determined by two methods; the specific gravity method, which reads the specific gravity of the electrolyte by means of a hydrometer, or the voltage method based on the voltage of the cells. The specific gravity is recommended as being superior to the voltage method, as the voltages denoting various conditions of the cell vary with the current as well as with temperature and with the age and condition of the plates; whereas the specific gravity is nearly independent of the current. It is in fact an accurate ampere-hour meter, as the effect of temperature can be easily corrected. This method, however, has the disadvantage that the hydrometer is not always easy to read, and that it is necessary to make a trip to the battery when readings are to be taken.

When batteries are inaccessible or the cells very small, the specific gravity method is impracticable, and voltage readings are relied on solely; but in general it is strongly recommended that both methods be used as mutual checks, with the specific gravity method as the principal indication. Even where conditions are such that this method cannot be used regularly, occasional specific gravity readings should be taken as a check. It should be noted that all voltage readings should be taken with cells under current. As has been said, the specific gravity is affected by temperature, being greater for lower temperatures, and allowance must be made for temperature variations. With the help of a thermometer this correction is taken care of without difficulty, all readings being reduced to a standard temperature by means of a simple formula.

For the regular operation of a stationary battery with a large number of cells, it is not necessary to take readings on all the cells; it is sufficient to select the most accessible cell as pilot cell, on which readings may then be taken to represent the rest. This cell must receive exactly the same usage as the cells for which it serves as an indicator. When batteries are charged or discharged in more than one series, a pilot cell should be selected in each series, as the various sections are apt to work differently and thus need individual watching. The other battery cells should be inspected every week or two. With vehicle batteries voltage readings, giving the voltage for the whole battery, furnish the general indication. It is, however, recommended that specific gravity readings be taken of several cells toward the end of the charge with the hydrometer. These readings are to serve as a check on those taken with the voltmeter, and while it is generally impracticable to take them every time the battery is charged, it is highly desirable that the gravity of each cell be taken at least once every two weeks (just after the so-called overcharge). As an additional indication of the relative condition of the cells in vehicle batteries, the voltage of each cell should be read with a low-reading voltmeter at least once every two weeks.

Initial Charge

After completing the assembling and installing, the battery must receive an initial charge before it can be put into regular service. This initial charge should be as continuous as possible, at the rate given by the manufacturer, until, with all cells "gassing" freely, the specific gravity and voltage show no rise over a period of 10 hours. The duration of such a charge may vary between 30 and 100 hours, and is always stated by the manufacturer. If, during the charge, the temperature in any one cell reaches 100 deg. Fahr. (110 deg. Fahr. for vehicle batteries) the charging rate should be reduced or the charge temporarily stopped.

After the initial charge, a stationary battery may be placed into commission, although it is sometimes recommended to discharge the battery about one half, at the normal rate and then immediately to recharge it, before putting it into regular use. Vehicle batteries will not give full capacity until they have been discharged and charged three or four times; and if it is necessary to obtain full capacity at the outset it is therefore considered imperative not to put a vehicle battery into service without its having been fully discharged through a resistance; or, if this is not practicable, the vehicle should be run about two hours on level ground without recharging the first two or three times it is used.

Charge

There are two kinds of charges in normal operation—the regular charge and the overcharge. The former is intended to restore the capacity of a battery after discharge; while the latter is given at regular weekly or biweekly intervals, and carried to a complete maximum for the purpose of equalizing all cells, reducing all sulphate, and keeping the plates in good general condition.

The overcharge is a regular charge continued until the specific gravity and voltage do not show any rise for four or five consecutive readings fifteen minutes apart. All cells should than gas freely. In order to permit a thorough and complete overcharge, a charging voltage of 2.7 volts per cell should be provided. In regular charge, stationary batteries are charged until they come within three to five points of the previous overcharge maximum of specific gravity, or until the voltage is from 0.05 to 0.1 volt below the maximum overcharge cell voltage. On vehicle batteries, as brought out before, gravity readings are ordinarily dispensed with in regular charges, the battery being charged until the voltage stops rising (the overcharge being continued about one hour after that). All charging should be done at the rates given by the manufacturers. For stationary batteries this rate with some manufacturers is equal to the eight-hour discharge rate; while other manufacturers prefer to start the charge between the three and five-hour rate, reducing the current to the eight-hour rate as soon as the plates gas freely. While with vehicle batteries the battery is first charged at a stated rate until the voltage per cell has risen to about 2.55 or 2.60 volts, the charging current then reduced to a smaller rate, and the charge completed. Under these conditions the regular charge of a stationary battery after a complete discharge will last between eight and nine hours, and the subsequent overcharge around two hours.

On the vehicle battery, if about two-thirds discharged, the charge at the "starting" rate will consume about three to four hours, the charge at the finishing rate about one and one-half to two hours, and the overcharge one hour. With vehicle batteries a rate 50 per cent. in excess of the stated "starting" rate may be used for the first part of the charge, and the normal "starting" rate for the latter part. Some manufacturers permit starting the charge of either stationary or vehicle batteries at a rate even as high as the one-hour discharge rate, provided the rate is reduced as the charging progresses so as to keep the cell temperature below about 100 deg. Fahr., and to avoid free gassing until the final or normal rate is reached. Higher charging rates than those given by the manufacturers should not be used, as they tend to throw off too much active material on account of the rapid change of volume and of the rapid evolution of gas within the pore of the plates. Furthermore, temperatures incidental to heavy charging rates are apt to soften the active material in the plate, resulting in quicker deterioration.

Moderate rates of charge allow the concentration changes of the electrolyte in the pores of the active material to take place more gradually, thereby more nearly equalizing the charge throughout the mass of the material. The contraction in volume of the active material moreover takes place so slowly that the active material does not crack or shed unduly. Extremely low rates are objectionable, especially towards the end of the charge, because the indications of the completion of charge are not nearly as well defined as with normal rates, and the battery is more liable to be overcharged or undercharged, aside from the greater length of time necessary for the charge. It is undesirable to prolong a charge or overcharge unduly. When all active material is converted to peroxide of lead and lead sponge, further charge cannot add capacity and is simply a waste of energy. On the other hand, the gas bubbles liberated

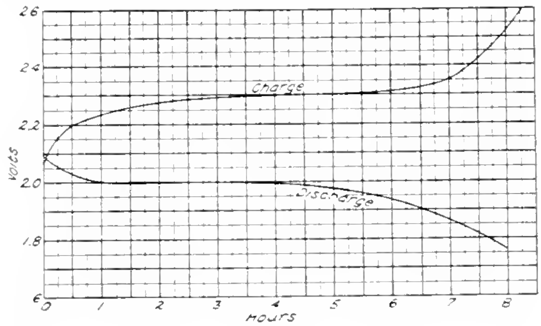


Fig. 3. Curve Showing Voltage Variation on Lead Battery During 8-Hour Charge and Discharge with Normal Current

at the end of a charge agitate the liquid and cause "washing" of the active material; and, being generated more or less beneath the surface of the active material, will loosen the particles and tend to shed them from the surface as they work their way through.

Charging is sometimes done with constant charging voltage. The charging current is then variable, being greatest at the beginning of the charge, when the counter e.m.f. of the battery is smallest, gradually tapering off at the end of the charge.

Discharge

It is not advisable to discharge a battery too far, as the coating of non-conductive lead sulphate formed on the plates during discharge would grow too thick and present a considerable resistance to electrochemical reduction during charge.

Over-sulphation will also cause a dangerously great change in the volume of active material (the volume of lead sulphate being greater than lead peroxide or lead sponge), resulting in fracture, shedding or buckling. In general, the voltage of a stationary battery should not be allowed to fall below a certain limit per cell, depending on the rate of discharge current.

Stationary batteries are generally discharged to 1.75 volts at the 8-hour rate. Vehicle batteries should not be discharged below 1.70 volts per cell, with the vehicle running at full speed on level ground. If the average discharge rate is greater than normal, the working voltage will be correspondingly lowered. It is, however, safer not to go below 1.70 volts per cell except momentarily, when starting or on a grade. Momentary high-rate discharges will, of course, bring the voltage down considerably below this limit; but this voltage drop does not indicate the state of the battery, as it is only temporary, the voltage rising to its proper figure as soon as the overload disappears. Fig. 3 shows an average charge and discharge voltage curve for a stationary battery based on eight-hour discharge and normal rate charge.

Withdrawal From Service

If a battery is to be shut down for any considerable length of time, and if it is impossible or inconvenient to give an occasional overcharge, it is recommended that the battery be given a full charge and taken out of service. When it becomes necessary to put the battery in commission again, it must be subjected to a full or partial "initial" charge. All manufacturers issue special instructions for withdrawal from service varying with the type of cell in question.

Diseases of Lead Batteries and Their Remedies

The most common of battery troubles are the following:

1. Excess of sulphate, caused by prolonged standing after over discharge, due to either intentional load discharge or local action and leakage; or loosening of active material, which reduces the capacity of a plate, and therefore over-discharges it at normal rated discharge or finally short-circuit between plates.

2. Reversal of plates. This may happen when a cell loses its capacity through some accident or defect, and its discharge is ended before the other cells in series with it have been completely discharged. The large-capacity cells then overpower the defective cell and reverse it.

3. Changes in the structure of the plates. Negative plates may show a decided loss of capacity due to clogging or contraction of the pores of the lead sponge. Positive plates, especially pasted ones, may show a softening of the active material toward the end of their life, owing to the expansion and contraction on discharge, and the action of escaping bubbles of oxygen formed on charge.

If not checked the entire mass will finally turn into a soft, mushy substance. This softening may occur prematurely if the charge and discharge is excessive.

4. Fracture and buckling of the plates. These troubles are due to excessive or unequal expansion, usually the latter, when discharge has repeatedly been carried too far; or with short-circuits especially when the plates are repeatedly allowed to stand in a discharged condition.

5. Shedding of active material, due either to imperfect formation or application of the active material; or, again, to undue expansion or contraction, or to the rapid release of gas bubbles, when charging is done at high rates or carried too far.

The remedies for these defects are as follows:

1. A thorough overcharge preferably at low rate and several cycles of charge and discharge will generally be sufficient. If it is desirable to overhaul one defective cell without affecting the whole battery, a jumper may be arranged, which leaves the cell in at the regular charge and cuts it out at discharge, or reverse it at discharge, so that in the latter method the cell receives a continuous charge.

Large installations are generally provided with cell boosters, sometimes called "milkers," i.e., an auxiliary dynamo with a potential of about 3-5 volts, for charging single cells without interfering with the operation of the whole battery. Boosters may be utilized for this purpose. Their field is generally connected to one of several cells, preferably through the end-cell switch, where there is one; so that by movement of the end-cell switch the field voltage may be regulated in addition to the action of the rheostat.

2. The same method is followed as for No. 1.

3. The rejuvenation of hardened negatives is brought about by discharging, reversing and changing, so that the positive plate becomes a negative and *vice versa*, then reversing back again. In some types of plates it is preferable to charge them at low rate to full capacity. The process should be conducted under the supervision of the manufacturer. There is no method of rejuvenating softened positives.

4 and 5. The explanation of the reasons for these troubles indicates the remedy.

On vehicle batteries cells should be taken out of the carriage in order to trace the trouble. If the trouble cannot be located by the eye (leaky jar or external short-circuit) the battery should be discharged at the normal rate through a suitable resistance. As the discharge progresses, the voltage will gradually decrease and it should be read frequently at the battery terminals. As soon as it shows a sudden drop, the voltage of each cell should be read with a low-reading voltmeter. The discharge should be continued until the majority of cells read 1.70 volts; those reading less should be noted. The discharge should be followed by a charge until the good cells are up. The low cells should then be cut out, examined and the trouble remedied. The low cells should then be grouped by themselves and charged as a separate battery.

Floating

Where, with heavy momentary load fluctuations, only approximate voltage regulation is required, or where it is necessary that the full capacity of the battery be always available, lead batteries are often permanently connected to the charging source without any means for regulating them. They are then said to float on the charging source. At normal load, the open-circuit voltage of the battery should be equal to the voltage of the charging source; no current will then flow in or out of the battery. When the load increases, the voltage of the charging source will drop below the battery voltage, and the battery will discharge into the load. When the load decreases, the voltage of the charging source will rise above the battery voltage and the battery will be charged. In this manner a floating battery is kept always fully, or nearly fully, charged.

For such service the charging source must have a "dropping" characteristic, i. e., its voltage must vary with the load. The average floating voltage of a lead battery, the voltage at which it will neither receive a charge or discharge, is about 2.08 to 2.11 volts, in some cases 2.13 volts, per cell. The gravity of the pilot cell should be within 3 to 5 points below the previous overcharge maximum and should be maintained there. If the gravity rises above normal, the battery should be caused to discharge by temporarily lowering the voltage of the charging source until the gravity has become normal again. If, on the other hand, the gravity is temporarily below normal, the battery should be charged by raising the voltage of the charging source, until the gravity has risen to normal. The manufacturers of storage batteries recommend gravity readings for the purpose of determining the conditions of a floating battery at frequent intervals (1 hour for railway batteries, 6 hours for oil switch batteries).

A floating battery does not need to be charged regularly, but an overcharge must be given at stated intervals, generally about every 2 weeks. The advantages of floating are: first, the battery is always fully, or very nearly fully, charged, always ready to do its full share of the work. Secondly, owing to the fact that a floating battery is never regularly discharged and only subjected to momentary current rushes, the life of a positive plate in a floating battery and the total efficiency of the battery is very much greater than in a battery which is regularly charged and discharged. Finally, the load carried by the charging source is quite steady. It can, however, readily be seen that for exact voltage regulation or for carrying steady peaks, a floating battery will not be adaptable.

(To be Continued)

ENCLOSED FLAME ARC LAMPS

By G. N. Chamberlin

Engineer, Arc Lamp Department, General Electric Company

The principal difficulty encountered in the development of the enclosed flame arc lamp has been to find some means of effectually preventing the fumes thrown off by the arc stream from forming a deposit on the surface of the enclosing globe and thus seriously interfering with the illuminating efficiency of the unit. The author shows how the trouble has been satisfactorily overcome, with the result that long burning enclosed flame arc lamps are now available for operation on standard commercial series and multiple circuits, both alternating and direct current.—Editor.

In considering the design and operation of arc lamps commonly designated as the long burning enclosed flame lamp, it is interesting to note the inherent characteristics of the arc itself, together with the successful solutions of the various problems encountered in the design and perfection of the operating mechanism.

Flame carbon electrodes are composed mainly of carbon impregnated or mixed with certain salts, usually a calcium compound for producing a yellow light and a cerium compound when a whiter light is required. These salts are volatilized at a comparatively low temperature and become luminescent as they pass into the carbon vapor stream. As little light is obtained from the carbon tips, their temperature is not of vital importance. Therefore, comparatively large diameter carbons can be used without sacrificing the illuminating efficiency of the arc stream.

The introduction into the electrode of calcium fluoride or other mineral salts from which the arc receives its luminosity, causes a gas to be emitted during operation which on cooling condenses in the form of a fine white powder. This powder, if not suitably disposed of, will form a coating upon the globe immediately surrounding the arc in a comparatively short time. This coating obstructs the light rays in proportion to the density of the deposit.

Fig. 1 shows the inner enclosing globe surmounted by the condensing chamber, which is supported from the base plate of the lamp. The gases emitted by the arc rise and follow a path as indicated by the arrows. On striking the cooler metal of the condenser, they are reduced to the temperature of condensation. A small quantity of the gases, however, not having come in contact with the condenser, pass back and down the sides of the globe, and on reaching the lower section of the globe leave a deposit and again rise, once more passing the arc and entering the condenser; this circulation continuing until all condensible matter is deposited.

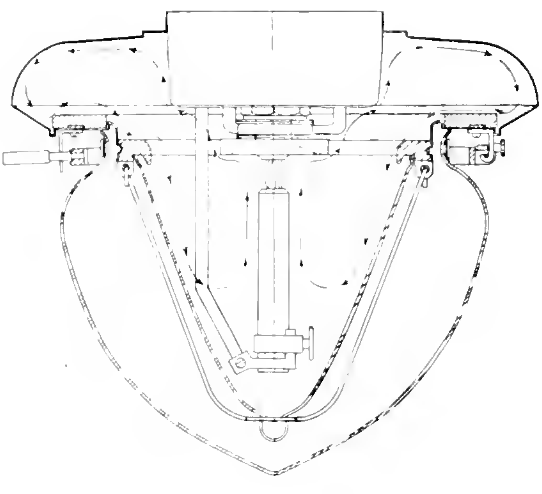


Fig. 1. Diagram of Enclosed Flame Arc Lamp, Showing Circulation of Air and Gases

In order to protect the surface of the globe from the effect of outside air, an outer globe is used.

Since the carbons are relatively expensive, it devolved upon the designers of the operating mechanism to obtain the longest possible life per inch of carbon consumed and to utilize the greatest percentage of the total carbon length employed. This condition has been admirably met in the design of the lamps shown in Figs. 3 and 4. A phosphor bronze bail holds the ground surface of the enclosing globe against the machined surface of a composition metal globe seat, this globe seat being permanently attached to the bottom opening of the condenser.

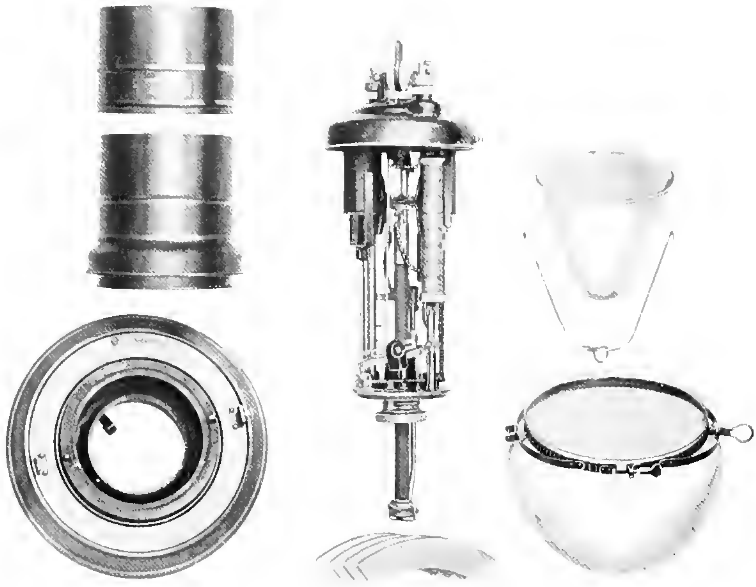
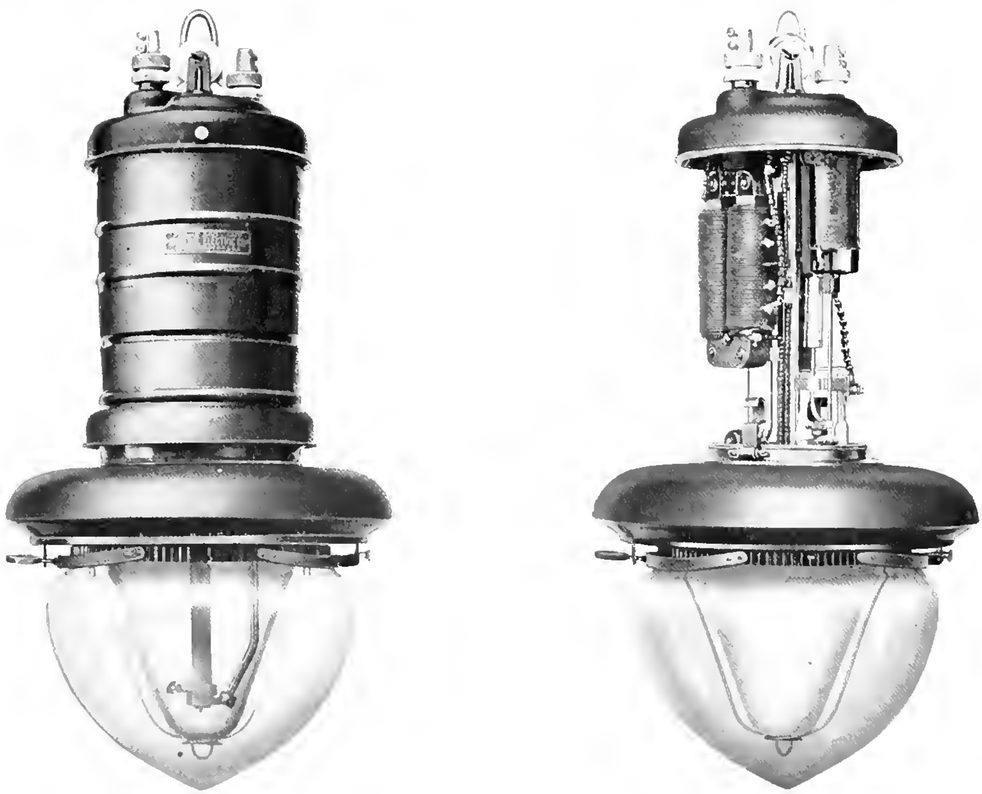


Fig. 2. Parts of Enclosed Flame Arc Lamp



10 Ampere A.C. Series

6.6 and 7.5 Ampere A.C. Series

Figs. 3 and 4. General Appearance of Enclosed Flame Arc Lamps

An asbestos gasket between the top opening of the condenser and lamp base assures an effective arc enclosure, and therefore the lowest possible rate of carbon consumption.

In trimming this lamp, a 12 in. upper and a 6¼ in. lower carbon are used. At the end of the trim the upper carbon measures 6¼ in. and the lower 1½ in. It is apparent that the stub from the upper carbon is of suitable length to be used as the lower, leaving only 1½ in. of unconsumed carbon to be thrown away and necessitating the use of but one carbon for each trimming—a most economical arrangement.

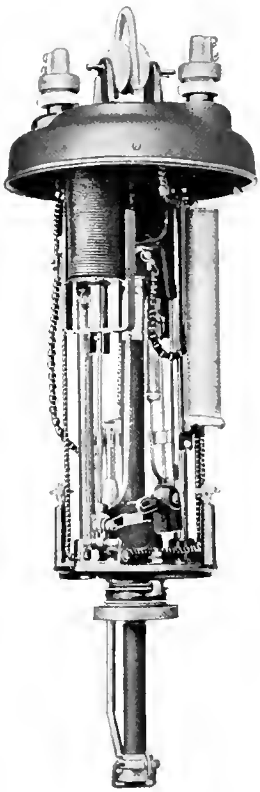


Fig. 5. 10 Ampere A.C. Series Lamp

Experience in the operation of both open and enclosed flame arcs has shown repeatedly the necessity of using directly above the arc a baffle, or as commonly called, an economizer. This part consists of a cup-shaped plate opening around the upper electrode and serving as a pocket for the lighter gases. These gases serve the function of lessening the leakage of air through the carbon bushing, thereby retarding the oxidation of the upper carbon and keeping the burning end square.

The lamp mechanism, as shown in Fig. 5, is built along the lines of modern American practice, which has been perfected during years of experience with the enclosed plain carbon lamp. A series magnet separating the carbons, a shunt magnet opposing the series through a suitable transfer lever, and a mechanical cut-out connected in series with an adequate starting resistance constitute the main elements. The upper carbon is weighted, this arrangement serving to bring the carbons together with sufficient force to insure the establishment of the arc. This construction, together with the use of liberally designed operating magnets, insures extreme operating reliability.

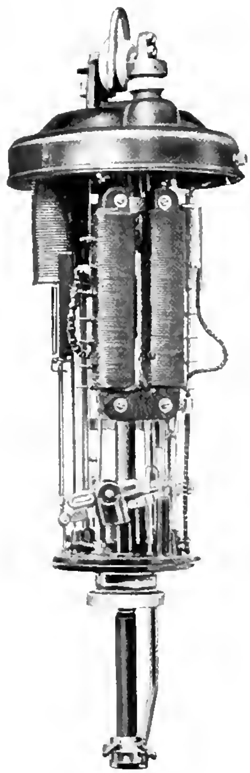


Fig. 6. Multiple Lamp

With the carbons at present commercially available, the best results as regards steadiness and efficiency are obtained with an arc of 10.0 amperes and 45 volts. Fig. 5 shows a lamp designed for operation on a 10.0 ampere alternating current series circuit. Where such a circuit is available, or where new station apparatus is required, this system is recommended.

There are at present in operation a large number of 6.6 and 7.5 ampere alternating current series enclosed arc systems, and where such station apparatus is already installed, the lamp shown in Fig. 4 should be used. This lamp operates at 7.5 amperes and 65 volts across the arc. Where a 10.0 ampere, 45 volt arc is desired, an internal auto-transformer lamp is used, as shown in Fig. 7. This lamp possesses the advantages of a 10.0 ampere, 45 volt arc when operated from existing constant current arc circuits, the auto-transformer being adjustable for 6.6 or 7.5 ampere circuits. The older enclosed lamps can be replaced lamp for lamp. For existing 7.5 ampere alternating current circuits,

Fig. 7. Lamps Supplied with Auto-transformer for Operation at 10 Amperes on 7.5 Ampere Series Circuit

the lamp shown in Figs. 3 and 5, with 7.5 ampere windings, may be used.

Constant Potential Types

The enclosed flame carbon lamp is also available for use on both alternating and direct current constant potential circuits of the usual commercial voltages. In external appearance the lamp is identical with that of the series type shown in Fig. 3. The mechanism of the alternating current type, shown in Fig. 6, differs from the series

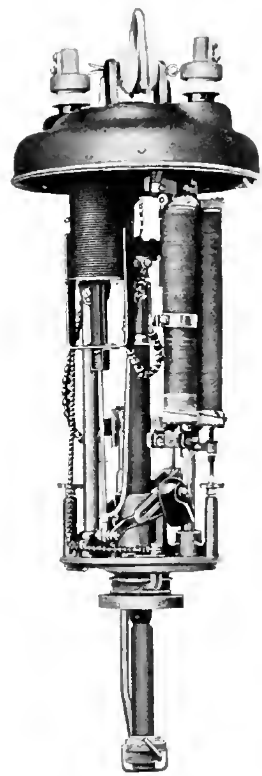


Fig. 8. D.C. Lamp

type only in that the shunt coil, cut-out and cut-out resistance are omitted and the series reactance necessary for multiple operation is supplied.

The direct current lamp shown in Fig. 8 is of the same general construction as the alternating current lamp, the reactance being replaced by a steadying resistance. The standard direct current lamp is adjusted for 6.5 amperes when operating on circuits that are nominally 110 volts. This type of lamp can also be furnished for operation in multiple-series on circuits of 220 volts and over.

The introduction of the enclosed flame carbon and the perfection of its mechanisms for operation on both series and multiple circuits affords an additional means for the attainment of better general illumination.

NEW TYPES OF ORNAMENTAL LUMINOUS ARC LAMPS FOR THE LIGHTING OF PARKWAYS, BUSINESS AND RESIDENTIAL STREETS

By C. A. B. Halvorson, Jr.

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This article may be regarded as a continuation of the paper on "the design of luminous arc lamps," by Mr. Halvorson, which appeared in the December, 1911, Review, which dealt with some of the more important fundamentals in the theory and design of the magnetite arc lamp. Since that time much new work has been carried out on this type of lamp, and the unit is receiving an increased application for various fields of exterior lighting. The present article deals with three new forms of ornamental luminous arc lamps which have been now developed: first, for the principal business streets of a city, second, for use on residential streets and boulevards bordered by large estates, and third, for roadway work where an extremely low intensity of illumination is adequate for all purposes. In this paper Mr. Halvorson deals with the particular requirements of these three fields of exterior lighting, and shows how the lamps referred to meet these requirements.—Editor.

During the past decade the improvement in the character of display lighting, as well as the greatly extended use of such illumination, has been truly remarkable. Many thriving communities point with pride to their attractively and well-lighted thoroughfares and attribute much of their growth and prosperity to this feature. The great potential value of good street illumination is now generally appreciated, so that today the city that does not realize, at least to some extent, how modern street lighting may become a potent factor in its development is indeed the exception rather than the rule.

The immense value of good exterior as well as interior illumination in connection with mercantile establishments has long been realized by the wide-awake and "up-to-the-minute" merchant, who has won business from his competitor across the way by means of the electric sign in some of its various forms or by the use of flaming arc lamps of high candle power hung without his place of business. Likewise places of amusement and refreshment have turned into great practical account well-known psychological phenomena induced by the lavish use of display illumination.

Municipal authorities have long been cognizant of the importance of good street lighting as an adjunct to the successful policing of the districts within their jurisdiction. Consider the cases of the property owner, the stranger and the pedestrian: each from his own point of view appreciates and enjoys the aid and protection afforded by well-lighted streets and parks.

With the development and growth of the automobile industry and the consequent improvement of the highways, there has arisen another large class of people widely awake to the importance of good street lighting and appreciative of its benefits.

On every hand the subject of good exterior illumination is receiving careful study and attention. Business men's associations, civic leagues, and prominent individuals carry this matter uppermost in their deliberations. The local lighting company takes pride in the adequateness of its lighting system, and endeavors to keep pace with all engineering development bearing on this important subject. Art commissions pass on the desirability of the standards and fixtures employed from the viewpoint of æsthetics. Our great national scientific associations from time to time appoint able committees to investigate and report on every phase of the new developments in street lighting, and the electrical industry annually expends a vast sum in research and investigations pertaining to this problem.

What then, can be of more importance to a community than the broad subject of adequate and proper exterior illumination? To quote from a recent publication. *"Good street lighting pays in dollars and cents, pays tremendously in attracting business, pays in greater real estate values, pays in animating avenues that would die after sunset. It is light that has made Broadway in New York the most talked of street in North and South America and the most prosperous avenue in the world; light that causes newspapers to advertise it gratuitously as the 'Great White Way.' "

In planning a system of exterior illumination to meet the requirements of the city of today, the needs of each section of the city must be carefully considered. The shopping centres demand one type of illu-

* "Ornamental Street Lighting" published by the National Electric Light Association.

mination peculiarly their own; the residential streets, open parks, drives and outlying districts each in their turn require special consideration and quite different treatment, as regards both the illuminating units and the ornamental standards or fixtures employed.

Unfortunately, it is quite impossible by the use of illuminating data alone to show exactly what system of lighting should be employed in each case to accomplish the best result, as frequently certain psychological and physiological requirements play parts of vast importance. However, with the general use of the underground system of distribution well established, it is now pretty thoroughly agreed that ornamental lighting units should be employed wherever possible. It is with the subject of street illumination by the most modern ornamental lighting units only that the present paper deals.

Less than a year has elapsed since the ornamental luminous arc lamp was first described in the GENERAL ELECTRIC REVIEW†, and considerably less than that period since the commercial introduction of this efficient unit in the now justly celebrated "Great White Way" at New Haven. Since that time the success attained by this type of arc lamp, both there and elsewhere, has resulted in the design and standardization of three new forms of ornamental luminous arc lighting units which are known as the Great White Way lamps (two forms) consuming 520 watts at 6.6 amperes, and 320 watts at 4 amperes; the residential lamp, consuming 300 watts at 4 amperes; and the parkway lamp designed for operation at both 4 and 6.6 amperes, 300 and 500 watts respectively (Fig. 1).

The Great White Way lamps are for use on the principal business streets of cities, where the purpose of the illumination is to create sunny day effects with the consequent stimulation and exhilaration which accompanies such conditions. The intensity of such illumination of necessity must be high and the distribution good. Therefore the units employed should be placed comparatively close together.

The residential lamp, as its name implies, in addition to its use in Great White Way lighting is also used on fine residential streets and on boulevards bordered by large estates, where as a rule, shade trees overhang the lamp location. In such cases the low mounting of the light source (12 ft.) permits good illumination as it escapes screening by the foliage. A denser globe equipment is recommended for this kind of lighting, where a lower intensity illumination is permissible and where a reduced brilliancy is desirable.

The parkway lamp gives a somewhat more extended light distribution than the two units just mentioned and is designed especially for roadway work where an extremely low intensity of illumination is adequate for all purposes. In lighting roadways the requirements of vehicles are usually of first importance, and therefore this light source is mounted well above and to one side of the direct line of vision, and is screened with a large diffusing globe acting as a semi-secondary light source of

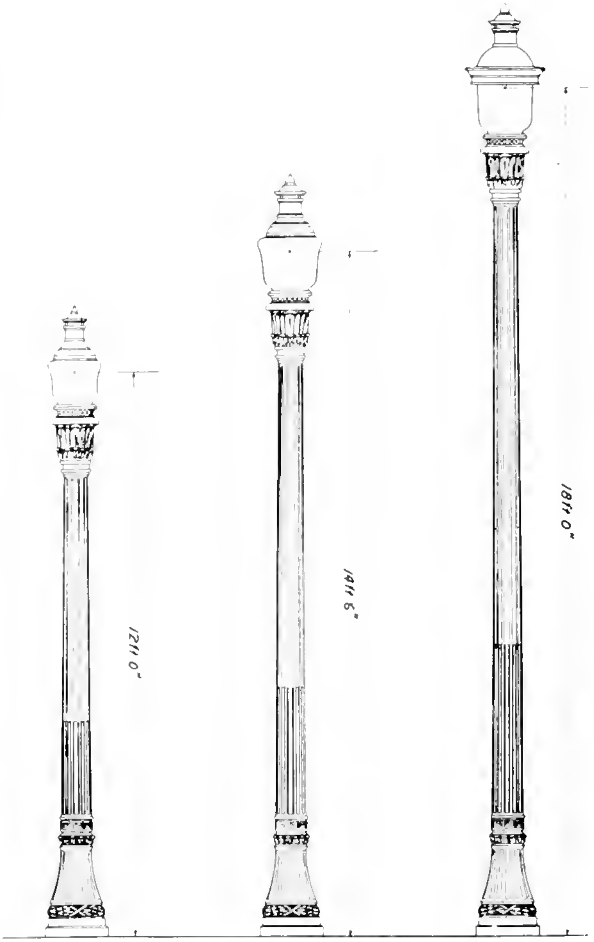

Fig. 1. Ornamental Luminous Arc Standards for White Way, Residential Streets and Parkway Lighting

† December, 1911.

fairly low intrinsic brilliancy. With this form of luminous arc lamp an internal reflector is furnished, and therefore the characteristic light distribution is not greatly different from the well-known standard pendant types of luminous arc lamps. A

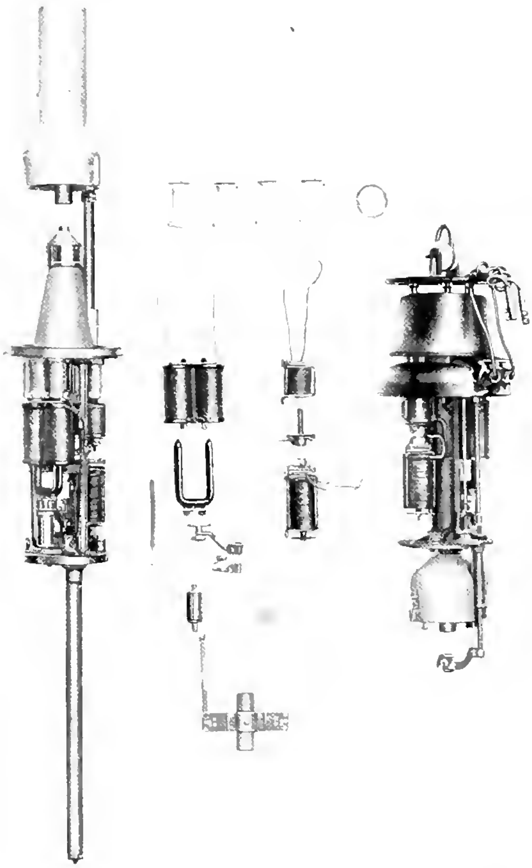

Fig. 2. Mechanism of Luminous Arc Lamps and Parts which are Used in Common in Standard Pendant and New Ornamental Types

large hood is provided to prevent dust and dirt from washing down and depositing over the glassware, as this lamp is of the extremely long burning type (per trim) and consequently requires attention at infrequent intervals.

With these three units shown in Fig. 1 it is believed that the complex and exacting requirements of scientific street illumination can be successfully met, both from a utilitarian and from an artistic viewpoint. The introduction of the smaller and consequently lower candle-powered units will be greatly appreciated by those cities which possess at the present time an installation of the pendant type of standard luminous arc lamps, as these new ornamental units are interchangeable with the pendant type units insofar as their operating characteristics are concerned, and contain many vital mechanism parts such as magnets, clutches, etc., which are common to both. (Fig. 2.)

In designing a proper system of lighting, careful consideration must be paid to the purpose of the illumination, that is, what is the illumination for and what is to be accomplished?

The lighting of the business streets requires, in addition to the usual purposes of good general lighting (police protection, ability to read easily and distinguish persons, etc.), an illumination tolerable and pleasing to the eye, yet sufficiently brilliant to produce a marked effect in the improvement of business —obviously a matter of great general interest to the city.

It is necessary, then, to provide an illumination which will attract people to the brilliantly lighted thoroughfares and at the same time allow their attention to be drawn freely to the matter of next importance, which is, of course, the attractive window displays and decorations. This object is largely attained by means of the contrast between the color schemes employed in these decorations and the color of the general illumination. It follows, therefore, that general illumination must be furnished that differs in color from the small lighting units usually employed in the merchant's local display, and also differing from and not interfering with the color effects obtained by reflection or secondary illumination from the goods displayed. White light falling on the show window from without can only enhance the color values by showing them correctly. Obviously, then, color and quality of the light play a most important part in successful lighting of this kind; accordingly white light of low intrinsic brilliancy must be employed in order to obtain the best results.

The intensity of the illumination, perhaps, should be considered of next importance; i.e., the ratio of general illumination to window illumination should be such that the window illumination far outweighs the general illumination. As good window display lighting requires in the neighborhood of 15 ft. candles, it is highly improbable that any economical scheme of general illumination that could be obtained would approach this figure. A possible exception is yellow flame arc lighting, which on account of the color would be highly unsuitable, assuming that such illuminants were placed low, as they usually are in this country, and in the direct range of vision; in which case an immense volume of light would be directed toward the show windows.

Other important considerations are: the appearance of the lighted unit; the illumination of the building fronts from both æsthetic and economic viewpoints, the latter particularly as regards the benefits accruing to the upper-floor tenants; the minimizing of light sources for a fundamental physiological reason, i.e., the irritation produced on the eye by many light sources; the daytime appearance of the lighting standard, dignified, simple, or ornate, as harmony with its surroundings requires, and yet unobtrusive and free from overhanging arms and glassware that may impede teaming and endanger pedestrians. Above all it must aid in beautifying the street rather than to produce the effect of crowding and overburdening which is so characteristic of many systems of so-called ornamental lighting.

Fig. 3. Great White Way Lamp Mounted on Iron Standard Designed for Rochester, N. Y.

Illuminating data on the New Haven Great White Way installation may be found in the April issue of the GENERAL ELECTRIC REVIEW, and may be of interest, as by many the New Haven lighting has been regarded as eminently satisfactory. An illustrated description of the lighting at Baltimore by means of these lamps will be published in a later issue of the REVIEW.

The problem of laying out a Great White Way system is quite different from the problem of lighting the streets of the residential section, for the latter is largely a utilitarian one and bears on the matter of police protection and suitable lighting for pedestrians, motorists, and other users of the thoroughfare.

Residential street lighting from its very nature is of low average intensity. As this class of lighting comprises a relatively large percentage of the city's streets, it is important for obvious reasons that the most efficient unit suitable be used. It is desirable, also, to employ as few light sources as possible for a given average intensity of illumination; otherwise, the apparent effect produced by many small light sources is that of a very much lower intensity of illumination, because the only images produced on the retina of the eye are those of the light sources themselves. Especially is this so in the case of oiled roadways where the amount of light reflected is extremely small.

Fig. 4. A Simple Design of Parkway Ornamental Luminous Arc Lamp Mounted on Wooden Column with Iron Base

We are all familiar with the difficulty of seeing by moonlight under certain conditions. Discernment of objects is practically impossible if the moon happens to be within the range of vision, while with the moon at the observer's back the ability of the eye to discern objects in silhouette against the lighted background is greatly improved. So it is with the uniform low intensity illumination obtained with the use of small units; if the light sources could be removed absolutely from the line of vision, such low intensity illumination might be used.

In residential street lighting the principle of silhouette lighting* must be employed;

*"An Unrecognized Aspect of Street Illumination" by Preston S. Millar, Transactions of the Illuminating Engineering Society, October, 1910.

that is, most of the seeing is accomplished by the discernment of objects in contrast with a lighted background, which is usually the street surface, rather than by light reflected from the objects themselves. (Fig. 6). In the opinion of the writer a non-

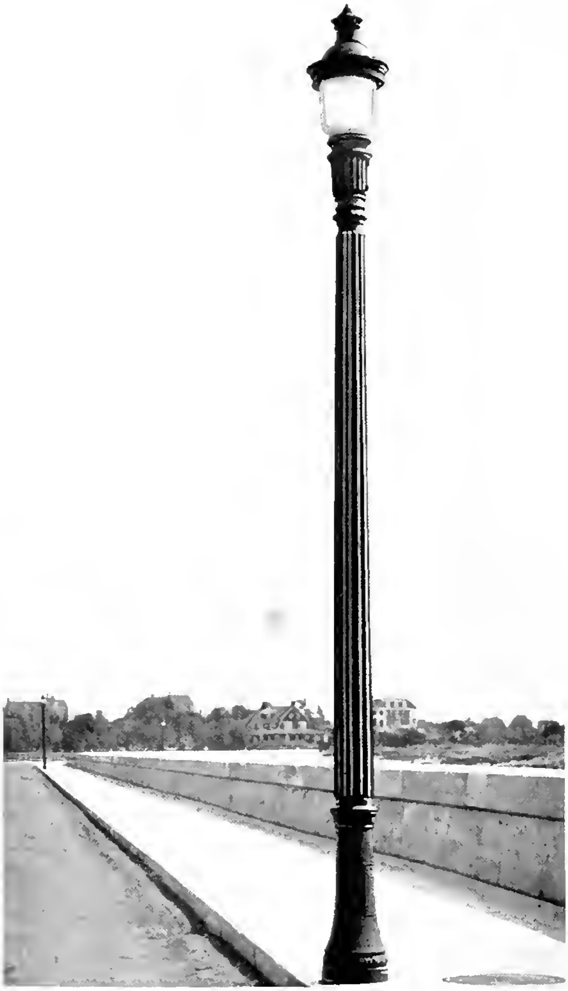

Fig. 5. Installation of Three 4-Ampere Parkway Ornamental Luminous Arc Lamps on Marblehead Causeway

uniform illumination is more desirable for this kind of lighting than one extremely uniform, assuming that the minimum intensity in each case is about equal, but the average intensity higher in the case of the arc lamps than in the case of low candle-powered units; and assuming of course the same expenditure of energy per linear foot of street and that each light source is properly screened by means of a diffusing globe.

The 4 ampere residential type lamp fulfills these peculiar requirements. An installation of this character will show fewer light sources within the range of vision, beautify the streets to a much greater extent, and produce a more satisfactory illumination for the same cost of installation and maintenance than any other lighting unit available at the present time. The globes used with these lamps act as secondary sources of pure white light of low intrinsic brilliancy; consequently the units themselves are extremely pleasing to the eye by night as well as by day, fulfilling all æsthetic requirements.

The proper lighting of drives, highways and parkways requires the use of a special lighting unit which combines white light with maximum efficiency and a low maintenance cost, as well as a low initial cost when compared with the installation of many small units of low candle-power. The cost of installation for such lighting is a serious factor, for there is usually comparatively little money available for this kind of lighting. The problem of illumination concerns almost wholly the motorist and drivers of other vehicles. We are continually reading of serious night accidents, involving the automobile usually with a horse-driven vehicle or a motorcycle, which statistics show could have been avoided had adequate illumination been provided. The requirements of such illumination are not greatly different from those of the residential streets, as described above; that is, the silhouette principle of lighting should be employed. With such lighting the ability of the eye to see objects clearly a sufficient distance ahead to avoid collision, is greater than with any other type of illumination. Obviously, it is necessary that the light sources should be mounted well above and outside the direct line of vision, and that they should be of low intrinsic brilliancy, as too intense a light source injures the adaptability of the eye to such average low intensity work. For this reason also, the use of low, closely spaced units of 100 c-p. or less with unscreened sources should be avoided.

Figs. 4 and 5 show the parkway ornamental luminous arc lamp. By reference to Fig. 5 it will be observed that there is nothing to reflect light except the roadway and sidewalk. The roadway is heavily oiled and the lamps are spaced 565 feet apart. Automobiles and pedestrians can be discerned in silhouette with the greatest ease.

Another objection to uniform low intensity lighting on roadways is that the glare of the approaching automobile absolutely destroys the adaptability of the eye to such low intensities. Therefore, the desirable thing to be attained is the elimination of the light from

light flux possible to be obtained from the magnetite arc at the present writing. The lower electrode in the 6.6 ampere lamp is $\frac{9}{16}$ in. in diameter by 15 in. long, and gives a life of not less than 125 hours per trim; while

Fig. 6. Photograph of Automobile Silhouetted Against Lighted Roadway as a Background

(This photograph is greatly under-exposed, and does not do this type of illumination anything like justice.)

the width of the street, all playing important parts. These lamps, mounted on ornamental brackets, also lend themselves to monumental pillar lighting where there may be many units on each pillar. These two lamps are designed to give the maximum

accumulate on the outside of the globe.

For residential streets and broad boulevards where the screening effect of foliage must be considered and for all other lighting which can be classified under the heading of "second class", the residential lamp can be employed with best results. The spacing of this lamp, like that of the lamps just described, varies with the local conditions, but 300 ft. apart in staggered arrangement gives an exceedingly satisfactory illumination.

For highways, open parks and drives and all other purposes where an efficient ornamental unit is desired and where there is but little chance of screening the light source by foliage, the Parkway lamp must be employed in order to utilize to the highest degree the principle of silhouette lighting. Such lighting can be classified under the heading of "third class." This classification applies only to lighting by these three modern units, as obviously there are further classes of lighting where the illumination is very much lower and can hardly be considered as satisfactory street lighting for any purpose except to mark the highway. For 4 ampere operation, a $\frac{9}{16}$ in. by 15 in. electrode is employed, giving approximately 200 hours life per trim, and at 6.6 amperes electrode of the same dimensions is used giving 125 hours per trim.

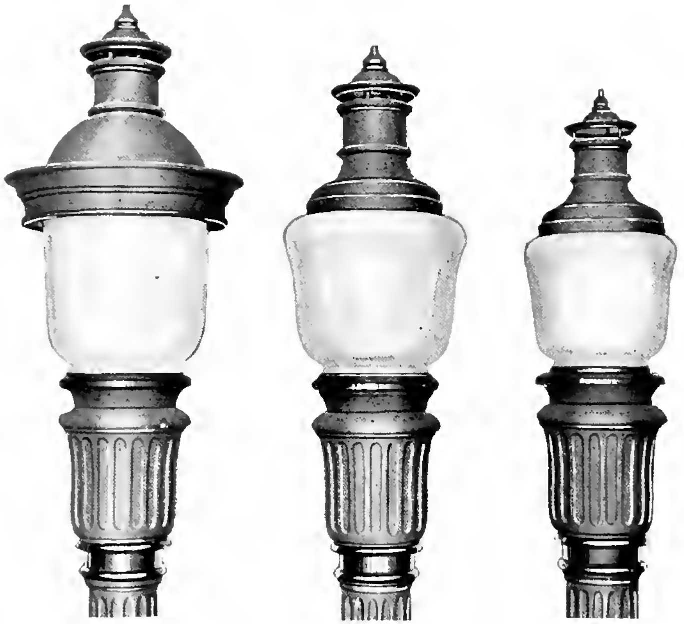

Fig. 8. View Showing Difference in External Appearance of the Three Ornamental Luminous Arc Lamps

The complete standardization of design as carried out in these units increases the flexibility of the present standard luminous arc lighting system so that the requirements of these three classes of lighting can be successfully met without the employment of various kinds of lighting units differing greatly one from another in their mechanical design (Figs. 7 and 8). This feature is one which will be greatly appreciated by the operating man.

BOOK NOTICE

ORNAMENTAL STREET LIGHTING

By Waldemar Kaempffert

Published by the Commercial Section of the National Electric Light Association

48 Pages Profusely Illustrated

The text of the book has been put together from information compiled by a very strong committee on electric advertising and ornamental street lighting appointed by the Commercial Section of the N.E.L.A.; and the purpose of the volume is to collect and present in the most compelling manner all the arguments in favor of the adoption of ornamental street lighting by the municipal corporations; to educate the city authorities as to what constitutes good ornamental lighting, and how the various sections of their city should be lighted; to provide them with figures from which they can form some idea of what the cost of such lighting will be in their own particular case; and to give them full references as to names of manufacturers who are willing, and in a suitable position, to provide them with expert advice on their local propositions. The book is a splendid example of co-operation between the various electrical interests all with a common object in view. The publication is receiving a very wide circulation; and it is impossible to conceive that there can be any man in this country, occupying a position of authority in the administration of his city's government, who, after reading the booklet and studying the pictures, could resist the impulse to commence then and there an agitation for a modern ornamental system of street lighting, should his city be one of those whose names are not yet on the list of the progressive municipalities. He is led gently along through the body of the book until he comes upon the After-word: "Ornamental street-lighting is not an experiment. Three hundred cities in the United States and Canada have tried it and approved it; three hundred cities whose inhabitants have worked together whole-heartedly in the effort to make their streets more attractive; three hundred cities that have found that every dollar invested in an ornamental lighting system for business sections, residential districts, and parks is not only returned manifold in higher real estate values and in greater prosperity, but returned in prestige, in heightened civic pride, and in better citizenship. In the following pages you will find a list of these cities. Is your city among them?" The design of the cover and body is strictly in keeping with the subject—tasteful, substantial, dignified. The press work is excellent and the cuts well arranged.

AN INVESTIGATION ON REFLECTORS FOR TUNGSTEN LAMPS

By A. L. Powell

Edison Lamp Works, Harrison, N. J.

This article summarizes the results of an extensive investigation of various commercial types of reflectors, divisible into two main groups, industrial and decorative. The text describes the physical nature of the reflector, while the cuts illustrate its appearance and its distribution properties. The photometric values of the various reflectors tested are grouped into an interesting table. The article includes some information on the general trend of practice with regard to this apparatus, and concludes with a summary of the points to be considered in the selection of a reflector to suit a particular service.—Editor.

The primary functions of any reflecting device are to redirect the light, and to shade the light source of high intrinsic brilliancy. The artistic effect of the complete unit is, in many case, of primary importance, but in other instances, such as industrial lighting, it is only a secondary consideration.

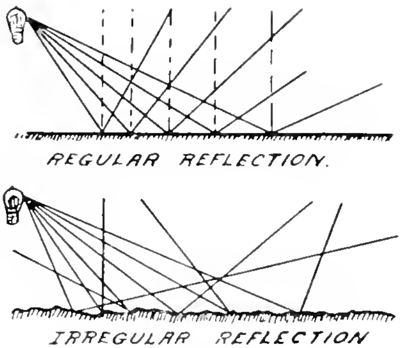

Fig. 1

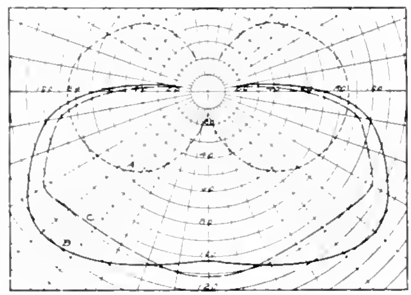

Fig. 3. Characteristic Distribution of Reflectors Shown in Fig. 2

The necessity of some device in connection with the incandescent lamp is apparent, when we consider its distribution curves. The maximum candle-power of the tungsten filament lamp is in the horizontal direction, and is six and one-half times the downward; hence, with a bare lamp, most of the light is thrown to the side walls, and not on a working plane, where it is desired. On a hasty survey one might say: "Why then do not manufacturers make the lamps with the maximum candle-power downward?" Further consideration shows that it is really a fortunate circumstance that this is not the case. With the present type of lamp we have a means of controlling the distribution; and, by choosing the proper reflectors, can obtain even illumination with almost any hanging height and spacing. Light from a bare lamp can only reach the working plane by secondary reflection from the walls, and this involves loss, due to absorption of the walls' coverings, some absorbing over 90 per cent of the total flux striking them. Not only is there this direct absorption; but any light which strikes the wall above the horizontal must be multi-reflected to reach the plane to be illuminated, involving much loss if the walls and ceilings are dark. Therefore, if we have a means of reflecting the maximum light with small absorption, increasing

Fig. 2. Flat Dome Type Reflector, Porcelain Enamel Finish

the downward candle-power, and allowing only a relatively small percentage of the total light flux to reach the side walls and ceilings, we have made a net gain in efficiency of a remarkable degree.

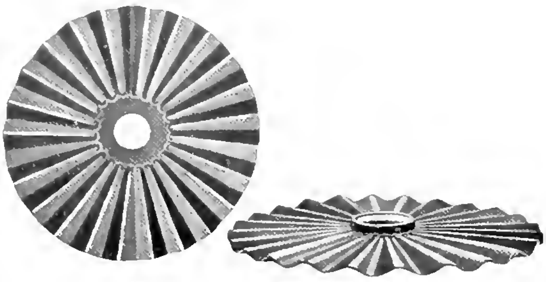

Fig. 4. Radial Fluted Type Reflector Porcelain Enamel Finish

From this discussion it should not be assumed that illumination on a certain working plane is always the primary factor. In residences, for instance, a diffused light is very necessary on the side walls and ceilings, and there are numerous other cases demanding similar treatment. As with any other light source, some protecting device must be used to properly diffuse the light and protect the eyes from the high intrinsic brilliancy. A shade more properly softens and diffuses the light, or produces the desired artistic effect; while a reflector redirects the light by either regular or diffuse reflection. If the light is transmitted through glass, with its direction changed by means of prisms, the device is known as a refractor.

Reflecting devices are very logically divided into three classes, decorative shades; diffusing shades; and reflectors and refractors. It is not the purpose of this article to discuss the first two classes, but rather to summarize the results of a series of investigations on various commercial types of the third class. A very excellent review of the properties of the entire field is found in Mr. V. R. Lansingh's *Shades, Reflectors and Diffusing Media,* pages 885 to 929, Lectures on Illuminating Engineering, the Johns Hopkins Press. The third class is readily divisible into two main groups: Industrial and Decorative. The industrial reflectors include the opaque diffusing and the opaque specular reflector; while the decorative, or the type used in stores, residences, etc., includes the translucent diffusing and the prismatic reflectors. This classification, however, is not absolute, as reflectors of the second class are frequently used in the industries; but the industrial reflector is rarely used in residences, stores, etc., with the exception of the indirect unit, which is an opaque specular reflector.

The difference between regular and irregular, or diffuse, reflection is readily shown by the sketch in Fig. 1. In regular reflection the angle of incidence equals the angle of reflection. With diffuse reflection, owing to the rough surface and each ray of light being regularly reflected from the small upset area which it hits, the individual rays are thrown in all directions.

The great majority of the industrial reflectors are of the opaque diffuse reflecting type. Their surfaces are of enameled porcelain, white enamel paint, or aluminum, painted or matt. The enameled porcelain reflectors are especially advantageous, as a good finish has virtually the effect of glass, and hence possesses all of its advantages. If not well made, however, it is liable to crack around the edges, thus exposing the inner metal to corrosion from the atmosphere; in addition to which if the coated metal is not rigid, it will bend in handling and the finish will chip off. Briefly its chief advantages are: (1) *Ease of cleaning.* Soap and water, or even a wet rag will give the porcelain a bright, clean surface, even though it has become greasy and dirty from being handled by operatives. The aluminum or paint finish, however, is liable to be marked and scratched if rubbed hard, and will, after a number of cleanings, be worn off in spots. (2) *Resistance to acid fumes.* The all-porcelain finish is not affected by any of the ordinary acids. Past experience has shown that the paint of both types has dropped off in scales when subjected to an atmosphere in which sulphurous or similar fumes are present. (3) *Resists heat better*

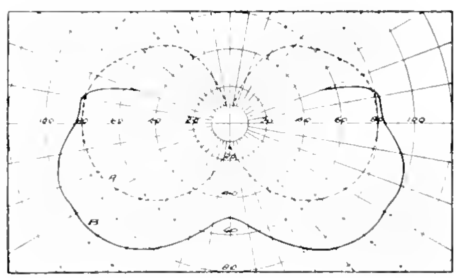

Fig. 5. Characteristic Distribution of Reflectors Shown in Fig. 4

than the paint finish. In numerous cases paint has been blistered or discolored merely from the heat of the lamp alone. (4) *Gives much better service in the open,* as it will not wash off with rain, and hence the under metal is not liable to rust. (5) *The porcelain finish is a somewhat better reflector* than the dull aluminum finish. It is not quite as good as in the white paint, but better than the paint which for some time has been in service. These reflectors usually give a wide angle of distribution, and cannot be designed to give as great a variation of curves as regular reflecting devices.

Before treating the various classes of reflectors, it might be well to mention the types of distributions usually found. Logically, these are arranged as follows: Distributing, extensive, intensive, focusing and concentrating. The terms denote quite clearly the kind of photometric curve.

Relative Efficiencies of Commercial Types

To determine the relative efficiencies of the various commercial types, sample reflectors of the 100-watt size were purchased in the open market. Both the industrial and decorative classes were investigated, using holding devices as recommended by the manufacturers.

Flat dome type. Porcelain enamel finish. Diffuse, opaque industrial reflector. Seven types of five makes investigated. Fig. 2 shows the group of reflectors tested. These reflectors give a distributive type of distribution, and are well adapted for use in rooms with low ceilings, or other places where the spacing is comparatively wide, and where evenly-distributed general illumination is required. The maximum candle-power of the reflectors tested is found between the angles of 40 and 60 degrees, and is constant throughout that zone. Some makes are white under surface, with green or blue upper; others are white on both surfaces, with green or blue elastic binding edge, and one is white porcelain enamel throughout. The deep-colored upper surface has the claimed advantage that it does not readily show collected dust. The white porcelain on both sides is the easier reflector to manufacture; a better coating results, and since the collected dust shows more readily, these reflectors are more likely to be cleaned. The under surface and lamp will undoubtedly be wiped off at the same time, increasing their efficiency. Everyone realizes that this is a desirable condition. The binding edge adds to the appearance of the unit. As seen, some of the types are weatherproof, the socket being contained in a protecting cap. Fig. 3 shows the characteristic distribution of this type of reflector, and Table No. 1 gives the photometric values.

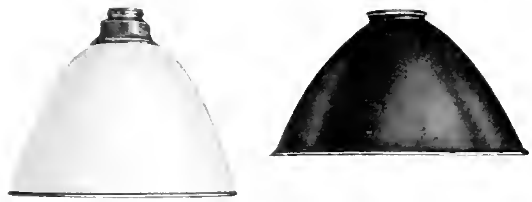

Fig. 6. Bowl Type Reflector, Porcelain Enamel Finish

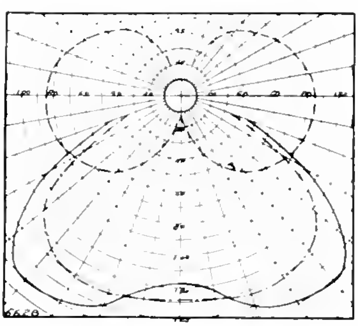

Fig. 7. Characteristic Distribution of Reflectors Shown in Fig. 6

Radial fluted type. Porcelain enamel finish. Diffuse opaque industrial reflector. Two types of two makes investigated. Fig. 4 shows the group tested. These give a very wide angle of distribution, and are well used in street or yard lighting, or in interiors on low suspension and very wide spacing. The maximum candle-power is at 75 deg. and a little light is allowed to escape above the horizontal and light the surrounding buildings to a low intensity—a desirable condition in street illumination. Fig. 5 shows the characteristic distribution, while efficiency values are shown in Table No. 1.

Bowl type. Porcelain enamel finish. Diffuse opaque industrial reflector. Two types of two makes investigated. Fig. 6 shows these. The distribution is extensive and serves well for general illumination with reasonably high hanging and moderate spacing, or localized general illumination. The bowl type, while

These reflectors were tested with clear and bowl-frosted, high operating efficiency, tungsten filament lamps in the regular photometric method for obtaining the distribution in a vertical plane. These results have been averaged for each group and the values for the *clear* lamp and reflector given in tables 1, 2, and 3.

TABLE 1—INDUSTRIAL REFLECTOR

	Flat Dome Enamel 5 Makes 7 Types			Radially Fluted Enamel 2 Makes—2 Types			Bowl Enameled 2 Makes—2 Types			Bowl Aluminized 4 Makes—5 Types			Clear Lamp
	Max.	Min.	Average	Max.	Min.	Average	Max.	Min.	Average	Max.	Min.	Average	
Mean lower hemispherical candle-power	113	93.9	104.0	94.5	90.8	92.6	82.0	80.3	81.1	81.5	64.2	75.5	70.7
Mean spherical candle-power	61.3	47.0	54.0	63.5	60.0	61.7	40.9	40.2	40.7	40.7	32.1	37.8	67.3
Percentage decrease in mean spherical over clear bare lamp	30	9	20	11	7	9	40	39	40	52	39	44	
Lumens flux (0 to 60° zone)	484	369	398	294	280	287	447	436	442	496	319	419	177
Downward lumens (0 to 90° zone)	771	591	654	595	570	583	515	505	510	514	403	475	444
Total lumens	773	591	677	794	755	774	515	505	510	514	403	475	846
Weight in ounces *	51	24	39	48	31	40	24	13	20	19	11	13	
Diameter	18	12	16	20	16	18	9	8¼	8½	9	7	8	

TABLE 2—DECORATIVE OPALESCENT REFLECTORS

	Blown Bowl 6 Makes 9 Types			Pressed Bowl 8 Makes—16 Types			Blown Flared 5 Makes—7 Types			Pressed Flared 7 Makes—9 Types			Clear Bare Lamp
	Max.	Min.	Average	Max.	Min.	Average	Max.	Min.	Average	Max.	Min.	Average	
Mean lower hemispherical candle-power	81.3	69.5	72.3	88.0	64.3	73.0	93.5	78.5	88.3	96.0	80.0	85.7	70.7
Mean spherical candle-power	61.4	51.7	56.0	63.4	46.1	57.6	61.6	54.2	58.5	62.0	56.0	60.0	67.3
Percentage decrease in mean spherical candle-power over clear bare lamp	23	8	17	31	6	14	19	8	13	17	8	11	
Lumens flux (0 to 60° zone)	324	268	303	355	244	304	391	305	349	332	226	295	177
Downward lumens (0 to 90° zone)	511	429	454	553	405	458	586	493	553	602	503	537	444
Total lumens	774	650	703	769	578	723	776	680	735	778	704	755	846
Weight in ounces	22	11	17	45	24	35	38	20	30	54	24	43	

TABLE 3—PRISMATIC BOWL

	4 Makes 11 Types		
	Max.	Min.	Average
Mean lower hemispherical candle-power	92.6	72.2	80.6
Mean spherical candle-power	60.9	54.9	58.1
Decrease in mean spherical candle-power over clear bare lamp	19	10	13
Lumens flux (0 to 60° zone)	443	267	331
Downward lumens (0 to 90° zone)	580	454	506
Total lumens	760	690	732
Weight in ounces	33	21	27

* Some have socket included.

NOTE.—The maximum and minimum values are the values obtained from the group and not on any reflector, i.e., the maximum mean lower hemispherical candle-power may be from one reflector, the maximum spherical candle-power from another of the same group and so on.

not as efficient over all as the wider reflectors, has the great advantage that the lamp is hidden, preventing eye strain and glare. The maximum candle-power is between 30 deg. and 40 deg. One type has the green exterior finish, while the other is white with a green binding edge. Fig. 7 shows the characteristic distribution; while the efficiency values are found in Table No. 1.

Bowl type. Aluminum interior finish. Diffuse regular (or spread) reflection opaque, industrial reflector. Five types of four makes investigated. Fig. 8 shows these. With aluminum interior finish it is possible to vary the photometric curve through a wide range. If the finish is not good, there is deterioration through the wearing of the surface, and the embedding of small dust particles in the pores of the metal. The distributions are characteristically extensive, intensive or focusing, depending on the shape of the reflector. This class is, with extensive distribution, applicable to localized general, or general illumination; or, with the more concentrating curves, for local lighting, and has the usual advantages of the bowl type. The maximum candle-power is found at angles from 0 to 45 deg., depending on the shape. No one curve is characteristic of the group, and the values in Table No. 1 should not be given undue weight, due to this variation of distribution; i.e., one reflector may have a maximum efficiency in certain angles, and be best adapted for the case in hand, although another has a higher overall efficiency. Aluminum finish, bowl reflectors are also made in angle types, giving an asymmetrical distribution. Space will not permit a discussion of their properties. This class finds application in localized machine lighting, art gallery lighting, stage lighting, etc.

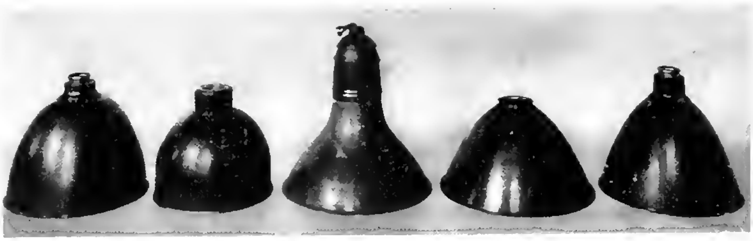

Fig. 8. Bowl Type Reflector, Aluminum Interior Finish

Opaque direct reflectors. Polished metals are very efficient but give more or less streaked illumination, and hence are not in common use. Mirrored reflectors are made of plain mirror strips, corrugated strips and reflectors directly silvered. The plain mirror strips are usually made in cone shape. They have high reflecting power, but deteriorate from the temperature. The cone reflectors give a concentrating distribution but produce considerable glare, and, hence, are rather poor for use anywhere in the line of vision. With corrugated strips, the light is broken up and diffused. The streaks may be eliminated with some loss of efficiency; and since we have regular reflection, any desired distribution is obtainable with properly designed reflectors. Made in the form of a trough, they are suitable for window and picture lighting. With the silvered reflector the body is made of clear glass, silvered on the back and this covered with enamel. The glass can be blown to any shape, and any dis-

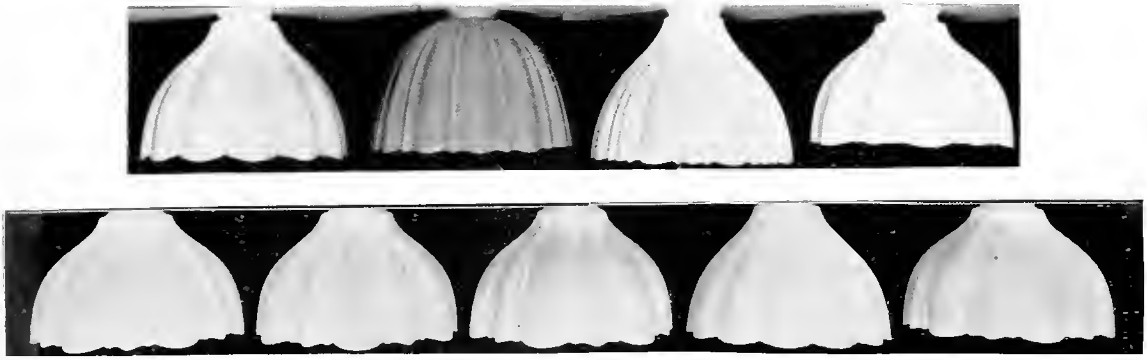

Fig. 9. Blown Bowl Shaped Opalescent Reflectors

tribution can be obtained. Streaks are prevented by ribs or corrugations on the glass. The deterioration is probably less than the mirrored strip reflector; but in the case of the inverted unit the dust will settle

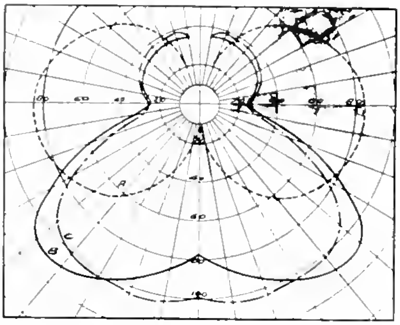

Fig. 10. Characteristic Distribution of Reflectors Shown in Fig. 9

in the bowl-shaped glass portion. As most of the reflectors of this class are designed to give an asymmetrical curve, or to be used indirectly, space will not permit a discussion of the actual efficiencies.

This covers the common types of industrial reflectors and brings us to the final division, namely, those such as would be in good taste in residences, stores, etc. There are translucent diffusers and prismatic. Fabrics lined with white and ground glass come under the first of these decorative classes.

Opal and white reflectors are coming more and more into prominence, and have assumed considerable importance. If their interior surface is polished, or in its natural state, there is considerable direct reflection. If the interior surface is depolished, we get but little variation of the distribution curve by changing the shape of the reflector. The light reflected comes from three sources: (1) Reflected from the glazed interior surface; (2) reflected from the opal particles in the body of the glass; (3) reflected from the outer surface, after passing through the body and striking at less than the critical angle.

Reflectors of the opalescent type are of two general methods of manufacture, blown and pressed. The blown reflector is of even thickness throughout, as the glass is evenly distributed over the surface of the mould and the inner surface has the same convolutions as the outer. The inner surface of the pressed reflector is smooth, taking the shape of the plunger while the exterior follows the outline of the mould. In general the blown reflector is thinner and hence lighter in weight. The glass in the blown reflectors must be quite dense, or else roughed on one or both surfaces, in order to produce good diffusion. If these requirements are not fulfilled, the ridges and hollows are light and dark, due to the thickness of the glass, and the reflector does not present an attractive appearance. The pressed reflector with its greater thickness can use a lighter density glass and yet have good diffusion, and be evenly lighted without a roughed surface.

The opalescent glasses are of several varieties: *Opal of varying densities.* This is employed in both blown and pressed commercial reflectors. *Glass having an infinite number of small white particles in a solid coloidal solution.* This is employed in several makes of pressed reflectors. *Plated, flashed or "alabaster" glasses.* Commercially employed in a number of blown reflectors. The opalescent reflector is exploited in two principal shapes, bowl and flared. The bowl may be made in numerous contours but the flared reflectors of the different manufacturers approximate very closely to a standard. There is often an intermediate shape, known as the "semi-flared." As to size, the various companies follow very closely in each other's

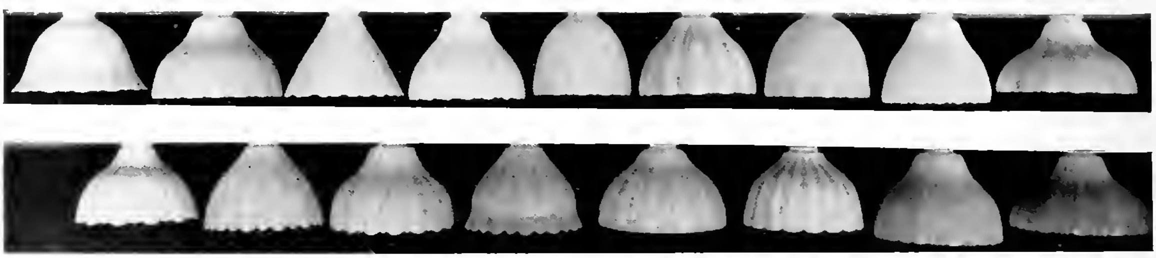

Fig. 11. Pressed Bowl-shaped Opalescent Reflectors

Fig. 12. Blown Flare-shaped Opalescent Reflectors

footsteps. For example, the 100-watt bowl-shaped opalescent reflector is almost always about eight inches at the maximum diameter; and the flare-shaped for the same size lamp is eleven inches. The bowl type is to be preferred in numerous instances, in that it covers a larger portion of the lamp so that the filament is not visible at quite so flat an angle as with the flared type. We should not expect this class of reflectors to be as efficient as a mirror or other opaque reflector, but they will be used in places where decoration is of more importance. Practically none of these reflectors have smooth exterior surfaces, but are broken by a number of small prisms. These are for purely decorative purposes, and have nothing to do with the illuminating efficiency. With almost all the opalescent reflectors, quite a percentage of the total light flux is in the

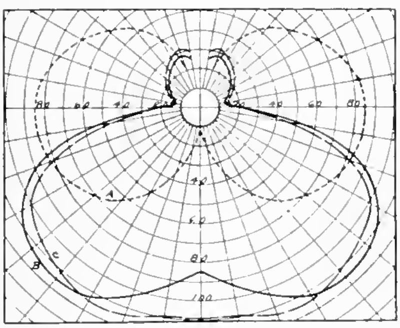

Fig. 13. Characteristic Distribution of Reflectors Shown in Fig. 12

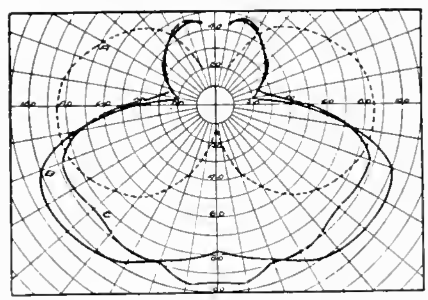

Fig. 15. Characteristic Distribution of Reflectors Shown in Fig. 14

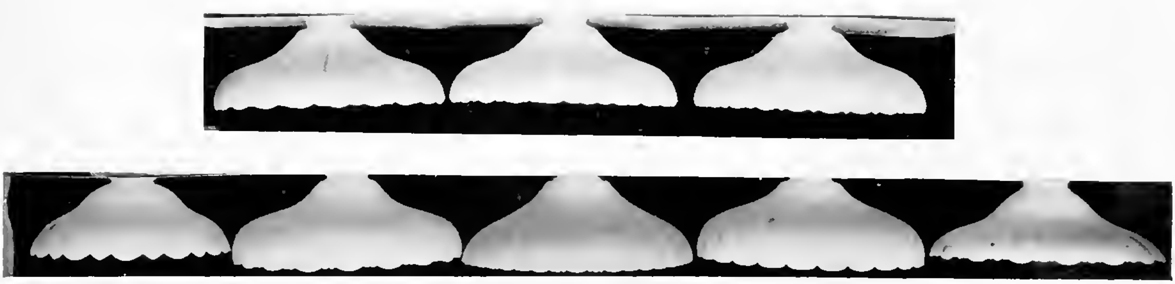

Fig. 14. Pressed Flare-shaped Opalescent Reflectors

upper hemisphere, and serves to illuminate the side walls and ceiling.

Blown, bowl-shaped opalescent, translucent, diffuse reflectors. Nine types of six makes investigated Fig. 9 shows the appearance of this group. The characteristic distribution with the clear lamp is extensive; and, with the bowl-frosted lamp, intensive. Fig. 10 is a typical curve. Efficiency values are given in Table 2.

Pressed, bowl shaped, opalescent, translucent, diffuse reflectors. Sixteen types of eight makes investigated. Fig. 11 is illustrative of these. A variety of distributions are found, depending on the shape of the reflector, the average being approximately a mean between the extensive and intensive, no one curve being characteristic of the class. Bowl-frosting the lamp increases the downward candle-power, and tends to concentrate the flux.

Blown, flared shaped, opalescent, translucent, diffuse reflectors. Seven types of five makes investigated. Fig. 12 shows these. Both clear and bowl frosted distributions are of a wide angle character, typically shown in Fig. 13.

Pressed, flared opalescent, translucent, diffuse reflectors. Nine types of seven makes investigated. Shown in Fig. 14. The light flux is distributed over a wide angle with the clear lamp, the bowl frosting narrowing this but slightly. A typical example is shown in Fig. 15.

The last class to be treated is the prism reflector. Prof. Andre Blondel first applied the principle of changing the angle of light by means of prisms, and at the same time obtaining diffusion. The principle on which these reflectors act, has been demonstrated again and again, and will not be dwelt upon. To obtain the best results, each prism must be calculated with reference to the light source in its correct position. This necessitates the use of the holder, which the manufacturers recommend with a certain lamp and reflector combination. Since the prismatic reflectors act by direct reflection, any desired distribution is obtainable. One company in America, who controls the fundamental patents of this type of reflector, have gone into the matter extensively, and, carefully calculating each reflector, have on the market a large variety of types. A standard line is available, giving the distributions mentioned above, with all sizes of the tungsten filament lamp. Other lines have been developed of a more decorative nature, for use in residences, stores, etc. A group of eleven reflectors of four makes was tested (see Fig. 16). As stated, the distributions vary widely, and these reflectors are applicable for general illumination with almost any height and spacing, or for localized lighting. For any given height and spacing the proper reflector should be chosen, and the manufacturer's engineers have prepared tables and charts, showing the novice the proper combination. The values given in Table 3 are not very significant, as reflectors giving widely different distributions were tested in the same group; but the maximum and minimum figures show to some extent the possible variation, due to incorrectly calculated prisms or imitations of the patented article.

The commercial types of reflectors for the medium size lamps have been briefly

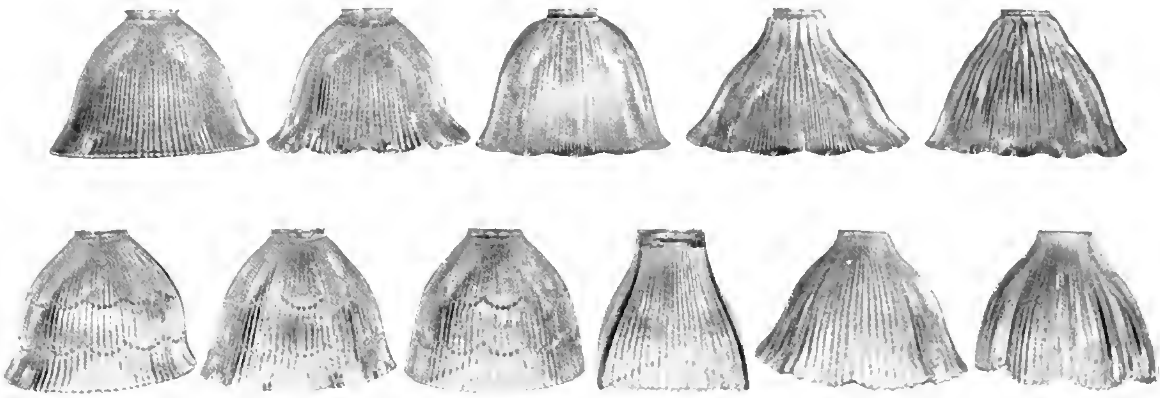

Fig. 16. Eleven Types of Prism Reflectors

reviewed. Leaded art glass is very often used for the larger size lamps, and if glass of the proper character is chosen, they are efficient and decorative. For smaller lamps, such as are used in residences a large variety of purely decorative reflectors of various colored glasses are marketed. Efficiency is a secondary consideration, the blending of these reflectors with the general artistic scheme being their primary function.

In conclusion, we may briefly sum up the points to be considered in the choice of a reflector. In the industrial field, efficiency is a prime factor; and, as a rough measure of relative efficiencies of the various reflectors, we can empirically compare them as follows: *First*, assume that all the lumens in the (0-60°) zone, and one-half the remaining lumens, are useful. *Second*, the distribution must also be taken into account and the reflector chosen which will produce the desired intensity at any given spot with a certain hanging position. *Third*, protection of the eyes of the workmen; *Fourth*, strength and durability are very essential. This naturally includes ease of cleaning and resistance to blows. *Fifth*, the holding device must be such that the reflector is not jarred loose; *Sixth*, general workmanship and appearance of the reflector must be satisfactory. For out of door use, the protection of the lamp from storm is very important. With the decorative reflectors, appearance, both cold and lighted, is first, and diffusion next; while efficiency, distribution, ease of cleaning, and weight follow. All the factors mentioned should be given due consideration. The blending of the lighting units with the general artistic scheme, and the harmonizing of the reflectors with the fixtures, are the most salient points.

INTERPRETATION OF PHOTOMETRIC CURVES

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Harrison Lamp Works, General Electric Company

This article points out a few of the ways in which photometric curves may be interpreted for practical purposes, and suggests some of the errors likely to be encountered. At the outset the author enumerates the data necessary for the correct interpretation of such curves. Mr. Stickney throughout deals only with the numerical evaluation of intensity; but he points out in his conclusion that there are other factors to be taken into consideration and that these often play a more important part than intensity and efficiency in the design of a lighting installation.—Editor.

Photometric curves are commonly submitted to indicate the lighting performance of various types of illuminants, with or without reflectors and globes. Since the curves frequently form the basis of selection of lighting equipments and the design of lighting installations, it is important that those upon whom this responsibility falls should be able to make correct estimates of the lighting values corresponding to such curves. The first essential is that the curve should be accurate and should give the necessary accompanying data, and the second that the engineer should be able to apply it in a fair manner to his conditions.

In order to simplify the discussion, let us consider only the case of illuminants having a symmetrical distribution about a vertical axis; that is to say, illuminants which deliver approximately the same intensity toward all points of the compass. With such an illuminant, an average or mean curve of candle-power for each angle of elevation gives a close indication of the candle-power distribution in all vertical planes. There are, of course, illuminants (such as a tubular light source or angle reflector units) which do not distribute their light symmetrically. These involve a number of special cases requiring particular treatment. However, the simple case takes care of nearly all of the common and important illuminants.

A proper curve should be the result of careful and accurate measurements by a competent authority. The equipment should be carefully specified, including, as far as possible, data on the grade of glassware used. A curve which is supposed to show the working performance of some particular type of unit should be made with the regular equipment. For example, if a unit is ordinarily provided with an opal globe, it should be measured with a globe of average commercial density, rather than with a clear globe or without globes. Likewise, if the efficiency can be varied by raising the electrical or gas pressure, the equipment should be tested at the pressure which gives its normal efficiency. Again, tests on a gas lamp employing gas of an unusually high calorific value will not indicate its commercial performance.

It often happens that conditions vary so in practice that tests must be made under ideal laboratory conditions. In such a case, accompanying curves should show the effect of the different commercial variations.

All types of lamps are subject to depreciation, but some lamps depreciate much more rapidly than others. It is common practice to indicate the initial performance of the lamp. A comparison based on the initial candle-power would probably be unfair to such a lamp as the tungsten filament incandescent, which has a relatively small depreciation. So, when possible, performance curves should either show the average candle-powers, allowing for depreciation, or be accompanied by depreciation curves showing the rate and amount of inherent depreciation. It is sometimes practicable to supplement this with a curve of acquired depreciation under some particular conditions; as, for example, when operated in an iron foundry.

Inherent depreciation is that due to the operation or aging of the lamp independent of its environment; while the acquired depreciation is that due to the surroundings, the two summing up to form the total depreciation under the specified conditions.

Perhaps the most difficult factor to provide for in a photometric curve is the instantaneous variation in intensity to which several types of lamps are subject. The present practice is to plot a curve of mean intensity; but the relative value of a fluctuating source, as compared with a steady source, is not properly shown by such a curve.* The rate and extent of such variation is different not only in different lamps of the same type, but also under different periods of burning and other conditions which it is not practicable to specify. In some cases average maximum and minimum curves accompanying the mean curve will give a measure of this variation; but, so far, no method has been suggested that gives an accurate means of comparing values.

Probably no better summary of the data necessary for the correct interpretation of photometric curves has been prepared than that contained in the 1912 Report of the Illuminating Committee of the Association of Iron & Steel Electrical Engineers, which gives the viewpoint of the operating engineers. It is tabulated opposite.

* See page 657 Transactions I.E.S. 1911, paper on "Photometry of Large Light Sources," by Stickney & Rose.

Interpretation of Curves

Assuming the adequate photometric curves are available, it is apparent that some knowledge of conditions is necessary in order to obtain an intelligent understanding of the values of the equipment for practical lighting purposes. No particular training, beyond a rudimentary understanding of polar co-ordinates, is necessary to enable one to determine the candle-power corresponding to any angle of elevation. But when it becomes a question of determining the value of a particular candle-power characteristic for a certain lighting condition or class of lighting conditions, the problem is much more complex.

There are, in ordinary practice, two principal methods of comparing the photometric

DATA DESIRABLE WITH CURVES

On all curves:

1. Date of test.
2. Authority of test.
3. Full equipment of lamp, such as reflector, electrodes, globes, etc.
4. Total per cent absorption by globe equipment.
7. Kind of current, a-c. or d-c.
8. Frequency, if a-c.
9. Series or multiple operation.
10. Terminal watts.
11. Terminal volts.
12. Terminal amperes.
13. Arc volts, if an arc lamp.
14. If an incandescent lamp, total lumens† per watt or watts per horizontal candle-power at which the test was made.

On candle-power curves:

1. Radius at which test was made.
2. Total lumens or mean spherical candle-power.
3. Downward lumens‡ or mean hemispherical candle-power.
4. If tests are made in several vertical planes and the average taken, this should be indicated and the position of the planes shown diagrammatically.
5. If candle-power or lumens per watt are given, these should be based on terminal, and not on arc watts.

† Total lumens equal M.S.C.P. x 4 π.
‡ Downward lumens equals M.L.H.S.C.P. x 2 π.

performance of lamps, which we might designate as "abstract" and "concrete", or as "general" and "particular." The abstract, or general comparison, assigns a value to the flux, either total or in certain zones; while the concrete, or particular, requires an analysis of the candle-power at various angles with reference to the illumination, as distributed under actual or assumed arrangements or conditions.

In rating the value of a lighting equipment by the flux method, the most common and most general practice is to employ the total flux (lumens) or average intensity in all directions (mean spherical candle-power). This is a fair measure of the equipment as a light producer, but it takes no account of the direction in which the light is emitted. As a general thing, upward light is less valuable than downward. In some cases of street lighting or the lighting of dark-roofed interiors all upward light is practically wasted. On this account, flux below the horizontal, as measured in downward lumens, or mean lower hemispherical candle-power, is sometimes used. For such cases as mentioned above, these units are more useful than those of total flux. Here again the conclusions may be misleading; since no account is made of whether the light is directed straight downward, or how proportioned among the oblique angles. In many cases a certain amount of upward light is exceedingly useful in illuminating the ceiling or being reflected downward from the ceiling. For example, an indirect lighting fixture delivers no light downward, except as reflected by the ceiling, and yet some exceedingly satisfactory installations of this type have been made. Another measure of this type is the flux (as expressed in lumens or mean candle-power) in a zone from 0 deg. to 60 deg.*. This is often of use, if properly applied, in industrial lighting, especially where localized effects are used. For street lighting, where lamps are to be placed far apart, the intensity just below the horizontal, say 75 to 80 deg. from the vertical, is the limiting feature, and good general comparisons have been made on the basis of the intensity in this direction.

The mean horizontal candle-power has been adopted by long practice as the conventional measure of the performance of an incandescent lamp. This, of course, originated through the need of a simple comparison of one lamp with another of the same type, before the necessity of comparing lamps of different types arose. It is a very useful unit, if properly used; but under present conditions, should be accompanied by a reduction factor, from which the mean spherical candle-power (and hence the total lumens) can be figured. Lamp manufacturers usually give with the candle-power rating of a lamp, either the reduction factor, mean spherical candle-power or total lumens.

Perhaps the most common mistake made by an amateur in judging the total flux of light from a photometric curve is that of assuming that the lumens, or mean spherical candle-power, are proportional to the area enclosed by the curve. While this would be true for curves of exactly the same shape, it is often far from true in comparing curves of varying shape. It must be realized that 100 candle-power at one angle of elevation does not represent the same flux of light as 100 candle-power at a different angle. For example, consider the extreme cases; 100 candle-power directly downward shows the intensity only of a very small pencil of light, while 100 candle-power at the horizontal represents the intensity emitted to all points of the compass. Between these two the value of 100 candle-power as a measure of light flux varies in accordance with the sine law. The relation is similar to variation of length of a degree in longitude from the equator to the poles on the earth's surface. In determining the mean spherical candle-power we do not average the candle-power at, say, every ten degrees. To obtain a true result they must be weighted with a sine factor; or the curves plotted on so-called cosine co-ordinates, and the area integrated. The lumens over any angular zone for which the candle-power may be considered uniform, can be obtained by multiplying the candle-power by the corresponding solid angle. By summing these values up, the total lumens or those for any zone are obtained; and thence the mean spherical candle-power or the mean candle-power over the zone, found by dividing by the corresponding solid angle.

Besides those mentioned, there are a number of other general values taken from the photometric curves which are used in special cases to measure the value of a light source. But none of them is entirely satisfactory in indicating the performance under all conditions. The best that can be done is to select the one most suitable for the case at hand, realizing that, at best, the values are approximate only.

In the class of concrete interpretation come the estimate of the value of the light source

* 0 deg. as here used, means vertically downward.

in connection with a particular condition, where a desired intensity of illumination at various points can be approximately predetermined. For any given height of lamps, one can calculate from the photometric curve either the normal foot-candles (that is, the foot-candles on planes perpendicular to the rays), or the horizontal foot-candles (that is, the foot-candles on the horizontal plane) for various distances from the lamp.* These intensities may be plotted in illumination curves, which ordinarily have horizontal distances in feet from the axis of the lamp as abscissæ, and the foot-candles as ordinates. For indoor lighting, the horizontal foot-candles are commonly used, and from such curves one can determine the most advantageous height and spacing of lamps, as well as the relative advantages of different types of equipments. If a number of lamps are to be used, it is possible to add up the illumination received from the several sources, point by point and thus determine the total intensity received. This is the method which is commonly styled the "point-by-point" method, and is applicable where the wall and ceiling reflection does not play an important part. It cannot be used under ordinary conditions with light finished rooms, unless some allowance is made for reflected light. This, of course, complicates the problem and renders it impracticable of application with indirect or semi-indirect units. To take care of cases where indirect or semi-indirect units are used, it is preferable to determine an illumination curve by measurement with a portable photometer with a lamp installed under the same or similar conditions of wall and ceiling reflection. From this, the intensity from an entire installation can be approximately predicted.

* This assumes that the area of the light source is not so large as to cause a variation from the law of inverse squares. Where such a deviation is likely to occur, the curve should specify that the values are in *apparent* candle-power measured at a given distance (10 feet is commonly used). Then the values can ordinarily be calculated for distances approximating those at which the candle-power measurements were made.

Another method of calculation where the mean intensity over the horizontal plane only is desired, is the so-called "flux-of-light" method. In this case the useful flux is estimated from the candle-power or illumination curve, which, multiplied by the number of lamps, gives the total useful lumens; dividing this by the floor area in square feet will give the mean intensity in foot-candles.

The foot-candle intensity on a horizontal plane is used largely on account of its convenience. It is sometimes responsible for misleading results where light is needed particularly on vertical or oblique planes, as in the lighting of paintings hung on walls or stock on wall shelves, and in some classes of machine work. Where such conditions occur allowance should be made, since the method tends to favor slightly light directed straight down.

Conclusion

In the preceding, an attempt has been made merely to point out a few of the ways in which photometric curves may be interpreted for practical purposes and to suggest some of the errors likely to be encountered. There are many other applications which may be made to suit particular problems. While this article deals only with intensity, it should be remembered that there are many other features, such as color of light, diffusion, direction of light, control of shadows, avoidance of glare, appearance, etc., which may, in some cases, play even a more important part than intensity or efficiency in the selection of lighting units or in the design of lighting installations. On account of the greater ease with which numerical comparisons can be made, there is sometimes a tendency to neglect these other less definite features; and, while this article is devoted particularly to numerical evaluation, the author desires to emphasize the importance of these other characteristics.

BOOK NOTICES

ELECTRIC LIGHTING, AND MISCELLANEOUS APPLICATIONS OF ELECTRICITY

By W. S. Franklin

The Macmillan Company

299 pages — Illustrated — Price, $2.50 net

As it stands, Professor Franklin's book is of chief value to the student unfamiliar with modern illuminants and methods of providing electrical service. While the book purports to be, in the main, simply an exposition of principles underlying operating engineering, it may be mentioned that actually a considerable amount of concrete data is presented illustrative of present-day practice. Central station costs and selling prices are treated in a very practical manner in Chapter 1; whereafter the principles of distribution, wiring, and transmission system (in the order mentioned) receive brief discussion. A very complete bibliography is maintained right through the book, keyed by footnotes: and this will undoubtedly make the volume of additional value to engineers of some practical experience, who may desire to refresh their memory on the underlying principles of their business, as well as to find a convenient connecting link between the fundamentals and modern refinements, treated in more intricate papers with which the technical press and the proceedings of institutes abound. About one hundred pages, or one-third of the book, are given to purely lighting matters—photometry and illumination, lamps, lamp shades and reflectors, interior and street lighting. In these sections much valuable material is included; and the principles which are herein propounded seem more in accordance with latest accepted theory, and the data which are given more inclusive of the results of modern practice, than is usual in books of this nature.

THE INDUCTION MOTOR

By B. F. Bailey

McGraw-Hill Book Company

225 pages — 120 Illustrations — $2.50 net

This new treatise on the induction motor fills the gap between the elementary treatment of the subject which is given in most text books on alternating current machinery and the more theoretical discussions given in advanced works. The author's interpretations of the various phenomena are in most cases so simple that a student with a general knowledge of alternating current theory can follow all of his ideas; and, at the same time, get a physical conception of the different points that will be of great use in studying more theoretical works. The greater part of the volume is given up to discussions of the polyphase motor, but there are chapters dealing with the induction generator, the single-phase motor, a number of different types of commutator motors and also various motor starting devices.

The author develops the proof for the circle diagram using the equivalent circuit of the induction motor as a basis. A large number of very useful relations are then brought out from the consideration of the diagram. The manner in which these fundamental relations are treated is, in fact, one of the best attributes of the work, since a knowledge of the way in which the various characteristics of an induction motor are interlinked is necessary in order to have a clear understanding of its operation. In explaining the effect of different design features upon the characteristics of induction motors the author cites examples of typical machines, and shows by actual values the effect of a change in one characteristic upon all of the others. The examples given are of modern motors and thus express present-day conditions. In the first part of the work, the author develops a number of formulas for designing and predetermining the characteristics of induction motors. Later a chapter is given up to applying these formulas to the design of a specific machine. It is rather unfortunate that more complete explanations of the various steps in this design are not given, as such an example as this, worked out in detail, would have served to make clear points not previously understood. While the volume is evidently intended primarily for those who are making a study of the induction motor for the first time, it will, no doubt, find favor also among those with a more complete knowledge of the subject.

SYLLABUS OF INSTRUCTION ON ILLUMINATION AND SALESMANSHIP

Education Department of the Edison Lamp Works

Harrison, N. J.

To the layman, accustomed to hearing high-sounding generalities with regard to this modern industrial era and latter-day aggregations of highly specialized units, this 18-page syllabus should give food for much reflection on what is an accomplished fact in the field of specialized commercial engineering. For this syllabus relates to but one line of manufacture of a great corporation—lamps; to but one department of the lamp organization—education; to but one course in the work of that department—a course specially fitted for employees not eligible for the regular course of instruction and factory experience. "It is for the benefit of *all* those who are interested in the incandescent lamp industry . . . and is open to central station men and salesmen of jobbers and dealers who are selling lamps." This syllabus gives a list of lectures, experiments, trips and talks by specialists which anyone taking the course should include in his program. The reviewer in this instance has no space in which to cover in detail all the instruction which goes to make up the course; but the mere fact of the publication of this program appears to be such an eloquent symbol of what is really quite a remarkable modern institution as to merit at least some mention. Here we have the manufacturer performing all the functions of the regular university, the object in view being to turn out an educated salesman. The saying, "Salesmen are born and not made" may possess some truth, but even this small grain of truth is growing to be doubted. At any rate, it is a fact that, in selling as in any other branch of industry, few are perfect; and a wider knowledge of methods in selling, such as disposition of time, distribution of expenses, methods of laying out a campaign, and a study of what competitors are doing cannot but be of benefit when applied to the individual case with the necessary modification. Although an attempt is made in this course to cover these various elements, the syllabus admits that it cannot constitute a complete training, but should serve more as a means of guidance in starting the student along a path whose direction ultimately means the greatest success. Mention should be made of the bibliography which is included in this program, in which a very complete collection of references is given relating to published literature on street lighting, general outdoor lighting, industrial and factory lighting, lighting of drafting rooms, offices, stores, signs, automobiles, trains, residences, and so on.

CONFERENCES OF GENERAL ELECTRIC SPECIALISTS

1. Arc Lamps and Allied Apparatus

The annual arc lamp conference of the General Electric Company was held on September 9th, 10th, 11th and 12th last, at Pittsfield, Mass. and Lynn, Mass. On the 9th of September, Dr. C. P. Steinmetz gave an address and a discussion was held upon matters connected with the multiple enclosed flame arc lamp, at which Mr. S. H. Blake was the chief speaker. On the morning of September 10th, Mr. L. Arnold addressed the conference and led a discussion on constant current transformers. There was then an inspection of transformer operation and manufacture as carried out in building 63 of the River Works. In the afternoon Mr. P. S. Bailey conducted a discussion on street system fixtures and series center span fixtures; following which Mr. W. L. Harraden and Mr. C. M. Greene spoke on standard luminous arc lamps and luminous lamp rectifiers respectively. An inspection was then made of new developments, tube manufacture and tests. After dinner Prof. Elihu Thomson addressed the meeting, and Mr. C. A. B. Halvorson, Jr., gave a short talk on silhouette lighting. A very interesting feature of the program was the automobile tour of inspection, which was commenced at 8 p.m., and in which various installations of modern lighting units in Boston and vicinity were visited. On Wednesday, September 11th, Mr. C. A. B. Halvorson, Jr. conducted a discussion on the ornamental luminous arc lamp, the various types of lamps discussed including the Great White Way lamp, the residential lamp, and the parkway lamp. Mr. E. R. Berry delivered an interesting paper on the positive electrodes for luminous arc lamps and means for preventing oxidation. The afternoon business included a discussion of series enclosed flame arc lamp, absolute and automatic cutouts, color-matching outfits, intensified arc lamps, indirect lighting, and blue printing lamps, at which Messrs. P. S. Bailey, R. B. Hussey and C. B. Harthan were the principal speakers. On Thursday, September 12th, Dr. Weintraub read a paper on the quartz mercury lamp. Mr. W. G. Mitchell addressed the conference on the treatment of steel for rust prevention, after which there was a general discussion of headlights. After lunch the party left in automobiles for an outing at the Suntaug Inn, Lynnfield, where dinner was served at 5.30 p.m. The menu cards used at the dinner were quite a novelty, illustrating the silhouette principle of lighting. There was a main table decoration consisting of a miniature parkway 25 feet long lighted by 13 1 1/2 ampere miniature parkway luminous arc lamps operated from a storage battery.

2. Industrial Control Apparatus

The first annual meeting of the Industrial Control Specialists was held at Schenectady, Sept. 11th, 12th and 13th. The first two days of the meeting were given over to discussions between the visiting Specialists and the Commercial and Engineering departments. Many questions of a commercial and engineering nature were discussed, some of the more important being:—Improvements in design of standard apparatus; the standardization of new designs; and ways and means of increasing the sale of Industrial Control apparatus. The third day was given over to inspection of the factory. At the conclusion of the conference on Friday, a dinner was given in the Renssalaer Inn at Troy.

3. Switchboards and Switchboard Apparatus

The third meeting of Switchboard Specialists took place in Schenectady and Lynn, September 9th to 14th inclusive. Among the many topics discussed were the selection and application of relays—a subject which is also being much considered by operating companies; the increased tendency towards the use of remote control oil-switches and circuit-breakers, especially in large stations; the limit of transmission voltages; and outdoor switching equipments and protective devices for rural developments and branch lines. For the remote control of apparatus the solenoids for solenoid-operated oil-switches have been improved; and two new devices, viz., electrically operated remote control switches, for the convenient control of small motors or lights located at a distance and a one-coil circuit breaker, which is held closed by part of the closing current remaining on the breaker, have been placed in production. A new circuit breaker was developed especially for steel mill service, but will be found useful in any connection where it is desired to open the circuit immediately on low or no voltage, and to insure motors against damage on its recurrence. For outdoor switching systems oil switches up to 35,000 volts are in production. When used for automatic service, the switch will be equipped with bushing type current transformers, and all the operating and tripping mechanism will be entirely enclosed and weatherproof. This switch will soon be available for 70,000 and 110,000 volts. At Lynn, meters, instruments, current and potential transformers were discussed; and among the new developments shown were outdoor potential transformers for use on lines running up to 88,000 volts.

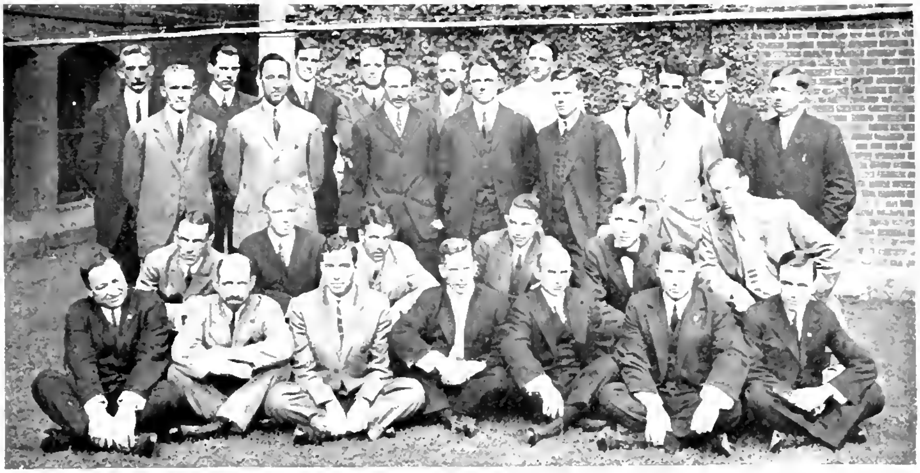
Portrait Groups of Specialists

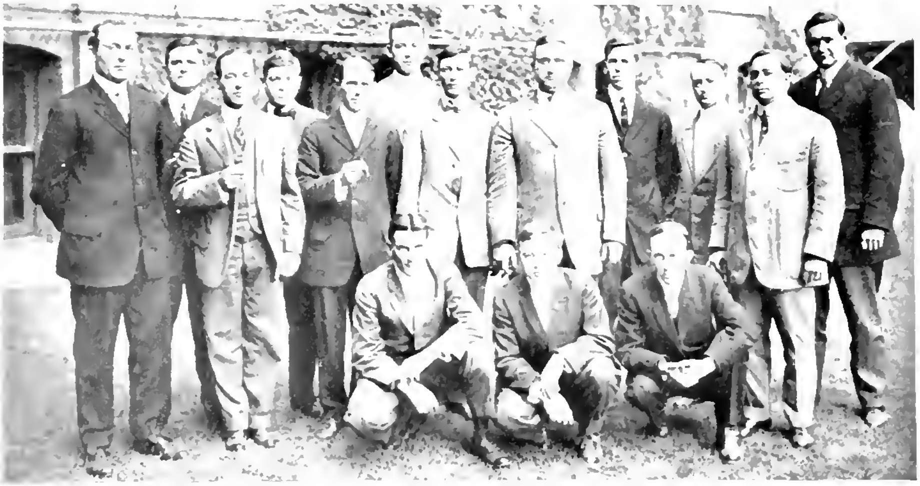
On the following page are shown three portrait groups of the apparatus specialists whose doings at the September conferences are chronicled above. The upper picture is the switchboard group, and includes: *back row, standing—left to right*—O. G. Langley, F. B. Shelby, G. O. Bason, J. J. Kline, E. M. Hewlett, H. L. Smith, H. H. Gardner, E. B. Merriam; *second row, standing*—G. A. Elder, F. W. Paterson, J. W. Upp, H. H. Bodge, A. R. Dennis, C. M. Langfield, O. B. Rhinehart; *third row, kneeling*—C. M. Parker, H. P. Walker, H. E. Starbuck, W. H. Heinz, F. W. Sliter, H. M. Lewis; *front row, sitting*—B. V. Wilburn, S. W. Mauger, H. E. Harkness, A. B. Lawrence, R. M. Huntley, D. S. Morgan, T. B. Culhane.

The middle picture shows the arc lamp engineers and sales specialists, and the names are: *Standing—left to right*—M. E. Smith, W. F. Hall, A. I. Sundheimer, H. H. Reeves, I. S. Crocker, J. A. Corcoran, R. J. Kirchner, C. A. Winder, B. S. Craig, C. Hendrickson, P. B. Reed, R. Cheesman, J. L. Hemphill, L. A. Hawkins, E. B. Comfort, W. D. Pangburn, Geo. Fiske, C. R. Wallis, W. E. Carpenter, W. F. Cale, W. H. Jones, S. D. Gilbert, D. E. Cogan, L. H. Couchey, R. G. Standerwick, D. L. Wood, D. M. Diggs, R. F. Fiske, T. W. Behan, C. B. Davis, J. L. R. Hayden, C. R. Krueger; *sitting—left to right*—E. L. Nash, N. R. Birge, S. H. Blake, C. P. Steinmetz, Joseph Lyons, G. N. Chamberlin, W. D'A. Ryan, Louis Friedman, C. M. Axford, J. H. Allen.

The lower picture is the Industrial Control group, and the names are: *standing—left to right*—E. P. Bassett, J. E. Thigpen, W. M. Watkins, W. C. Sage, C. W. Bartlett, E. E. Gifford, Jr., Paul Caldwell, V. A. Hain, R. D. Reed, F. W. Pearse, W. C. Yates; *kneeling*—C. H. Williams, A. P. Danz, V. W. Dockstader.

September Conferences of Specialists of General Electric Company





The names of the delegates whose photographs are here shown are given on page 730.

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Vice-President and Chief Engineer, General Electric Company

GENERAL ELECTRIC REVIEW

CONTINUOUS CURRENT AND C.C. *versus* DIRECT CURRENT AND D.C.

A SYMPOSIUM

Maxwell Day, H. M. Hobart, L. T. Robinson, C. P. Steinmetz, C. W. Stone
J. B. Taylor, and Elihu Thomson

We recently received from Mr. T. C. Martin, Secretary of the National Electric Light Association, a letter reading as follows:

We have recently found in our literature and discussions a marked tendency to the adoption of "continuous current" and "c.c." in the place of "direct current" and "d.c." We have, in fact, virtually adopted the change into our literature but feel that there still exists considerable difference of usage in this respect and probably difference of opinion. The "Suggestions and Rules to Authors" of the A.I.E.E. for example, do not make any use of either "continuous current" or "c.c." but mention and list only "direct current" and "d.c." It is of course extremely important that electrical nomenclature and phraseology should be uniform and standardized, and the N.E.L.A. has no wish to set up any individual practice of its own in such matters. After discussion of the subject with Mr. John W. Lieb, Jr., in connection with whose report on street lighting at Seattle this question came up very notably, we have thought it might be well to consult with some of our friends on the subject and to publish in symposium form the views expressed as to the desirability of the change indicated above. I shall be greatly obliged if you will let me hear from you at your early convenience in regard to the subject. Mr. Lieb, says "I believe you would be accomplishing considerable good by ventilating the subject as you propose in the N.E.L.A. Bulletin, and I may say that the use of the term 'continuous current' has my full indorsement."

On receipt of this letter we took the matter up with various engineers in the General Electric organization and succeeded in obtaining their views as to the usage of these expressions. We now publish these views without any editorial comment whatever; *not with the intention of delivering a final judgment as to what is good and what bad in technical diction; but in order that, when the matter comes up for discussion before the national bodies, there may at once be found on record the personal views of some of the more prominent of the engineers connected with the manufacturing element of the industry.*

Prof. Elihu Thomson* writes:

Some years ago, the Standardization Committee of the American Institute of Electrical Engineers adopted a set of definitions for the various terms, among them "direct current," "continuous current," "alternating current," "oscillating current," etc., and reference may be had to the Standardization Rules for these definitions. It seems as if the work of the Standardization Committee is not as familiar as it should be. At that time the term "direct current" was adopted to apply to any current which did not change its direction, whether that current was continuous in flow or pulsating or interrupted, or, in other words, it was a generic term. Now, it so happens that "continuous current" comes under "direct current" as a species of "direct current," one in which there is a continuous maintenance of voltage or current strength under definite conditions. It so happens, of course, that most of the direct current used today has the characteristics of the continuous current, but what shall we say of a telegraph line where the key is opened and closed rapidly? Is that a "continuous current?" What shall we say of the current given by a machine in which the current rises to a maximum and drops to zero at regular intervals or periodically? Is that a "continuous current?" At the same time, the definition of "alternating current" was adopted as to be given to a current which had the positive and negative directions at regular periodic intervals sustained in amplitude, while the term "oscillatory current" or "oscillating current" was adopted for that kind of a current represented by the discharge of a condenser, where the amplitude at the start is great and falls progressively, according to the general law.

It seems to me that there is no real occasion for changing the conditions or changing the terminology. It is perfectly permissible to use "c.c." wherever continuous current is meant and "d.c." where a current has one direction and it is not a continuous current.

Manifestly, all these questions are questions for such bodies as the Standardization Committee of the American Institute of Electrical Engineers, and looking still further, they are questions which might well come up for discussion before the International bodies, such as the International Electro-technical Commission.

* Prof. Thomson's views on this subject, together with those of other authorities, have already been published in the N.E.L.A. bulletin, Vol. VI, No. 11.

Dr. Charles P. Steinmetz advises us that his views on this matter have already been given to the National Electric Light Association, and forwards us a copy of his letter to Mr. T. C. Martin. This letter reads as follows:

The definition of the A.I.E.E. Standard Rules is: " 'direct current' is a current which always flows in the same direction." Such a current, therefore, may be constant in intensity, or may be pulsating, like that of a rectifier or some arc lighting machine. "Continuous current" is a direct current of constant intensity; it, therefore, is distinguished from a pulsating direct current. The direct current commutating machine gives a continuous direct current, and therefore may, and usually is, called a continuous current machine, and the production of pulsating direct currents which, therefore, cannot be called continuous currents, is now limited only to rectifiers. Therefore, the name "continuous current" has become practically universal, because practically all direct currents now are continuous currents.

Mr. H. M. Hobart, Consulting Engineer with the General Electric Company, favors the use of "continuous current." From the preface to his *Dictionary of Electrical Engineering*, published in 1909, we may quote the following:

The old question of the relative merits of the terms "continuous current" and "direct current" is still unsettled. There is little to choose between the two terms; nevertheless it should be practicable definitely to adopt one or the other. The term "continuous current" has been selected in the present work; and in addition to the support of such authorities as Prof. Sylvanus Thompson and Prof. Gisbert Kapp, there is the considerable advantage that it conforms with the terms employed in the French and Italian languages.

Turning to the definition of "continuous current" in this dictionary, we find the following:

Continuous current (preferable abbreviation c.c.) —A continuous current is a current flowing in one direction only. The above is the preferable and also the most widely adopted definition of continuous current, and is in accordance with the decision of the I.E.C., who report as follows: "Continuous current, an electric current in one direction and sensibly steady or free from pulsation. Abbreviated c.c. The term 'direct current' is not recommended. Unfortunately in the 1907 Standardizing Rules of the A.I.E.E., the term direct current is adopted for expressing the above meaning, thus: 'A direct current is a unidirectional current;' and this definition is followed by: 'A continuous current is a steady or non-pulsating direct current.' "

Quoting from Mr. Hobart's dictionary again, we find under the entry "Direct current" the following:

Direct current. See the preferable term, continuous current, the abbreviation of which is c.c. Kapp and Thompson in their various treatises both employ the term "continuous current" instead of the term "direct current."

Mr. L. T. Robinson, of the Standardizing Laboratory of the General Electric Company, tells us that "the question of the proper way to use these terms has never arisen in his own mind:"

Before I give you my views covering the proper way in which these two terms should be employed, I must say that I have given little attention to the absolute correctness of expression which seems to be the basis of the present discussion. In my opinion it matters not at all whether the terms chosen are academically correct or not, if a general understanding can be reached so that all writers and speakers use the terms in exactly the same way and with the same meaning. I thought we had such a general understanding and that it was covered by the A.I.E.E. Standardization Rules. Without having had the opportunity to read these up or to read some of the comments which have been printed expressing the views of others, I will give my own:

Direct current—this term I consider to be a contraction of ***unidirectional current*** and to be properly applicable to the current in any circuit which flows always in one direction. Under this heading may properly be included any pulsating or intermittent current which does not pass through zero.

Continuous current—this term I consider to be properly applicable only to a unidirectional current (direct current) which at the same time is unvarying in intensity. A storage battery current or the current from a modern "continuous current machine" would come under this heading. The current from the usual rectifier I would call a direct current but not a continuous current. The latter term is, therefore, of limited usefulness, and perhaps it would be as well to avoid it altogether.

Mr. C. W. Stone, Manager of the Lighting Department of the General Electric Company, writes us as follows:

While I believe that "continuous current" is correct, and in many ways is the best term to use, "direct current" has been used for so many years in reference to constant voltage commutating machines, that I think it will be difficult to change. In addition to this, for many years the abbreviation d.c. has referred to constant voltage direct current apparatus or continuous current apparatus; whereas the abbreviation c.c. has been used almost exclusively in reference to arc apparatus in its various forms, such as constant current transformers, constant current rectifiers and constant current arc commutating generators. I believe, therefore, that it will be preferable to continue the words "direct current" and the abbreviation "d.c."

Mr. John B. Taylor, Engineer of the Foreign Department, of the General Electric Company writes:

In general, and unless special consideration is given to some particular system or piece of apparatus, I am inclined to prefer the expression "direct current" as distinguishing a system or piece of apparatus from one employing or operating by alternating current.

"Direct current" conveys the idea that the direction of flow is unchanging, and the term is therefore applicable to currents derived from rectifiers, or from generators with only a two-part commutator, or from a commutator with some other small number of segments. In these cases the direction of the current remains the same, although there may be ripples, pulsations or even short interruptions of the current. These rippling, pulsating, or interrupted currents are properly called "direct currents" since, unlike alternating currents, they will produce electro-chemical effects and operate devices which depend on polarity.

The expression "continuous current" is a less general term, and conveys the idea of a special system of direct currents in which ripples, pulsations and interruptions are absent. Thus defined, and strictly speaking, continuous currents are obtainable only from primary and storage batteries and electro-thermal generators, as the ordinary commercial "direct" or "continuous" currents derived through the agency of commutators or collectors will have ripples or irregularities in the electromotive force and current, as is most readily made evident by connecting a telephone receiver.

"Continuous current" as a general term is also objectionable, as it may convey the idea of a current that continues at a given value, irrespective of the number of devices connected to the system or of changes in load. Series arc lighting systems are the most familiar examples of such a continuous or constant current system, although there have been made several notable power transmission installations on the Thury series "direct" or "continuous" or "constant" current systems.

The abbreviated expression for continuous current, "c.c.," also seems objectionable, since these two letters for some time have been used referring quite specifically to "constant current" (arc lighting) systems.

From the above discussion it will be seen that "continuous current" is a special and restricted form of direct current, and that unless special distinctions are to be made, the expression "direct current" with the time-honored abbreviation "d.c." is the proper expression and abbreviation for general use.

Mr. Maxwell W. Day, Assistant Engineer of the Power and Mining Department of the General Electric Company, gives his views on the matter as follows:—

In reference to the use of the terms "direct current" or "continuous current" to describe an electric current of uniform direction and without pulsation, it would seem, at first thought, that the definition given at the beginning of the standardization rules of the A.I.E.E. ought to be decisive. These rules state that a direct current is a unidirectional current, and a continuous current is a steady or non-pulsating direct current.

Some years ago, an effort was made to adopt the expression "continuous current" in the meaning of the A.I.E.E., but ordinary practice still retains, very largely, the use of the expression "direct current" or the abbreviation "d.c." to represent a steady, or non-pulsating, direct current. The use of this expression has become so general that it seems practically impossible to adopt the expression "direct current" in a sufficiently broad sense to include unidirectional current of a pulsating character; as this expression will be generally understood to mean a non-pulsating, direct current, and therefore it will always be necessary to use the word "pulsating" in addition to the expression "direct," when it is intended to designate pulsating current. Further, the standardization report makes frequent use of the term "direct current" where the meaning is limited to continuous current machines.

Although the expression "continuous current" is used considerably, the abbreviation "c.c." for this purpose is not extensively used with that particular meaning; while "d.c." is the common expression. I therefore recommend that the expression "direct current" be used where continuous current is meant, in accordance with the general usage of the standardization rules; and that the definition at the beginning of these rules be changed to correspond. In the case where a direct current of a pulsating character is meant, the expression "direct, pulsating current" should be used.

THE PROMISED LAND OF CENTRAL STATION DEVELOPMENT

Dr. Steinmetz's recent address at Chicago on the future of the electrical industry opened up a vista of very interesting possibilities. The fancy of the average engineer is pleased by the contemplation of these possible developments; while he has the further satisfaction of knowing that the prospect is not merely the creature of fancy—an interesting illusion; but that it is an end which will ultimately be reached, through the combined exertions of many average engineers. Dr. Steinmetz possesses a bold imagination, and can paint for us a picture of the promised land in firm and attractive outline. From his eminence he also is gifted with a foresight of the mountains yet to be climbed and the rivers yet to be forded before that promised land is reached; and the average engineer believes him capable of judging of the ability of electrical men to overcome these obstacles, and their chances of attaining their goal. His "future of the electrical industry" therefore becomes highly instructive, as well as interesting, reading.

The most successful systems of to-day are those which have realized to the full all that is meant by diversity factor, and who have extracted the most from their knowledge. As a general rule the big central station can extract more profit out of this diversity-factor than can the small; so that, for economical electric service, the bulk-supply idea must be fully worked out. As Dr. Steinmetz has been consistently telling us for many years, electric power supply in the future is going to be concentrated, for all uses in a given large territory, in one system. Local distribution systems will remain pretty much as they are to-day. The distributing substations will probably be supplied over 2200-volt a.c. feeders, beyond which there will be an intermediate system of feeders around 10,000 volts. For some of the longer distances, 20,000, 30,000, or even 60,000 volts may be employed for these transmission feeders; while, in addition to this network, there will be the main lines of the electrical supply service—trunk lines radiating from giant power stations, and built for the highest practicable operating voltages, possibly 150,000 or 200,000 volts. The exceptionally high voltage lines will probably not carry large amounts of energy; but will act rather in the capacity of tie-lines between two great city systems, carrying as a rule only a moderate degree of electrical energy. They will be for emergency connections between two great systems, and for use in helping out in cases of peak load, contributing to the general reliability of the system and serving as a sort of insurance.

That is simply a rough outline of the future electrical supply system, as regards its physical characteristics. It would appear at first glance that the responsibility for its achievement rests mainly upon the operating men. All the apparatus, however, has not yet been developed; and a very large share of the responsibility for future progress is going to rest on the producer, for which posterity, we may be sure, will award him full credit. In order to design efficient apparatus he must go on studying corona and its limiting effect, switching operations and disturbances set up thereby, the capacity of copper wires and the fatal effects of excessive charging currents. And besides proceeding with the design of his main generators, main transformers and main switchboards (to say nothing at all of the power-consuming devices—motors, lamps, and so on) he is pretty certain to find a demand for a multiplicity of auxiliaries, all, of course, tending to safeguard and simplify the finished scheme—power limiting reactances, arcing ground suppressors, arresters, discharge recorders, relays and other apparatus in the same category.

The power limiting reactance is a very modern development and is a very interesting one. In the summer of 1911 at Chicago, Dr. Steinmetz said: "These then are the two problems before the modern central station. The localization of any disturbance by power limiting reactances; and the synchronous operation over lines of limited power, by speed control of the prime movers." In the September, 1911, Review his article on these reactances, discussing their theory and the practical requirements which they had to meet, and one of the first ever published on this subject, concluded with the words: "It is believed that the design finally adopted and represented in the present power limiting reactances, has solved the problem." That is only a little over twelve months ago, and Mr. Eby's article, on page 788 of the present issue of this magazine, contains the words: "The production of power limiting reactances has already been considerable. One operating company alone has over fifty of them in service . . . . . Their general acceptance throughout the country by many of the larger operating companies is a tribute to their design, and to the attention given to this problem by the manufacturer." Since the matter, in the words of Dr. Steinmetz 17 months ago, is concerned with one of the most vital problems which the electrical industry, on its purely engineering side, has to face, it seems to us that this is a very striking indication of the rapidity with which electrical history can be made; and an eloquent symbol of the share which the manufacturer is capable of performing in making this history.

We may take this opportunity of referring also to the papers on the economic parallel operation of synchronous machinery, which Mr. Lee Hagood has been contributing to the Review. It will have been noticed that this is, to a certain extent, concerned with the second of the two prime problems which Dr. Steinmetz headlined in his 1911 Chicago paper. Considerably more has been written on this subject than on the question of power limiting reactances; but, of the published contributions to what always has been, is still, and will continue to be, one of the most fascinating of problems to operating and designing engineers, very few have taken such a novel viewpoint and adopted such an original treatment as those of Mr. Hagood. In these essays Mr. Hagood has taken up chiefly the question of the economical control of the exciting or wattless current in a system, so as to obtain suitable voltages at the centers of distribution; and the economical use of the generators, transformers and transmission lines involved. Still keeping one eye on the outline of the big electrical network of the future, one will realize that this is a subject most intimately connected therewith. Mr. Hagood has put himself to a vast amount of trouble in the preparation for this journal of his lengthy treatise on parallel operation. The importance of the subject cannot be overestimated; and we are duly appreciative of the author's kindness in presenting the Review with the results of a long and careful study of the problem.

ABNORMAL STRAINS IN TRANSFORMERS

By Charles P. Steinmetz

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The subject treated in this paper is one of the greatest intricacy but is presented here in the simplest possible manner. Abnormal strains in transformers are analysed under the headings of over-voltage, over-current, and over-frequency strains. Effective arresters, choke coils, and heavy end-turn insulation take care of the first; heavy current conditions may be handled by a stout mechanical design and the provision of high reactances, internal and sometimes external; while in guarding the transformer against high frequency strains, resort may be made to a combination of inductances with energy-absorbing devices, the former to guard against excessive intensity of travelling waves, the latter against the formation of standing waves from whatever travelling waves may appear in the system. Dr. Steinmetz is better fitted than any other man for handling this very intricate subject; and his ability to reduce this theory to simple terms for the benefit of designers, operators and salesmen, represents a very great feat of literary exposition.—Editor.

An electric circuit has voltage, current and frequency, and abnormal strains in transformers thus may be due to excessive voltage, excessive current or excessive frequency. Excessive voltage leads to puncture and destruction of the insulation, and, if by the puncture of the insulation a short-circuit is produced, may result in excessive current strains. Excessive current strains as occurring in short-circuits, etc., give mechanical stresses due to magnetic forces, which may result in deformation or tearing to pieces of the structure. Excessive frequencies lead to locally high voltages where the frequency exists, voltages which may be less than the line voltage, but, by appearing across a coil or part of the transformer only, may be higher than the insulation of this part can stand.

Excessive Voltage Strains

Such strains are produced by lightning, switching operation, as connecting and disconnecting the transformer from the generating system, or connecting and disconnecting apparatus from the transformer, etc. They may be between winding and the ground, or between turns or parts of the winding, or both. If for instance lightning suddenly raises the voltage of the line above ground, the insulation of the transformer to ground has to stand this voltage. All insulation is designed for, and tested for one minute (A.I.E.E. Standardization Rules) with a safety factor of 4. That is, while in normal operation the line voltage comes across two insulations—from terminal to ground and from ground back to the other terminal—double line voltage is applied across a single insulation, from coil to ground.

The maximum voltage rise which can occur under normal switching operation is limited to double voltage, at the end of the line, where the switching impulse adds itself to the line voltage, or the switching wave reflects, as it is usually expressed. It therefore still has a safety factor 2, so that over-voltage break down to ground as result of switching is not liable to occur; but where switching causes damage it is usually due to high frequency produced by it.

The voltage of lightning is unlimited, and the voltage which lightning can produce on the line thus is limited by the weakest part of the insulation to ground. This, with proper lightning protection is the lightning arrester; and by the lightning arrester the excess voltage which may be produced on the line and thereby on the transformer is limited by the discharge of the arrester, 50 to 100 per cent above line voltage, and therefore still well within the safety factor of the transformer insulation. Breakdown to ground by excess voltage due to lightning, with lightning arresters in the station, can therefore occur only if the energy of the lightning stroke at the station is very far beyond the discharge capacity of the arrester; that is, by a direct lightning stroke at or very near to the station. This is of such rare occurrence that it need hardly be considered.

Without lightning arrester, the weakest part of the system breaks down to ground. Before the introduction of the suspension insulator this usually was the line; since the introduction of the suspension insulator it usually is the transformer, and the necessity of installing lightning arresters at transformer stations thus has been very greatly increased by the introduction of the suspension insulator.

To conclude, then: with proper lightning protection at the transformer stations, the danger of breakdown to ground as the result of excess voltage is practically absent.

Excess voltages also appear between turns, especially the end turns of the transformer. Suppose a dead transformer of *negligible* *electrostatic capacity*, T in Fig. 1, is switched into a circuit of voltage e, by closing the switch S. Before the switch S is closed, all the transformer turns are at zero voltage. At the moment of closing the switch S, the voltage e is put on the first turn 1, but the second turn, 2, is still at zero voltage. The full voltage e thus comes across the insulation of the first turn. A moment—a ten-millionth or hundred-millionth of a second later—the voltage has passed around the first turn and reached the second turn, but the third turn is still at zero voltage. Then full voltage e comes across the first two turns, and each turn gets approximately half voltage, $e/2$. Thus the maximum voltage to which the insulation of the second turn is exposed, is $e/2$. Still a moment later the voltage has reached the third turn, while the fourth turn is still at zero voltage, and the first three turns thus divide the line voltage, each receiving $e/3$. In this manner in successive moments the voltage spreads over more and more turns, and each turn gets correspondingly less voltage, until the voltage has traversed all the transformer turns, and each turn gets e/n voltage—if n = number of transformer turns.

The voltages to which successive transformer turns are exposed in switching the transformer into a circuit of voltage e, thus are:

	1st Turn	2nd Turn	3rd Turn	4th Turn	5th Turn	6th Turn	nth Turn
Before switching	0	0	0	0	0	0	0
In the moment of switching	e	0	0	0	0	0	0
Next moment	$e/2$	$e/2$	0	0	0	0	0
3rd moment	$e/3$	$e/3$	$e/3$	0	0	0	0
4th moment	$e/4$	$e/4$	$e/4$	$e/4$	0	0	0
5th moment	$e/5$	$e/5$	$e/5$	$e/5$	$e/5$	0	0
nth moment	e/n	e/n	e/n	e/n	e/n	e/n	e/n

As seen, the voltage strain between the turns, resulting from switching, rapidly decreases and becomes negligible towards the interior of the transformer, but is excessive at the end turns.

Therefore end turns of the transformer are provided with extra heavy insulation.

Obviously, no extra heavy insulation, which could be put on the end turn, would stand for any length of time the full line voltage, to which the end turn is exposed in the first moment. However, the disruptive effect of voltage depends upon the time of voltage application, and full voltage is on the end turn only an extremely short time, less than a millionth of a second, while the voltage passes around this turn. Then the voltage drops to half, one-third, etc. Nevertheless, even for such short time, the extra heavy insulation can not give safety against the excessive voltages appearing on the first turns.

Assuming now we take the first 9 turns of the transformer, and put them outside, where we can specially insulate them, and where momentary discharge can not harm them; and call them a "choke coil" or "lightning protective inductance." The first remaining transformer turn then is what before was the 10th turn, and receives as maximum only one-tenth of the line voltage, and, as this voltage exists momentarily only, it is easy then to insulate for it. The installation of a very small choke coil—equal to 9 transformer turns only—thus has reduced the switching strains at the transformer end turns to one-tenth and brought them well within safe insulation.

In momentarily short-circuiting the transformer, the same strains are produced by momentarily withdrawing the voltage e, first from the end turn, then the first two turns, etc. This occurs when switching a transmission line, cable or other device of high capacity onto the transformer. The capacity, as a reservoir, acts as a momentary short-circuit and drops the terminal voltage to zero, until it is charged and the voltage

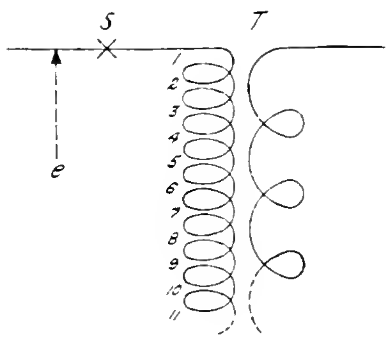


Fig. 1

comes back to normal again—in a thousandth of a second, more or less.

If lightning raises the line voltage momentarily 50 per cent, up to the discharge voltage of the lightning arrester, this momentary

50 per cent increase of voltage, suddenly put on the transformer, enters the transformer with the same voltage strains between the end turns, and sudden excess voltage to ground, this is accompanied by sudden excess voltage between the end turns.

Since, as seen, a very small choke coil, equal to a few transformer turns only, reduces the end turn strains so much as to be safely taken care of by extra heavy insulation, it follows that:

The combination of effective lightning arresters (the aluminum arrester), with a small choke coil (the hour-glass coil) and extra heavy insulation of the transformer end turns, affords practically complete protection against *excessive voltage strains* between transformer and ground, or between the end turns of the transformer, as may result from lightning, switching operation, etc.

Insulation breakdowns in transformers, aside from accidental faulty construction or mechanical damage, are therefore practically always due to high frequency.

Excessive Current Strains

In a loaded transformer a mechanical force, —a repulsion—exists between primary and secondary coil, or rather, between the primary and secondary coils and the magnetic stray field between the coils. This repulsive force is used in constant current transformers, to move primary and secondary coils with regard to each other and so give the constant current regulation. It equally exists in the ordinary transformers, and the coils therefore have to be supported mechanically against these forces. At full load, this mechanical magnetic force is small. It varies, however, with the square of the current (being proportional to the current *times* the stray field, and as the latter is proportional to the current it becomes proportional to the current square). The mechanical force thus rapidly increases with increasing current, and may become formidable and destructive at excessive currents, as those of short-circuit.

If the system to which the transformer is connected is of such large power as to keep up the impressed voltage on the transformer even if the secondary is short-circuited, then the only limit of current in the transformer is the transformer impedance, which practically is equal to the transformer reactance. In a transformer of 4 per cent reactance, that is, a transformer in which at full load the reactance voltage equals 4 per cent of full voltage, the short-circuit current at full impressed voltage would be 25 times full load current, and the mechanical forces thus $25^2 = 625$ times as large as at full load. In large transformers, of thousands of kilowatt capacity, these forces then amount to hundreds of tons. That is, the coils have to be supported mechanically so as to stand, in case of short-circuit, vibratory mechanical stresses of hundreds of tons.

As there necessarily is an economic limit to the mechanical strength which can be given to a structure, it follows that the lower the mechanical forces at short-circuit can be kept, the safer will be the structure. This means as low short-circuit current (hence as high reactance) as permissible. Therefore, in larger transformers it is not safe to permit less than 4 per cent internal reactance, and from 4 to 8 per cent will in general be the most satisfactory value of transformer reactance.

Since, even with the highest permissible internal reactance, in large transformers on high power systems which can keep up the voltage, a short-circuit puts tremendous stresses on the mechanical structure of the transformer, short-circuits necessarily involve a certain danger; and while transformers must be built, and are built to stand occasional short-circuits, very frequent short-circuits finally lead to mechanical damage, and therefore should be avoided as much as possible; and all apparatus and devices, which produce or may cause short-circuits, should as far as possible be eliminated from the neighborhood of the transformers.

At lower voltage, the short-circuit forces are decreased proportionally to the square of the voltage. Thus, if at short-circuit the voltage drops to half value, the short-circuit current also drops to half value, and the short-circuit strain to one quarter the value which it would have at full voltage. Therefore transformers which mechanically could not safely stand short-circuits at full voltage, as low reactance transformers, may in a system of limited power, as at the end of a transmission line, safely stand frequent short-circuits. But if finally the system is increased in power, and becomes more able to keep up the voltage at the transformer, the same transformer which before stood numerous short-circuits may be torn to pieces. That low reactance transformers have safely stood numerous short-circuits in one system is, therefore, no evidence that they would not be torn to pieces in another system of larger power; or in the same system at a place where the power is less limited, as near the generators; or in the same place, when by installing more generators the available power is increased.

External reactances in the phase leads are more effective in reducing the short-circuit stresses, than increased internal reactance, since the external reactance not only reduces the short-circuit current, but also the voltage at the transformer terminals. They are, however, more complicated and more expensive than the design of the transformer for higher reactance.

Excessive currents also may appear locally in a transformer, in short-circuited turns, coils or sections. Thus if some turns of a large transformer are short-circuited, as by high frequency discharge or mechanical deformation, in those turns a current flows, which is limited only by the impedance of these turns, and therefore may be very many times full load current. The mechanical repulsive force between the current in the short-circuited turns and the adjacent turns then may blow the adjacent turns away, and give the appearance as if something had exploded inside of the coil. The same phenomenon has been observed in generator coils, etc., but is not very frequent; and short-circuited turns, if not very numerous, usually lead to destruction of the insulation by heat, by charring, and thereby the short-circuit gradually spreads, until it becomes general. This is more frequent in smaller transformers.

To guard against the stresses of excessive currents, extremely strong mechanical construction of the transformer, a design for high internal reactance, and where needed additional reactances in the phase leads are available, together with all those precautions in the operation of the system, which avoid the occurrence of bad short-circuits as much as possible.

Excessive Frequency Strains

High frequency strains can as a rule only occur in transformers which have appreciable distributed capacity, that is, in high voltage transformers, above 50,000 volts. The low and medium voltage transformer usually contains only resistance and inductance, but no appreciable electrostatic capacity, and high frequency can not enter such a transformer and can not originate in it, but is limited to the end turns, and these are protected by extra heavy insulation, and a small choke coil in the lines. Therefore, high frequency troubles have become serious only with the development of the transformers for very high voltage transmissions. In these, the high potential winding, due to the many turns and the high voltage, gives appreciable capacity effects, that is, the winding is a circuit of distributed capacity, inductance and resistance, like a transmission line, and as in the latter, waves and impulses can enter into and traverse the transformer winding, and originate in it.

High frequency disturbances may be due to traveling waves, and to standing waves, and originate from lightning disturbances, switching operation, arcing grounds, etc.

Assuming for instance that the transformer winding in Fig. 1 contains appreciable electrostatic capacity. That is, every turn or coil of it can act as a reservoir, absorbing appreciable current. Before the switch S is closed, all the transformer coils are at zero voltage. In the moment when the switch is closed and voltage e impressed upon the transformer, the voltage does not instantly appear even on the first coil 1, but a big current rushes into this coil, gradually, within a hundred thousandth of a second or so—charging it, as a reservoir, up to voltage e. In the next moment, current rushes from the first into the second coil, charging this up to voltage, then in the third one and so on, and so successively—in an extremely short time the transformer coils are energized. When the first transformer coil has been charged up to voltage e, current is still rushing into it. This current can not instantly stop, and therefore, continuing to flow, raises the voltage of the first coil still higher, until finally the rising voltage stops the flow of current into coil 1, leaving this charged to a voltage nearly equal to $2e$. As this voltage is higher than the supply voltage e, current begins to rush out of the coil 1 again, back to the switch S and forward to coil 2, and the voltage of the first coil drops down to normal, e. When normal voltage is reached, the current still flows out of coil 1, and continues to flow, as it can not suddenly stop, and lowers coil 1 below the supply voltage, down to near zero, until the outrushing current is stopped by the decreasing voltage. Then current begins to flow in again, as the coil is below supply voltage, and so on alternately, with gradually decreasing amplitude, current rushes in and out of coil 1, and the voltage rises above and falls below supply voltage. The same play occurs in coil 2, 3, etc. Coil 2 however, receives the in-rushing current and the voltage after coil 1, and thus reaches maximum voltage a little later than 1, and a somewhat lower maximum voltage; coil 3 reaches maximum voltage again a little later than 2, and so on. That is, oscillations of voltage and current occur successively in the coils; or in other words, an electric wave travels into and through the transformer, starting at maximum intensity at the switching point, and progressing, with decreasing intensity, through the transformer, until it either dies out, or reaches the end of the winding and is there reflected back. In the latter case, the reflected returning wave combines with the incoming wave to form a standing wave, as will be shown later.

If the traveling wave is due to a single impulse, as closing the switch and putting the voltage on the transformer, or taking the voltage off, it usually dies out rapidly. If however, successive impulses follow each other, the successive trains of waves may build up to higher and higher intensities, and thereby reach destructive values. This for instance is the case with an arcing ground on the line, as the flash over or puncture of an insulator. Such an arcing ground gives a continuous succession of impulses by withdrawing and again applying the voltage: the arc puts the line on ground and thereby withdraws the voltage from the transformer, and at the same time, by the disappearance of the voltage, the arc goes out. This, however, lets the line build up again in voltage, again starting the arc; this arc discharges the line and goes out, the line again charges and starts the arc, and so on.

The formation of a traveling wave, and its transformation by reflection into a standing wave, may be illustrated by Fig. 2. Assuming we have a rope AB, (1) in Fig. 2, fastened rigidly at B, and give it an impulse by periodically moving it up and down at A. Then a wave forms and runs along the rope, as seen in (1) to (11) of Fig. 2. If the rope were not fastened at B, but continued, the wave would continue beyond B, as shown in dotted lines on the right-hand side of B in (12) to (21) of Fig. 2. However, in this case, in (12) (13) (14) the rope would have to move upwards at B; in (16) (17) (18) downwards, etc. As it is held fixed at B, this is the same as if in (12) (13) (14) a downward impulse were given to the rope at B, in (16) (17) (18) an upward impulse, to keep it in place. This virtual impulse at B, however, starts another traveling wave, running from B backwards towards A, and being the reverse of the continuation of the original wave beyond B, also shown dotted in Fig. 2. It is called the reflected wave or return wave. This return wave, which issues from B

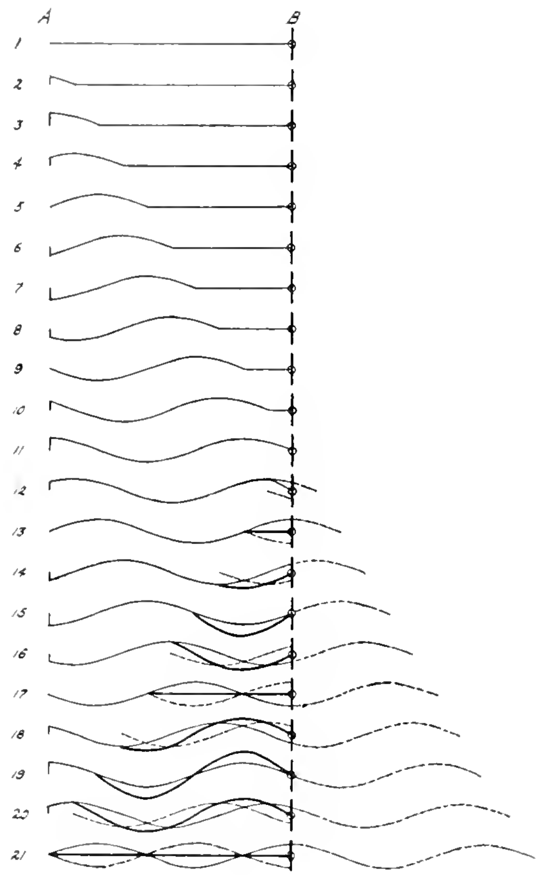


Fig. 2

towards A, superimposes on the original wave coming from A to B, and both combined are shown in curves (12) to (21) in heavy drawn lines. As seen, this resultant wave does not travel, but its maxima and its zeros are always at the same points; and it therefore is a stationary or standing wave, which spreads from B towards A, and is formed by the combination of the traveling wave and its reflected wave.

Just as the wave in the rope, Fig. 2, can not go beyond the rigid support B, so an electric current wave can not travel beyond the open end of the circuit—as this open end must always be zero current—and an electric voltage wave can not travel beyond the point of the transformer, which is held at ground potential. There it reflects and forms a standing wave. Fig. 2 also shows that the final standing wave is of twice the intensity of the traveling wave.

Assume now, that we do not fasten the rope at *B* in Fig. 2 but have it continued beyond *B*, and fasten to the rope at *B* a weight which is so heavy that the impulse of the rope can not appreciably move it. Then the traveling wave, when it reaches *B*, in (11) of Fig. 2, can not continue beyond it, but is reflected, and the part of the rope beyond *B* remains at rest. A weight thus stops the traveling wave and reflects it back. Inductance in an electric wave is the analogy of the weight on the rope, and an inductance interposed in the path of an electric traveling wave thus offers a barrier to this wave, and reflects it back on its path, the more completely, the higher the inductance is; just as the weight at *B* reflects the traveling wave on the rope back the more completely, the heavier the weight is, i.e., the less it can be set in motion by the wave.

In Fig. 2, if at *B* the rope is not fastened rigidly, but continues beyond *B*, and is loaded by a weight at *B*, the traveling wave coming from *A* is stopped and turned back by the weight at *B*. However, as the weight is not infinite, the wave impulse will give it some motion, however small it may be, and a part, even if only a very small part, of the traveling wave reaches beyond *B* into the rope on the right-hand side of *B*. If then, this part of the rope can oscillate, it will gradually be set in motion, and oscillate with increasing intensity, but in such a manner, that the weight *B*, which can not move much, is a zero point of the oscillation. That is, gradually a standing wave forms beyond *B*, transmitted from the standing wave on the left side of *B*, and this standing wave increases in amplitude, until it has reached the same intensity as the standing wave on the left side of *B*.

That is, the weight on the rope, while practically stopping the traveling wave, does not stop the standing wave, but merely retards its transfer across *B*. In the same manner an inductance in an electric circuit, no matter how large, while it more or less completely stops a traveling wave, does not stop a standing wave.

In other words, inductance, such as a choke coil offers no protection against standing waves, but merely forces these standing waves to form so as to make a zero point of current, or anode, at the inductance.

As the standing wave is the cumulative effect of traveling waves, it usually is of greater intensity, that is, higher voltage and destructiveness, than the traveling wave. Inductance offers no material protection against standing waves; but the necessary protection may be secured by preventing the formation of standing waves by the use of energy-absorbing devices, i.e., by consuming the energy of the traveling waves so rapidly that they cannot develop into standing waves: the analogy of anti-hunting devices in synchronous machines.

It seems to follow herefrom, that in the protection of transformers from abnormal frequency strains we have to rely on the combination of inductances with energy absorbing devices, the former to guard against excessive intensity of traveling waves, the latter to guard against the formation of standing waves from whatever traveling waves appear in the system.

CONTRIBUTION OF INDUSTRIAL COMBINATIONS TO NATIONAL WELFARE

By Magnus W. Alexander

Lynn Works of the General Electric Company

Mr. Alexander's whole argument is based on the proposition that the big industrial combination, from its very nature, is physically capable of subserving the public good to a greater extent than an aggregation of individual employers. Our complex social and industrial system offers many problems with which the individual cannot readily cope, on account of the large resources of money and the broad treatment which their solution demands. When banded together into an industrial combination, they can collectively carry into effect what individually they could not easily bring to pass. Mr. Alexander, as many of our readers are doubtless aware, has for a long time been particularly interested in the economic and sociological phases of corporation work, and has achieved much in the direction of increasing human efficiency and introducing improved business methods. He served as Chairman of the Massachusetts Commission on Old Age Pensions and Annuities from 1908 to 1910, since which time he has been serving on the Massachusetts Commission on Workmen's Compensation. The present paper was originally presented by the author before the American Academy of Political and Social Science, and is now reprinted from the Annals, after being revised by the author for the Review.—Editor.

A combination of either men or capital is in itself neither good nor bad, except in so far as it exercises its powers in the one way or the other. Its potentiality stands in direct proportion to the size of the combination and is even greater than the combined potentialities of its component parts, just as the purchasing power of a thousand dollars, due to the advantages of wholesale buying, is even larger than the combined purchasing powers of the individual dollars making up this sum.

The relation of industrial combinations to national welfare can, therefore, be discussed along two lines, according to whether the combination is a good or a bad one from the standpoint of the common good, or whether it is large or small in size. Eliminating the second differentiation as one of degree only, we must at once choose between the combination which utilizes its potential power for social good or social evil in order that we may be in a position to judge of the character of its contribution to national welfare.

In the final analysis, there can be no doubt that fair-minded men will lend neither their approval nor their moral support to any combine which operates in defiance of the common good, neither will they willingly countenance any act of an even well-intentioned body which does not successfully stand the test of fairness to all concerned. Admitting that any force which does or can react unfavorably upon the common welfare should be fought by all legitimate means, it follows that to discuss the relationship of such force to national welfare can serve no constructive useful purpose, save to outline its baneful influence in clear and strong contour to the end that men may be stirred and stimulated to wage war upon it. This war, however, must be one of fair discrimination, directed against the abuse of power and not the power itself, and concerned with the weaknesses and imperfections of the industrial system and not the elimination of the system itself, which has sprung up in response to the development of modern industrial activities.

As our political system is based on the conception of a government of law and not a government of men, so should our industrial system of combinations be judged by the character and inherent tendency of the combinations, either to subserve the public good, or to exploit the people for the benefit of the few, and not by the commissions or omissions of those who are the directing heads of the day, and who, if they act unmindful of their obligations to society as a whole, should become the personal target of our scorn.

Firmly convinced that the unfailing work of public opinion, and the certain, though often slow, process of remedial legislation and judicial adjustment in a well-ordered state will inevitably right what is wrong and harmful in any system, I shall refrain from a further consideration of the injurious and destructive, and turn to the helpful and constructive phase of the relation which industrial combinations bear to national welfare.

I submit as my fundamental proposition that an industrial combination is and ought to be made a powerful agency for the common good. Some of them are already working in this direction and many more are showing an unmistakable tendency along these same lines. Such combinations, to my mind, would be managed by able, fair-minded men who, though naturally engaged upon utilizing, in the most profitable manner, the money entrusted to their care by the stockholders are, at the same time, conscious of their social obligations to their employees, their customers, the community in which they operate, and to the people at large, and, in addition, possess the imagination and foresight to realize that such broad-minded conception of duty and obligation will in many ways help, and in no way hinder, the accomplishment of their legitimate business purposes.

On the other hand, it may be said that national welfare is synonymous with a condition under which the people enjoy a fair and adequate measure of contentment and happiness, of healthy physical and mental development, all of which, in an industrial sense, will result from the payment of an equitable compensation for labor, and the establishment of fair conditions of work. Each individual employer, as well as a combination of employers, can, of course, contribute his proportionate share toward the welfare of those working for him and with him. Yet our complex social and industrial life offers many problems with which the individual cannot readily cope on account of the large resources of money and the broad treatment which their solution demands, and also because the successful carrying out of some sociological plans must depend upon larger aggregation of workers and means than are ordinarily grouped under a single employer. When banded together in an industrial combination, they can collectively carry into effect what individually they could not easily bring to pass; while, at the same time their combined strength in capacity, finance and opportunity will permit the consummation of such benefits in a larger degree and on a firmer foundation than would otherwise be possible.

The care of sick and injured employees and of those who through old age can no longer render efficient service, but who by virtue of their past work are entitled to spend their declining years free from want and with the preservation of their self-respect; adequate assistance to those dependent on the victims of accident and sickness and who are thus deprived of their sole means of support; the establishment of sanitary and hygienic conditions of the most approved order in the work shops and throughout the premises of the employer, and even in the homes of the employees; the industrial education of the boys and girls who are to take up the burden of the work in the coming generation, and the advancement of those already employed who are anxious to reach a higher plane of industrial usefulness so that, with an increased skill and mentality, imagination and taste, they may derive greater enjoyment from their leisure hours and more contentment in their daily work; these and many other similar activities are merely indications of the vast field of genuine and lasting helpfulness in which the power and resourcefulness of the industrial combination can promote the well-being of the people.

These matters are indissolubly associated with the welfare of the working people; and inevitably we are led to inquire as to the relative capacity and opportunity of the individual employer and the large combination to open up this great field to the advantage of the employees. Can the average individual employer successfully compete with the larger combinations in the erection of workshops and factories which present model conditions of lighting and ventilation? Can he as readily afford to introduce every effective measure that will make for the safety and convenience of his workers? Above all else, can he assure to his employees that steadiness of employment throughout the year which is the very keynote of the welfare of the people? An increased daily or weekly wage alone, we must admit, will not permanently improve the lot and comfort of the workers; unless, in addition, the employee can have a fair assurance of this wage for every week of the year, provided he is ready, in return, to give of his labor in a fair and honest manner.

The struggle for an increased wage has always existed, and will continue as the centuries roll by; it is after all, only one phase of the everlasting struggle of evolution to a higher plane of existence. We should not deprecate this tendency, but rather make it our serious concern, if we truly desire to advance the welfare of the people, to find ways and means of affording to the workers steady opportunity for work, as far as this can be done under ordinary conditions of commerce and industry.

It would seem that the wisely managed industrial combination is in a fair position to do this, whereas the individual employer can only approximate it. By virtue of its resources and power, the large combination can effectively minimize waste of production and the larger waste of the distribution of goods; purchase its raw materials at a low rate; effect economies of manufacture through the introduction of special machinery and efficient business methods; and therefore, without lowering the wage scale, reduce the cost of production and, correspondingly, the selling price of the finished product. This in turn will place articles heretofore classed as luxuries within the reach of the masses, and, therefore, tend to open an enlarged market of consumption which must result in increased production and a greater opportunity for steady employment. Moreover, an industrial combination, more readily than an individual employer, can so adjust its production as to distribute it fairly equally over the whole year, being further aided in this respect by its ability to engage in various industries of the same general character and to anticipate future requirements by producing and stocking goods for future consumption. Its resources in money and brains give the industrial combination the potential advantage of stimulating and developing inventions for the advancement of the arts; with the resulting benefit that new fields of activity will be opened up for general use and, in consequence, the comfort and the pleasure of the life of the people enhanced and national welfare promoted. While I am aware of the argument on the other side that competition will more surely bring to the surface latent possibilities and capacities which may stimulate inventions and make for general efficiency, I submit that industrial combinations do not eliminate this condition, for the stimulant of ambition, acting upon genius, will make itself felt just as powerfully between men, whether they derive their opportunity and their reward from the same source or from different ones. The further claim that industrial combinations can, and sometimes do, deprive the people of the benefits of such improvements by withholding their exploitation and use, would, to my mind, if well founded at all, merely indicate the way along which the scope and character of our legal machinery should be improved.

The burden of my whole argument in support of the wholesome influence of industrial combinations on national welfare is based, as already stated, on the assumption that these combinations are and ought to be constructive and beneficial in character. It would be folly, however, to close one's eyes to existing deficiencies in the operation of some industrial combines, or to the possibilities of harmful results growing out of their future actions. An aroused public conscience will have to apply from time to time necessary corrective measures, as it is at present at work to crystallize into statutory provisions such safeguards and regulations as would now seem necessary for the protection of the people against real and alleged abuses of some combinations. These abuses, I contend, may be traced back largely to a lack of appreciation by some industrial managers of the sociological need of the times, and the psychological aspect of modern industries. In all fairness, however, to the sagacious business men who created and developed our wonderful industrial system until it challenges to-day the admiration of the whole industrial world, it should be remembered that the intensity of this upbuilding process so engrossed their thought and time that the sociological phase of their work had necessarily to be neglected. Meanwhile, the great expansion of the working force and the great influx of foreign workmen during the last two decades, consequent multiplying restrictive legislation and growing influence of organizations of workers and employers, greatly contributed to the present complexity of the conditions of labor, and forced closer attention to the human factor in industry than had heretofore been given. Much constructive work has been undertaken of late in this respect, but much more needs to be done by the employers of labor and particularly by the industrial combinations.

In order, then, that this work may receive proper direction and attention, I would earnestly advocate that a "Department of Applied Social Economics" be established in each industrial combination and, as far as practicable, by each individual employer. This department should concern itself with the study of human progress in its relation to industrial activities, so as to be able to analyze each existing condition and to propose an adequate and broad-gauged plan of action where such is required; and, more important yet, to foresee the conditions of labor which the development of the industrial system is bound to create, in order to suggest ways and means which will effectively meet the coming situation and even anticipate and direct it into its proper channels.

Experts in all matters pertaining to the welfare of the working classes, familiar with the history of the movement for improving human conditions, analytical and constructive in mind, ready and anxious at all times to assist the industrial managers in the treatment of the human phase of their great and vast problems —these practical economists and sociologists in our industrial system would prove an important factor in the further development of the potential power of industrial combinations for the promotion of national welfare.

The spirit of the times is tending towards humanitarianism. The human side of industry must, therefore, receive increased recognition and expert study and attention. Its adequate treatment would be an appropriate response to the demands of the day, and would prove beneficial alike to the interests of the employer and the employee, as well as society as a whole, by eliminating economic waste and conserving human energy. The Department of Applied Social Economics is proposed as the agency through which the desired result may be achieved.

SOME NOTES ON THE INSTALLATION AND OPERATION OF HIGH-VOLTAGE TRANSFORMERS

By H. H. Hodgman

Transformer Engineering Dept., General Electric Company

Dr. Steinmetz's article on page 737 of this issue gives a strikingly clear exposition of the abnormal strains (mechanical as well as electrical) which the modern power transformer is called upon to withstand, and the shifts to which the designer is put in his efforts to place in service transforming apparatus which will give reliable operation under the worst conditions which may arise. Having evolved such a design it is greatly to be deplored that a failure should occur through neglect (or ignorance) of the precautions necessary in placing such a unit in service. The present article offers a number of suggestions which should be observed in assembling and installing high tension transformers, and which, if explicitly followed, will ensure satisfactory operation. The article covers recommendations for inspecting and cleaning; drying and duration of the drying run; methods of sampling, testing, drying and straining the oil; filling of transformers, putting in service; and finally, operation.—Editor.

The following instructions, which must necessarily be somewhat general in nature, will serve as a guide to those engaged in installing and operating oil-immersed transformers of a large range in capacity and voltage, and especially those of high voltage.

Inspecting and Cleaning

A transformer, except when especially designed for outdoor installation, should never be permitted to stand out in the weather or be stored in a damp place. Transformers for outdoor service should not be exposed to the weather for any length of time before installing on account of their tendency to absorb moisture.

Whether the transformer is built up at its destination or shipped assembled, it should be thoroughly inspected before being permanently put into its tank. All dirt and dust should be wiped off. Castings, bushings, bushing-supports and leads should be examined for breakage or any other injury, and such repairs as may be found necessary should be made. All leads, throughout their length to the connection board, and all terminals in connection boards, should be examined to make sure that they have not been forced out of their proper positions during shipment. Likewise, the coil supports should be thoroughly inspected to see that they bear securely against the coils. The tank must be thoroughly cleaned. If a transformer is shipped in its tank, it should be removed for inspecting and cleaning. The transformer having been returned to its tank, the valve, thermometer and oil-gauge should be attached. Where there are no facilities for removing the transformer from its tank, an inspection, as thorough as possible, should be made of the transformer in the tank. The base may be cleaned by removing the valve and extending a swab through the valve opening.

Cooling coils, especially those made of brass or copper, should be inspected and tested to determine whether they have been injured during shipment. One method of testing for leaks is to fill the cooling coil full of water before putting it into the transformer tank, establish a pressure of 80 to 100 pounds per square inch, disconnect the source of pressure, holding the water in the cooling coil by means of a valve, and note whether the pressure gauge between the valve and the cooling coil proper maintains its indication throughout a period of one hour. Care should be taken that no air is left in the cooling coil in filling it with water. In removing the source of pressure it is preferable to entirely disconnect from the cooling coil, in order both to make sure that the source of pressure is entirely removed, and to note whether the lowering of the pressure, indicated by the gauge connected to the cooling coil, is due to leakage through the cooling coil valve, or to leakage through a hole in the cooling coil. If the gauge indicates a lowering of pressure in the cooling coil, and there is no evidence of leakage at either end of the coil, it should be inspected throughout its length until the hole is discovered. The water will gradually form at the hole and begin to drip.

After the cooling coil is filled with water, any convenient device, such as a small air pump, may be used for establishing the required pressure, in case there is not a satisfactory water source for obtaining it. In no case will it be necessary to establish a pressure higher than 100 pounds per sq. in., as the test is only for the purpose of discovering any leaks which may have developed during shipment. The cooling coil can be tested in the transformer tank by filling the coil with the same quality of oil that is used with the transformer, and applying the same method to obtain pressure as described under water test.

Another method of testing for leaks is to submerge the cooling coil in a liquid, establish an air pressure of 80 to 100 pounds for a period of an hour, and note if bubbles rise to the surface of the liquid. This test may be made conveniently after the transformer is filled with oil.

Drying

The question is often asked: "What are the limits of voltage and capacity at which drying and other precautions may be dispensed with, in putting transformers into service?" No unconditional limits can be fixed. Any transformer showing evidences of being moist must be dried. If the inspecting and cleaning indicate that the transformer is reasonably dry, and its voltage is not over 15,000 volts, then the drying of the transformer may in general be omitted. Aside from the voltage, some consideration should be given to the value of a transformer in determining whether or not it should be dried.

It may be said that all transformers 15,000 volts and over should be dried, and that transformers of 1000 kv-a. and over should be dried regardless of voltage. All transformers that show evidence of being moist, or that have been subjected to conditions that would cause them to be moist, should be dried regardless of voltage or capacity.

Before a transformer is dried out it should never be subjected to a higher voltage than necessary to force sufficient current, for the purpose of drying, through the windings with one winding short-circuited. After a transformer is dried out it should never have a potential higher than 10,000 volts applied to it, unless it is filled with oil of standard quality and dryness; while, if the voltage for which the transformer is wound is less than 20,000 volts, it should never be subjected to a potential greater than one-half its normal voltage unless immersed in oil. In no case should the inspecting, cleaning and straining of oil be omitted.

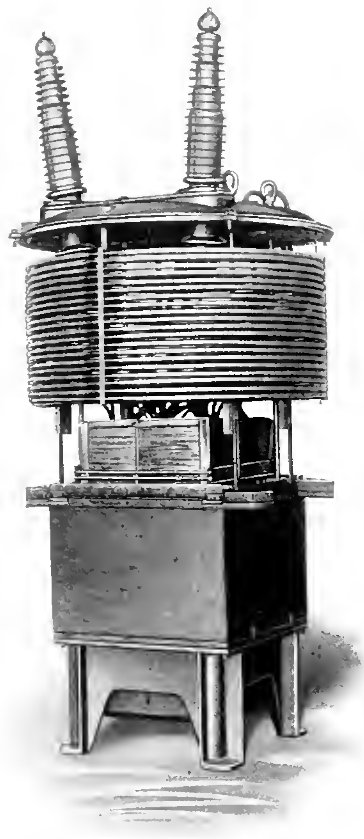


Fig. 1. Water-cooled shell type Transformer Removed from Tank, Showing Low Crowned Cover

Method of Drying

Two methods for drying transformers, designated "first method" and "second method," are here described. The first has been adopted as standard and should be used in all cases; the second is not recommended, and should not be used unless facilities for applying the first method are not available and cannot be obtained. Should it be necessary to use the second method great care should be taken to see that the current and temperature do not at any time during the drying exceed that specified on page 749.

In using the first method the caps on the ends of the cooling coil should be removed to prevent the development of dangerous pressure in the coil, which may result from vaporizing the liquid put in it to prevent bursting due to freezing.

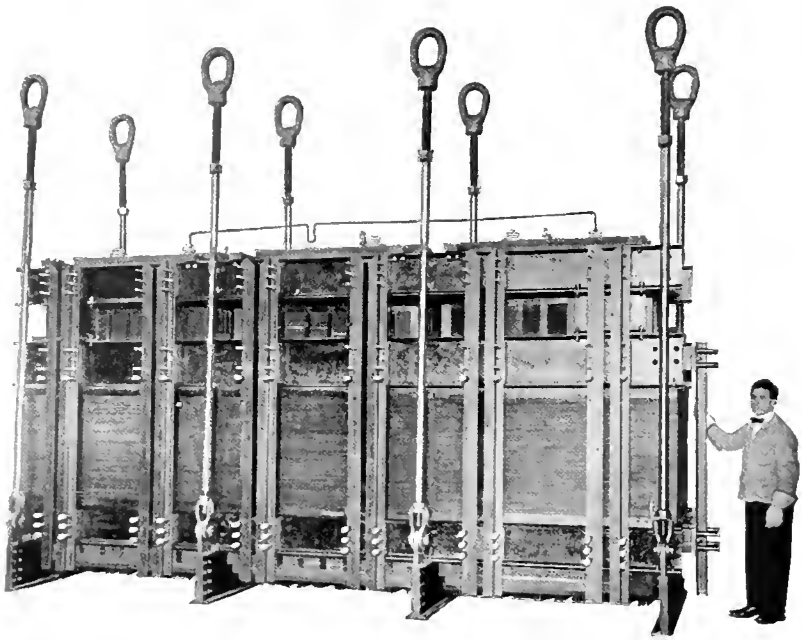


Fig. 2. 14,000 Kv-a., 100,000 Volt, 3-Phase Water-cooled Transformer Removed from Tank

First Method. This method requires the circulation of heated air through the transformer while in its tank. The transformer having been cleaned, inspected and returned to its tank, the sources of heated air should be connected to the base valve and the manhole cover removed. In order to maintain a sufficiently high temperature inside of the transformer, it will be found necessary to partly close the manhole, thus restricting the flow of air. The temperature of the heated air as it enters the transformer should not exceed 90 deg. C., and the process should be carried on for a period of about three days. However, the same discretion regarding the length of the drying run mentioned in the following section, "Duration of Drying Run," may be used here.

Outfits may be obtained especially adapted for furnishing hot air for this purpose. They consist of an electric air heater, blower and air strainer. The air heater requires 20 to 25 kv-a. at 110 or 220 volts to operate it. The blower is designed to run at 3300 to 3500 r.p.m. and requires 2 h.p. to drive it at normal output. The blower may be driven by means of a gasolene engine, motor or any other prime mover which may be available. The air strainer when in operation should be wrapped with cheesecloth, to prevent the dust from entering the blower and being blown into the transformer. This cloth should be changed from time to time as the dirt accumulates on it. The general appearance of the outfit is shown in Fig. 3.

If the oil in the barrels or tanks is found to puncture below the limit fixed under the heading "sampling and testing oil," the oil must be dried as described under the heading "drying oil." The transformer must be filled with oil immediately after the drying.

Second Method. Drying by this method should preferably be done with the transformer out of its tank; but if the transformer is in its tank the manhole cover should be removed, and the valve in the base opened to give as great a circulation of air as possible under the conditions.

Short-circuit one winding, and apply such voltage to the other that sufficient current will flow in the windings to raise the temperature to approximately 80 deg. C. actual. The amount of current necessary to effect this temperature ranges between one-fifth and one-third of the full load current, depending upon the room temperature and the design of the transformer. The impedance volts necessary to give the specified range in current varies from 0.4 to 1.5 per cent of the rated voltage of the winding to which the impedance voltage is applied. In every case, however, the current admitted must be so regulated that the temperature of the windings does not exceed the 80 degrees specified. The temperature of the winding can be determined by the increase in resistance, which is calculated as follows:

Let Rc = resistance at room temperature, or cold resistance.

tc = room or coil temperature for cold resistance.

Rh = hot resistance.

th = temperature of windings hot.

then $th = \frac{Rh\,(238+tc)-238\,Rc}{Rc}$

and rise $= th - tc$.

A simple method for determining the temperature of the winding is to assume that for each per cent increase in resistance the temperature rise is approximately $2\frac{1}{2}$ deg. C.;

then $\frac{Rh-Rc}{Rc}$ = per cent increase in resistance.

As one per cent increase in resistance $= 2\frac{1}{2}$ degrees temperature rise, then

per cent increase $\times 2\frac{1}{2}$ degrees = degrees rise, and

tc + degrees rise = actual temperature.

When facilities for these methods are not available the bulb of a spirit thermometer may be placed in direct contact with the low-tension coils at the top. Low-tension coils are specified for the reason that, to place the bulb of the thermometer in contact with the high-tension coils may not give the temperature of the coils; the pressboard pieces fitted around the ends of the high-tension coils being built up on the copper to such a height as to prevent the thermometer recording the temperature of the copper. The bulb of the thermometer should be placed well down between the low-tension coils. Mercury thermometers must not be used for this purpose.

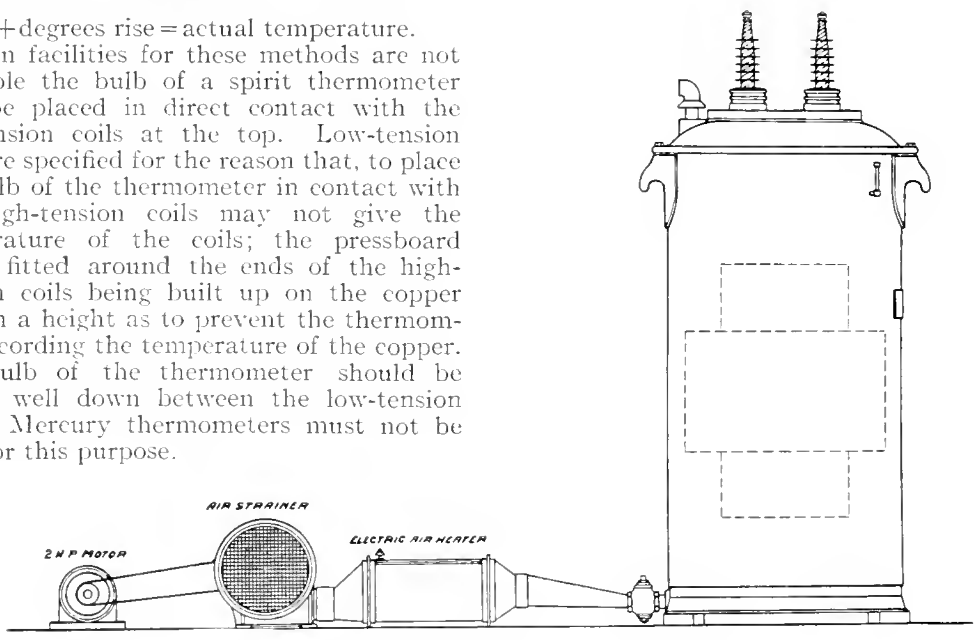


Fig. 3. Hot Air Drying Outfit for Drying Transformers

Duration of Drying Run

The duration of the drying run depends upon the voltage and size of the transformer and also upon its condition as to moisture at the time it is dried. For transformers under 20,000 volts the drying should be continued not less than 24 hours; 20,000 to 30,000 volts, 48 hours; between 30,000 and 40,000 volts, 72 hours. Higher voltages may require longer. It is obvious that some consideration must be given to the capacity of the transformer. Transformers of less than 100 kv-a. may only require 24 hours. For transformers between 200 kv-a. and 500 kv-a. the process may be limited to 36 hours; between 500 kv-a. and 1000 kv-a., to 48 hours; between 1000 kv-a. and 2000 kv-a., to 60 hours; for all larger capacities the process should be carried on for at least 72 hours. In case there is no evidence that the transformer is unduly moist, discretion may be used in slightly decreasing the limits given for the voltage. A transformer of 20,000 to 30,000 volts, for instance, having a capacity of 200 kv-a. or less may be dried in only 24 hours. The limits given for the capacities, however, should be rigidly adhered to, and in no case should the process be carried on for less than 24 hours.

The above instructions apply to both methods of drying, and are based on ordinarily good conditions of the weather during shipment. If the transformers have been exposed to the weather for a long time, or if during shipment it was very stormy, or in the case of the smaller sizes with very high voltages (such as testing transformers), the hours of duration may have to be increased to twice or three times the numbers specified.

Drying Oil

Transformers should be operated only in the oil furnished with the transformers. Oil is usually shipped in sealed barrels. If, however, the consignment should be a very large one, it may be shipped in special tank cars direct from the manufacturer to save repeated handling. In any event, it may require drying at its destination before it is suitable for use in high voltage transformers.

The apparatus illustrated in Fig. 4 may be found useful in drying and purifying transformer oil. The oil is treated in a filter press, by being forced through several layers of blotting paper, which removes all moisture and solid matter. By this method from 360 to 1200 gallons of oil, according to the size of press, can be treated in an hour. With oil of average quality, as regards moisture and foreign matter, one treatment will usually remove all sediment and bring the puncture voltage up to 40,000 volts or more. If the oil requires more than one treatment, it can be determined by tests, as described under "sampling and testing oil."

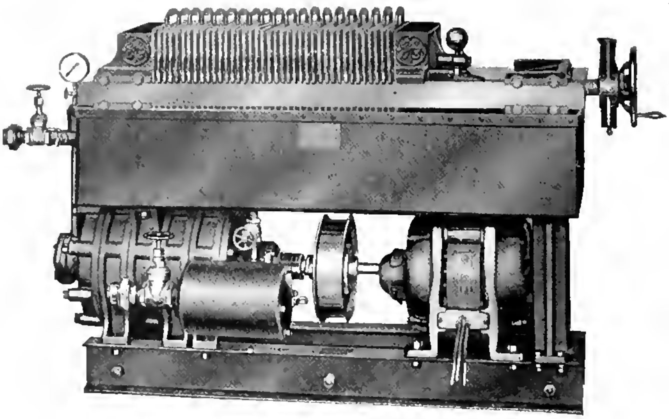


Fig. 4. Oil Drying Apparatus Complete

Straining Oil and Filling Transformer

Before the transformer is filled with oil, the valve, gauges, thermometer, and all other attachments must be fitted to the transformer. Also, the plug in the center of the base should be screwed in tight to prevent the leaking of oil. The transformer must be thoroughly cleaned, as directed under "inspecting and cleaning." To fill a transformer, the oil should be pumped or poured into the tank through a strainer in the top. *Oil should not be run through rubber hose because of sulphur in the rubber.* In filling transformers rubber hose has been used to a considerable extent in the past; and, while no immediate injury has been observed, it is known that if sulphur exists in sufficient quantities the copper conductor of the windings will be injuriously attacked. For this reason it is best to eliminate the use of rubber hose in handling oil.

The frame for the strainer is shown in Fig. 5. The sketch merely shows the frame for supporting the straining cloth which forms a lining for the inside of the frame. The frame is first lined with a wire screen of such a mesh as will form a support for the straining cloth. The straining is done in two stages, as indicated in the sketch. The cloth used should be of such weave as not to admit a barrel of oil in less than four to six minutes. This cloth should be of considerably closer weave than ordinary cheesecloth, preferably muslin or cotton cloth. The vertical sides of the frame should be lined with two layers of the cloth, the horizontal stages which form the strainer proper to be of one layer each. The frame may be constructed of wood and should be of such dimensions as will permit it to fit into the manhole of the main cover; the projecting top pieces of the frame to rest on the cover to support the strainer as a whole. The straining cloths should be renewed as often as necessary, not less than one set of cloths being used for each transformer. When the filter press is available the straining may be omitted, as the oil can be pumped through the filter press into the transformer. After filling the transformer, the oil should be allowed to settle at least 12 hours before voltage is applied.

Sampling and Testing Oil

Extreme care is required in sampling oil. The receptacle for the sample should be of the quart size, preferably a bottle, and should be thoroughly clean and dry. The sample must be drawn from near the bottom of the barrel or tank containing the oil to be tested, after the oil has been undisturbed for a period of not less than 24 hours.

In drawing samples from barrels, a long glass tube of considerable diameter, thoroughly cleaned and dried, with the lower end drawn to a diameter of a quarter of an inch, may be used. Closing the top end of the tube with the hand, the tube is thrust to the bottom of the barrel. The hand is then removed, thus permitting the tube to fill. The hand is again placed over the top end of the tube and quickly withdrawn from the barrel, letting the oil run into sample bottle.

The receptacle of the oil-testing outfit that receives the sample should be dry and clean. Ordinarily, it will be sufficient, after each sample, to wipe the receptacle and the terminals with a clean cloth that leaves no lint. The high potential wires should be connected to the proper terminals of the sample receptacle, through fuses of such capacity as will protect the testing transformer under short-circuit. The adjustable terminals should be gauged to exactly 0.2 inch; and the sample poured into the receptacle, which should be slightly less than full of oil. Bring the voltage up slowly and continuously until snapping sparks pass at short intervals. This is called the "breakdown at short intervals" or B.D.S.I. point. The voltage that causes a continual passage of sparks is the puncture voltage, and may be considerably higher than the B.D.S.I. If the source of the test voltage is one of considerable power, there may be only a puncture voltage, which ordinarily would represent the B.D.S.I.

Oil for transformers of 40,000 volts and over should be dried before using, if it punctures below 35,000 volts. For transformers having voltages less than 40,000 volts, the oil must be dried if it punctures below 25,000 volts. Where oil is dried it may easily be brought to a puncture of 40,000 volts. If a sample contains sediment, it will puncture at a lower voltage than it would without the sediment. The small portable transformer shown in Fig. 6 has been especially designed for oil testing. It is arranged for operation on 100 and 200 volt circuits, while a maximum of 50,000 volts can be obtained on the primary.

In case a regular testing transformer is not available, two 22,000 volt potential transformers may be connected in series, and the center point of the series of windings grounded. An improvised water rheostat may be used in the low tension side of the transformers for regulating the voltage. In case no facilities are available for making puncture tests, the following rough method of determining the condition of the oil may be resorted to. On drawing out the sample by means of the glass tube, place the free hand over the bottom end of the tube to keep the oil from escaping, and turn the bottom end up. Water globules, if present, will precipitate slowly downward and the air bubbles upward. When this test shows globules of water, the oil should either be dried or other oil obtained.

Where it is necessary to draw samples of oil from the bottom of a transformer, or from

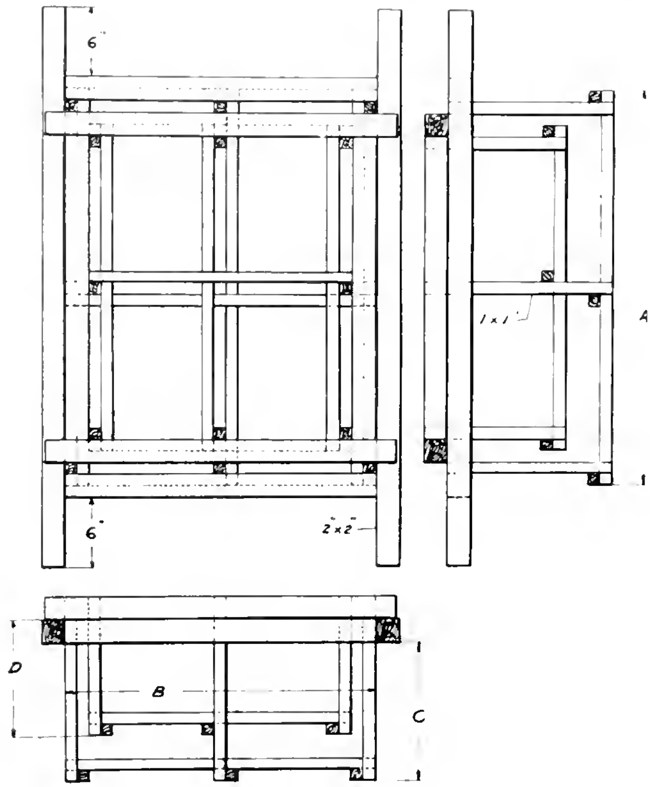


Fig. 5. Frame for Oil Strainer

the bottom of any large tank, one or two gallons of oil should be drawn before taking the sample, in order that whatever dirt and moisture that may have accumulated in the fittings, through which the oil passes, may be rinsed out. New dry corks must be used for stopping bottles filled with samples of oil.

To dry a bottle may be found a difficult task in a moist climate. The most satisfactory process is, after the bottle is washed clean, to place it either in a dry room or a dry oven, with its neck turned down, the bottle being supported in a position slightly slanting from the vertical. The position permits the liquid used for washing to drain out, and to spread out in a thin film over the inside of the bottle, thus facilitating rapid evaporation. It is necessary to have the room or oven sufficiently dry, regardless of whether it may be warm. An oven may be improvised by using a box practically air-tight with a pan of chloride of calcium placed in it, and the bottles set to drain and dry in the closed box. If a bottle is dried in a hot oven which obtains its air

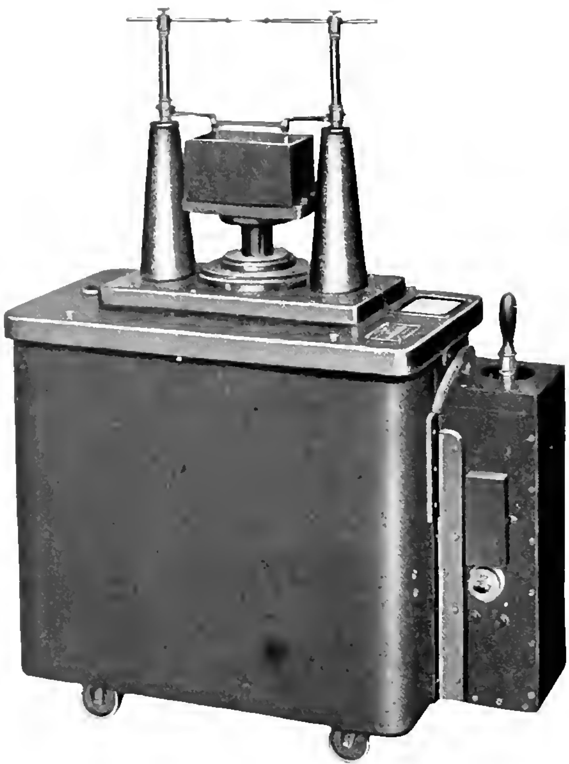


Fig. 6. Oil Testing Transformer

from a moist source, the bottle, when taken out, may be apparently dry; but, when placed in the coolness of the outside, the heated air in the bottle condenses its moisture. For ordinary conditions of atmosphere, it is sufficient to place the bottles in a draining position and let them dry without heating.

Occasion may arise for drawing oil out of a transformer and replacing it later, or for transferring oil in service from one station to another. If it is intended to use this oil again, the greatest care is necessary in order to have the barrels or tanks for receiving the oil dry and clean. The barrels or tanks must not be assumed to be dry; but in every instance, must be given a cleaning and drying, which should consist of rinsing with gasolene or alcohol, draining thoroughly, and rolling the barrel slowly in a dry room, so that liquid that cannot be drained out forms a thin film and evaporates. If necessary, close the room tight and set several pails of chloride of calcium around the room where the barrels are to be slowly rolled. If convenient, hot air may be circulated through the barrel for drying. Oil should never be put into a transformer without being tested and strained or filtered.

After installing a transformer, before putting it under voltage, samples should be drawn from the bottom after the oil has been undisturbed not less than 12 hours. These samples should be examined and if found all right the voltage may be applied.

Putting Transformers into Service

The transformer having been dried and filled with oil, the cooling coil ends should be connected to the water supply, which should never be taken from near the top of the water in the pen-stock or any other place where large quantities of air are likely to be in the water; as the presence of air in the water will greatly increase the rapidity of oxidation in the interior of the cooling coil. A visual indicator for indicating whether the water is flowing properly is inserted between the discharge end of the cooling coil and the drain. One of the simplest arrangements is to permit the discharged water to flow through the air into a funnel beneath connected to the drain pipes. The oil outlet at the bottom, which is provided with a valve, should preferably be connected to a permanent piping to facilitate emptying the transformer when it is required. Before the water is turned on, the spaces around the ends of the cooling coil, where they pass through the cover, should be filled with Portland cement to prevent any condensation that may accumulate on the piping from entering the transformer. This sealing is usually done in the factory for those transformers which are shipped completely assembled. However, it is very necessary in every case to closely examine the filling, which may be cracked or broken loose during shipment, in either of which cases the old compound should be gouged out and new put in. A sufficient quantity of cement is shipped with each order to provide for filling around the cooling coil ends. The cement should be mixed "*neat*" and of course mixed up every time it is used.

"Protection pieces," which are umbrella-shaped castings, are supplied with most water-cooled transformers, to be connected to the ends of the cooling coil that extend through the cover. Water piping is to be connected to the "protection pieces," the purpose of which is to deflect water from the cooling coil openings in the cover. The cover of the transformer should not be bolted in place when the transformer is connected in circuit, but a free exit should be allowed for any gases which may gather in the top part of the transformer. The transformers being connected to the line, and the lightning arresters properly adjusted, it is ready for service.

Operating Transformers

The idea that transformers in service need no attention may lead to serious results. Transformers depending upon the circulation of a cooling medium should not be run continuously, even at no load, without the cooling medium. It is, therefore, essential that such observations be made as will insure the proper circulation of the cooling medium.

In case the water circulation in a water-cooled transformer is for any reason stopped, the load should be immediately reduced as much as possible, and a close watch kept on the temperature to see that it does not reach abnormal limits. It will be necessary to reduce the load, whenever the oil at the top near the center of the tank approaches 80 deg. C. *This temperature should be recognized as an absolute limit and must not be exceeded. It should only be held during an emergency period which should be of short duration.*

The entering cooling water should never have a maximum temperature of over 25 deg. C., and sufficient observation should be made to see that the water does not exceed this temperature.

All cooling water contains more or less impurities, which cause scale or sediment to form in the cooling coils and clog them up. The time required to clog up a coil may be only a few months or it may take years, depending on the amount of impurities in the water. The clogging materially decreases the efficiency of the coil and is indicated by a higher oil temperature and a decreased flow of water, load conditions and water pressure remaining the same. The scale and sediment can be removed from the cooling coils without removing them from the tank. Especial care should be taken to prevent any acid, dirt or water from getting into the transformer tank, as the mixing of a very small quantity of foreign matter with the oil may result in serious injury to the transformer. To remove the deposit, first blow or siphon all the water from the cooling coils and then fill them with a solution of hydrochloride acid (specific gravity, 1.10). Equal parts of concentrated hydrochloride acid and commercially pure water will give the above specific gravity. After the solution has stood in the coils about an hour, flush out thoroughly with clean water. If all the scale is not removed the first time, repeat until the coil is clean, using new solution each time. The number of times it is necessary to repeat the process will depend on the condition of the coil, though ordinarily one or two fillings will be sufficient. The chemical action which takes place is very noticeable and often forces acid, sediment, etc., from both ends of the coil. It is therefore well to leave both ends open to prevent abnormal pressure. An indication of the effectiveness of each treatment can be noted, when flushing out with water, by attaching a pressure gauge to the in-going pipe and noting the gallons of discharge per minute with a given pressure.

After water-cooled transformers have been operated for some time, especially if the operating temperatures are high, the oil may leave a deposit on the outside surface of the cooling coils, which should be removed, as such a deposit will decrease the efficiency of the coil materially. This condition of the coils is indicated by higher oil temperature, the water and load conditions remaining the same. To prevent reaching the danger line, the coil, whenever indications point to the formation of a deposit, should be examined. This can be done by drawing the oil down slightly, exposing the first turns of the cooling coil; or the hand may be used to make the examination. In case deposit is found the coil should be taken out of the tank and cleaned.

During the first month of service of transformers having a potential of 40,000 volts and over, samples of oil should be drawn each week from the bottom of the tank and tested. Samples should also be drawn at least once every six months, after the first month, to give a check on the condition of the oil. If at any time the oil should puncture below a safe voltage the filter press may be used for treating it without taking the transformer out of service. The oil should be drawn from the valve in the base, passed through the filter press, and returned to the transformer through the cover, discharging into the tank at the end opposite the valve in the base, and the circulation being continued until the oil is satisfactory. The oil level should be periodically noted and should be kept sufficiently high.

In oil self-cooled transformers with external cooling pipes, the oil must always be kept sufficiently high in the tank to cover the top connections of pipes to the tank; otherwise, the oil cannot circulate through the pipes and the transformer will run hot.

When indoor transformers are installed where the atmospheric conditions are unusually moist occasional inspection of the inside of the cover should be made to make sure that condensation has not taken place. Should moisture or rust be found on the inside of the cover a chloride breather should be provided for the transformer.

Oil self-cooled transformers are occasionally operated under conditions of poor ventilation, or of overload, or of abnormal voltage. Any of these conditions, or a combination of them, is liable to raise the temperature of the oil unusually high, causing the oil to throw down a deposit, which forms on the transformer surfaces with which the oil comes in contact. Should the deposit on any surface, except the base, reach an average thickness of about one-eighth inch the oil should be renewed. To determine the thickness the oil should be drained from the tank and the transformer lifted out. Such a thickness of deposit does not necessarily mean that the transformer is in immediate danger, but the oil should be renewed as soon as conditions will permit. Before putting the new oil into the tank the sediment should be removed from all surfaces and the windings cleaned by forcing dry, clean transil oil through them with a force pump.

The thermometer should be noted at least daily. If it indicates a temperature of the oil 80 degrees or over, for the self-cooled, or 65 degrees or over for water-cooled, the transformer should be cut out of service at once, and the cause of the excessive heating looked into; for, should the transformer remain in service under this condition for any length of time, it is liable to be seriously damaged. Regardless of the temperature of oil as indicated by the thermometers, transformers must not be operated at overloads not stipulated by their specification. In operating water-cooled transformers at an overload the amount of water should be increased in proportion to the load. On account of the increased amount of water during overload, the temperature of the oil will not rise as fast as the temperature of the windings and any of the causes leading to excessive heating will have more pronounced effect under these conditions. Transformers during overload should therefore be watched with special care, to see that the oil temperatures are kept well below the limits above specified.

Compartments in which oil self-cooled transformers are installed should be thoroughly ventilated. Ample openings for the inlet of air should be provided at various points near the floor; and air outlets should be in or near the roof, which preferably should not be closer than six to ten feet from the top of transformer. The temperature of the room in which the transformers are installed should not exceed the temperature of the air entering the room by more than 5 degrees; and, presumably, the entering air will come from the outside, or at least from a source that does not cause the air to be very much warmer than the outside air.

For the purpose of preventing condensation of moisture on the oil surfaces and other inside transformer surfaces, it is preferable to keep the oil at all times at least 10 degrees above the room temperature. It is also desirable, especially in moist climates, to keep the oil in the transformers, when idle, slightly warm in order to eliminate the chance of the oil becoming moist. These results may be accomplished by applying voltage alone for a few hours each day. Water-cooled transformers in warm climates should be frequently observed to see that the oil temperature does not drop below the limits specified, and if it does, the amount of water must be decreased until the oil attains a temperature of at least 10 deg. above the surrounding air.

When it is necessary in case of an emergency to operate a three-phase shell-type transformer "open delta" due to one of the phase windings becoming damaged, care should be taken to see that both primary and secondary windings of the damaged phase are not only disconnected, but also that they are short-circuited upon themselves. Otherwise the flux through the damaged windings would appreciably increase the losses and further damage the coils. By short-circuiting the entire phase windings, however, enough ampere-turns are developed, with a current much less than load current, to drive back the flux. Three-phase core type transformers cannot be operated with two phases in open delta.

Connecting in Multiple

In case it is desirable to multiple transformers that are not of identically the same design, it is preferable to communicate with the engineer who designed the transformer. If it is not convenient to do this, great care should be exercised in determining that the polarity and ratios of transformers to be multipled are the same. When throwing transformers together for the first time, under operating voltage, they should be fused lightly, which necessitates that the load shall be discontinued at the time. After the transformers are under load, the division of the total current should be noted by means of ammeters; the load should be so limited that no transformer is subjected to more than its rated current.

MAGNETIC LEAKAGE IN TRANSFORMERS

Part I

By J. Murray Weed

Transformer Engineering Department, General Electric Company

This article discusses in an elementary manner the reactance, eddy current loss, and mechanical stresses resulting from magnetic leakage in transformers. As an introduction, the fundamental formulæ for magnetomotive force, magnetic density, and induced voltage are given, supplemented by a few pertinent statements outlining the relationship between the applied voltage, the exciting current, the magnetic flux, and the induced secondary voltage. In the present instalment formulæ are derived for the calculation of reactance and energy loss from eddy currents in the conductors; the calculation of any phenomena dependent upon magnetic leakage, however, being of necessity only approximate, since it is impossible to exactly define the leakage field, and since, for the purpose of simplifying equations, it is best to disregard many factors that have more or less bearing on the result. The remaining portion of the article, which will be published in the next issue of the Review, deals with the nature and calculation of mechanical stresses produced by the leakage field.—Editor.

We designate as magnetic leakage that magnetic flux which links the primary winding of a transformer without linking its secondary, or which links the secondary without linking the primary. All fluxes in the transformer result from magnetomotive forces produced by currents in the windings. The total magnetomotive force due to nI ampere-turns is

$$\frac{4\pi\ nI}{10}$$

and the magnetic density produced in any elementary flux circuit, if the density is uniform, is

$$\frac{4\pi nI\mu}{10l} \text{ lines per sq. cm.;}$$

l being the length of the elementary circuit in centimeters. Since the current I is expressed in terms of effective, or root-mean-square amperes, and the magnetic density is ordinarily calculated for the maximum value, the above expression should be multiplied by $\sqrt{2}$, giving

$$B=\sqrt{2}\,\frac{4\pi nI\mu}{10l} \text{ lines per cm.} \qquad (1)$$

In practical design it is more convenient to express the density in lines per square inch, and all dimensions in inches. If we do this, equation (1) becomes

$$B=2.54\sqrt{2}\,\frac{6\pi nI\mu}{10l} \qquad (1A)$$

If the cross section, length, or permeability of the magnetic circuit varies for different paths of the circuit, the flux is distributed in such a manner as to exactly consume the total magnetomotive force in each elementary circuit, and the magnetic density is variable for different parts of the circuit, and for different elementary circuits.

The exciting current in the primary winding of the transformer produces the main flux in the core, which is determined by the induced e.m.f., corresponding to the fundamental voltage equation:

$$E=\frac{\sqrt{2}\pi fn\phi}{10^8} \qquad (2)$$

whence

$$\phi=\frac{10^8E}{\sqrt{2}\pi fn} \qquad (3)$$

This induced e.m.f. is equal and opposite to the applied e.m.f. at no load. The distorted wave shape of the magnetizing current results from the variable permeability of the iron core. This current, neglecting the loss component, and assuming uniform permeability, lags 90 degrees behind the applied e.m.f. and leads the induced e.m.f. by a like amount, since the magnetizing current must correspond in phase with the flux required to generate this e.m.f. The magnetic leakage produced by the magnetomotive force of this current is usually negligible, since the permeability of the leakage paths between primary and secondary windings is very low as compared with that of the core, which links both primary and secondary.

When the secondary circuit is closed, the e.m.f. generated in the secondary winding produces current of a value and phase depending upon the impedance characteristics of the circuit. The action of this current upon the core permits the production of an equivalent current in the primary circuit. If the transformer is loaded, these currents are large as compared with the exciting current, and neutralize each other so far as action upon the core is concerned, but not with respect to the leakage paths. The magnetomotive forces of these currents produce the leakage fluxes which we are to consider.

The question has often been raised as to whether there is any leakage flux linking the secondary windings of a transformer. It has been argued that the total resultant e.m.f. generated by flux cutting the secondary must be consumed by the *IR* drop. This is true of any metallic circuit, but it does not hold that the secondary circuit does not possess reactance due to leakage flux. It is only necessary that the e.m.f. of this leakage flux should be neutralized by the e.m.f. of an equal amount of main flux cutting both primary and secondary windings in opposite senses. Of course, where these two fluxes, if existing, would occupy the same region, they neutralize each other directly, instead of their e.m.f.'s neutralizing each other. This, in fact, subtracts so much leakage flux from the secondary winding and adds it to the primary. This does not apply, however, to all the leakage paths linking the secondary windings; and so far as the actual distribution of flux in the leakage paths is concerned its effect is negligible. Also, so far as the inductive drop or reactance of the transformer is concerned, it makes no difference whether the leakage flux links the secondary or the primary.

Exact calculations cannot be made for phenomena which depend upon magnetic leakage in transformers: first, because it is impossible to exactly define the leakage field; and second, because if the exact distribution of flux were known, practical calculations would still have to be based upon simplifying assumptions. In making these calculations, only the reluctance in that part of the flux circuit external to the core is considered, the reluctance within the core being thought of as negligible. Also, all local paths around turns, or small parts of coils, are not considered. Each element of field is thought of as having uniform density throughout a certain assumed length, which may differ from its actual length in order to compensate for the real variations in length and in density. The density used is that which would result, with the assumed length, from the ampere turns which are active for the element

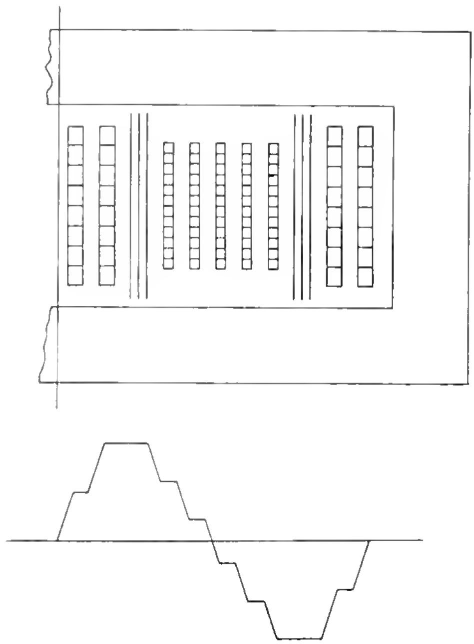


Fig. 1

considered. The effect of eddy currents in modifying this distribution of field is also neglected.

The distribution of flux density in the leakage field, in the region within the core, based upon the assumptions described above, is shown for a shell type transformer by the curve (a) of Fig. 1. The density at any point in this diagram is that given by the equation (1), where nI is the difference between primary and secondary ampere turns between this point and either end of the core window.

Reactance

A study of Fig. 1 will confirm the statement made above, that, so far as reactance is concerned, it makes no difference whether the leakage flux links the secondary or the primary. If we consider any element of flux, the resultant number of equivalent turns cut (algebraic sum of primary and secondary turns, with ratio of transformation 1 to 1) will be the same whether we consider it to vanish toward the right or toward the left. To determine the reactance e.m.f., it is therefore only necessary to consider all the flux as vanishing in one direction, finding the resultant number of equivalent turns cut by each element of flux, and substituting the summation of all such flux turn leakages for $n\phi$ in equation (2).

This calculation is simplified, without important sacrifice in accuracy, if we neglect the separation of coils by intervening ducts and represent the flux distribution corresponding to a single group of high tension coils by the smooth flux wave of Fig. 2 instead of the stepped ones in Fig. 1. We will consider the conductors very small and distributed uniformly throughout the spaces occupied by the respective windings. The flux occupying the element of space of width dx and of length $\overline{mlt}$, where $\overline{mlt}$ is the mean length of turn, or some empirical fraction thereof, is:

$$\frac{B_{max}x}{X}\overline{mlt}dx,$$

and the number of turns cut is $\frac{n_G x}{X}$ where n_G is the number of turns in the primary coil or group of coils producing this flux wave. The e.m.f. generated by this element of flux is therefore:

$$dE_x = \frac{\sqrt{2}\pi f}{10^8}\;\frac{B_{max}n_G\overline{mlt}}{X^2}x^2dx \qquad (4)$$

Integrating this e.m.f. for all the flux within the primary coil, or group, from O to X, we have:

$$\triangle_1 E_x = \frac{2fB_{max}n_G\overline{mlt}}{10^8}\;\frac{X}{3} \qquad (5)$$

Whence, substituting the value of B_{max} from equation 1A:

$$\triangle_1 E_x = \frac{2fn_G^2 I\overline{mlt}}{10^7 l}\;\frac{X}{3} \qquad (5A)$$

Similarly, the e.m.f. generated by the flux found within the secondary coil is:

$$\triangle_2 E_x = \frac{2fn_G^2 I\overline{mlt}}{10^7 l}\;\frac{Y}{3}; \qquad (6)$$

while that generated by the flux found between the primary and secondary is:

$$\triangle_3 E_x = \frac{2fn_G^2 I\overline{mlt}}{10^7 l}\;Z \qquad (7)$$

The total e.m.f. produced by the single

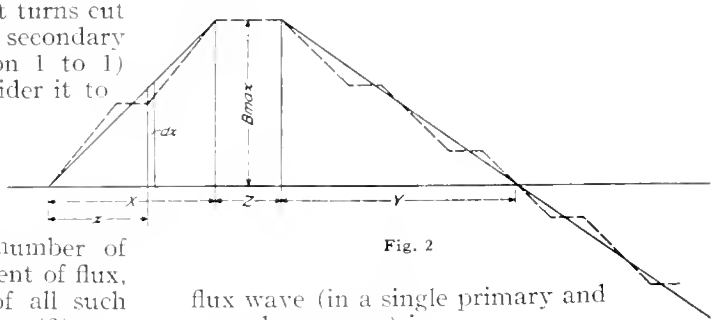


Fig. 2

flux wave (in a single primary and secondary group) is:

$$(\triangle_1+\triangle_2+\triangle_3)\,E_x =$$
$$\frac{2fn_G^2 I\overline{mlt}}{10^7 l}\left(\frac{X}{3}+\frac{Y}{3}+Z\right) \qquad (8)$$

The reactance e.m.f. for the entire transformer will be obtained by making this calculation for each flux wave and adding the results. Thus, if there are G groups of coils, all alike, so that $n_G = \frac{n}{G}$, where n is the total number of primary turns in the transformer, the total reactance e.m.f. will be:

$$E_x = \frac{2fn^2 I\overline{mlt}}{10^7 lG}\;\frac{X+Y+3Z}{3}$$
$$= \frac{6\frac{2}{3}fn^2 I\overline{mlt}(X+Y+3Z)}{10^8 lG} \qquad (9)$$

Greater accuracy in the calculation of reactance than that obtained with the above formula may be secured by making more detailed calculations, and this must be done for transformers of unsymmetrical design. For such transformers calculations for reactance are, however, subject to considerable error at the best.

Reactance in transformers has long been considered of importance as affecting regulation and parallel operation. For good regulation at low power-factors small reactance is desirable. For parallel operation, approximately equal percentages of both reactance and resistance drops are desirable. If, however, the percentages of total impedance are the same, considerable variations in percentages of reactance and resistance are permissible, the percentage reactance being greater in one, and the percentage resistance greater in the other. In this case, the currents in the two transformers will be out of phase with each other, but the out-of-phase components must be considerable before the resultant currents in the two transformers will be much increased thereby.

More recently, reactance in transformers has assumed importance in connection with the consideration of mechanical force due to magnetic leakage under conditions of short circuit. This phase of the question will be treated below under the topic of Mechanical Stresses.

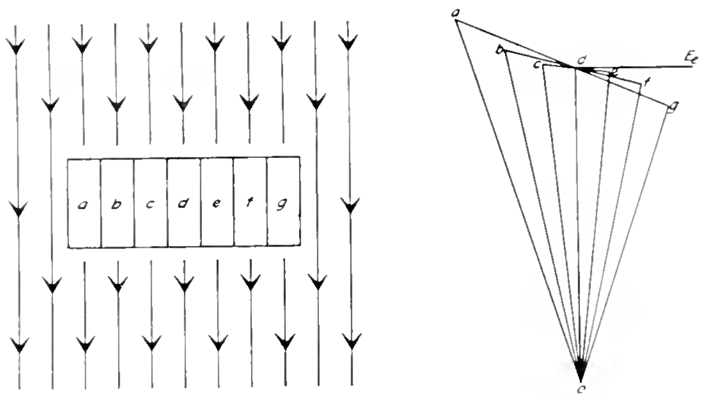


Fig. 3

Reactance in transformers is of great importance also as affecting the insulation strains resulting from high frequency oscillations and surges; but this constitutes a subject by itself and will not be discussed in this article.

Eddy Current Losses

A conductor in the path of an alternating magnetic field, such as the leakage field of a transformer, is intersected by portions of the flux passing through the conductor itself, which produce an e.m.f. only in that side of the conductor with which they link. This e.m.f. tapers from zero at one side of the conductor to a maximum value at the other side. It results in an extra current (not a part of the normal current of the transformer) which flows in the direction of the e.m.f. producing it, in that edge (or side) of the conductor where this e.m.f. is maximum, but which must find its return path in the other side of the conductor where this e.m.f. is smaller. These extra currents always exist in the individual conductors of a transformer, and extra currents which are of the same nature exist between parallel conductors which are insulated from each other between terminals, unless these conductors are so disposed, by crossing or otherwise, that they link the same amounts of flux.

The distribution of current within a single conductor which is assumed to be located within a leakage field of uniform density, is illustrated in Fig. 3. The conductor is divided up into elements *a*, *b*, *c*, *d*, *e*, *f*, *g*, the element *d* being at the neutral plane (in this case at the center of the conductor) where there is no extra current. In the vector diagram which represents the currents in the respective elementary conductors by the vectors *oa*, *ob*, *oc*, *od*, *oe*, *of*, and *og*, the vector *od*, which represents the current in the element *d*, represents the element of normal current in each of the other elementary conductors; but components of extra current are combined with these normal components in the other elements.

The e.m.f. which produces these extra currents results from the leakage flux, which is in phase with the normal current. This e.m.f. is therefore 90 degrees from the normal current, as represented by vector E_e. Remembering that the extra currents flowing in one direction on one side of the neutral element *d* find their return paths on the other side, it will be seen that those elementary circuits closest to the neutral element will have negligible reactance, while the circuits farther away will have greater and greater reactance, on account of the greater distance between going and returning elements. This results in a lagging of the extra current behind the e.m.f. which produces it, which becomes greater as we pass further from the neutral element. It will be seen, also, that the components of extra current in the various elementary circuits will be larger the farther they are from the neutral element, since the difference between the e.m.f.'s generated by the leakage flux in the going and return elements will be greater.

The resultant of all components of extra currents from one side of the conductor to the other is zero, so that the total resultant current in the conductor is the sum of the normal components.

In estimating the extra loss due to these extra or "eddy" currents in conductors, it should be considered that the components of extra current which are in phase with the normal current add to it at one side of the conductor and subtract from it at the other. Thus, if we have components of extra current in phase with the normal components in the outside elements of the conductor, equal to 10 per cent of the normal components, the current in the normal phase will be 90 per cent at one side of the conductor and 110 per cent at the other. The respective losses, proportional to the square of the currents, will be 81 per cent and 121 per cent, the sum being 202 per cent. With no extra current this would be 200 per cent, the excess loss being 2 per cent. This is just what we have with the 10 per cent component of extra current alone in the elements at the edges of the conductor. It is, of course, understood that the loss due to the other component of extra current, 90 degrees from the normal current, will not be affected by the normal current. This component would be in phase with the exciting current in the primary winding, but the loss would not be affected thereby for the same reason as that given above for the other component of extra current and the normal load current. We see, therefore, that the extra loss due to eddy current may be calculated from the extra current alone, and will not be affected by normal current in the same conductor.

Considering now a rectangular conductor in the uniform field shown in the figure, the e.m.f. producing extra current in any element is:

$$E_e = \frac{\sqrt{2}\pi f B x}{10^8} \text{ volts per inch length of conductor,} \qquad (10)$$

where x equals the distance of the element from the neutral plane at the center of the conductor in inches, and B the flux density in lines per square inch. If we neglect the reactance element of impedance in the eddy current circuit, we may also write:

$$E_e = \rho D \qquad (11)$$

where ρ is the specific resistance of copper (resistance per cubic inch) and D is the current density in amperes per square inch. The loss per cubic inch is:

$$\rho D^2 = \frac{E_e^2}{\rho} \qquad (12)$$

whence the watts per pound due to eddy currents is

$$w_e = 3.12\frac{E_e^2}{\rho} = \frac{6.24\pi^2 f^2 B^2 x^2}{10^{16}\rho} \qquad (13)$$

Integrating this rate of loss for the entire conductor, and dividing by the width of the conductor w, we find the average loss, which is:

$$w_e(ave) = \frac{2\ 6.24\pi^2 f^2 B^2}{10^{16}\rho w}\int_0^{\frac{w}{2}} x^2 dx$$

$$= \frac{5.2\ f^2 B^2 w^2}{10^{16}\rho} \text{ watts per pound.} \qquad (14)$$

At 25 degrees C. the value of ρ for copper is

$$\rho = 6.935 \times 10^{-7} \text{ ohms} \qquad (15)$$

Substituting this value, we have for the average loss due to eddy currents in a conductor located in a uniform field:

$$w_e\ (ave) = \frac{75\ f^2 B^2 w^2}{10^{11}} \qquad (16)$$

For a coil or group of coils located in a field which varies uniformly from zero flux density at one side to a maximum value of B at the other side, the density of this field for any particular conductor will be $\frac{B}{Y}y$, if we still consider the field uniform within each conductor; where Y is the width of the group of conductors, and y is the distance of the particular conductor from the side of the group where the flux density is zero. Substituting this value, integrating, and dividing by the width of the group, we find, for the average loss due to eddy currents in the whole group:

$$w_e\ (ave) = \frac{75\ f^2 B^2 w^2}{10^{11} Y^3}\int_0^{Y} y^2 dy = \frac{25\ f^2 B^2 w^2}{10^{11}} \qquad (17)$$

This result would be correct if the width of conductors was very small, but it may be considerably in error when applied to an actual transformer; first, because the reactance element of the impedance in the eddy current circuit may not be negligible; second, because the leakage field produced by the normal current is not uniform throughout the conductor, but increases from one side of it to the other, due to the magnetomotive force of its own current; and third, because we have applied the process of integration to a series of quantities which differ from each other by wide steps instead of by infinitesimal steps. However, the formula obtained will enable us to make rough calculations for loss due to eddy currents, and also shows upon what factors these losses depend. Thus, they vary with the square of the frequency; roughly, with the square of the maximum density of the magnetic leakage flux; and with the square of the width of the conductor in a direction at right angles to the field.

(To be Continued)

STORAGE BATTERIES IN MODERN ELECTRICAL ENGINEERING

Part II

By D. Basch

Switchboard Engineering Department, General Electric Company

The first of this paper was devoted exclusively to the lead battery. The opening paragraphs of the present installment deal with the principles, operation and advantages of the Edison nickel-iron battery. A section on charging sources discusses three common arrangements—d-c. bus, separate d-c. generator, and mercury arc rectifier. The next section, dealing with exciting current for the control circuits in power houses and substations is particularly interesting, and gives very lucid instructions as to figuring the size of battery required for a given number of switches, preferable charging source, figuring size of charging rheostat, connections, and the necessary auxiliaries. Next month's installment of Mr. Basch's paper will probably conclude the series, and will discuss batteries for small isolated plants, vehicle battery switchboards, public and private garage charging, ignition battery outfits, automatic cutouts, and boosters.—Editor.

EDISON BATTERIES

General

The Edison cell, like the lead cell, consists of positive and negative plates, electrolyte, and a container. The positive, or nickel, plate consists of several perforated and nickel-plated steel tubes, filled with alternate layers of nickel hydroxide and pure metallic nickel in very thin flakes. The negative, or iron, plate consists of a grid of cold rolled steel, nickel-plated, with pockets filled with powdered iron oxide. The jar, or container, is made of cold-rolled nickeled sheet steel, welded at the seams and with corrugated walls. A nickel-plated sheet steel cover is furnished, containing two bushings for the cell terminals, and one so-called gas separator, which also serves as an opening for filling the cell with electrolyte and for adding distilled water to take the place of that which evaporates during the charge. This cover is welded to the body of the container. (See Fig. 4.)

The electrolyte consists of a solution of potash in distilled water with a small admixture of lithia. The density of electrolyte does not change during charge or discharge, and consequently hydrometer readings are unnecessary.

Standard Types

There are two main standard types. One is being used extensively in electric vehicles of all descriptions; while the other is used more particularly for lighter work, such as ignition and small lighting outfits. The vehicle type cells are assembled in wooden trays or crates, several cells in one tray. (See Fig. 5.) Cells of the second type are generally assembled in a wood tray inside a steel box ready to bolt on a convenient place on the automobile. The electrical features of the two types of cell are identical, and the table below gives cell characteristics and ratings.

Operation and Maintenance

The rates given as normal in the table were determined by the manufacturers, to strike the best balance between the governing factors to suit the conditions of commercial practice. For the sake of convenience the table is based on constant charging current and seven hours is taken as the normal length of a charge, since output and efficiency were then judged to be in the best relation for average practice. However, especially where time for charging is limited, it is preferable to taper the rate; for instance, two hours at twice normal charging current, one and one-half hours at one and one-third normal, and one and one-half hours at two-thirds normal give five hours charge altogether; or charge at constant voltage with fixed resistance in

TABLE OF RATINGS OF EDISON STORAGE BATTERIES

Type of Cell	*A4	A6	A8	A10	A12	B2	B4	B6
Normal ampere-hour output	150	225	300	375	450	40	80	120
Aver. discharge voltage per cell	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Rate of charge ampere 7 hours	30	45	60	75	90	8	16	24
Normal rate discharge 5 hours	30	45	60	75	90	8	16	24
Normal watthour output	180	270	360	450	540	48	96	144
Maximum charge voltage	1.85	1.85	1.85	1.85	1.85	1.85	1.85	1.85
Minimum charge voltage	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5

* These type symbols are used by the manufacturers (The Edison Storage Battery Company) to distinguish their various cells.

series, so chosen that the average current during seven hours will be the normal rate.

The rates of charge and discharge are optional, but two points should be kept in mind. *First*, a very low charge rate, although improving slightly the current efficiency, will not completely reduce, i.e., charge, the iron element, resulting in very irregular discharge voltage. No permanent injury, however, will come from low-rate charging, and the discharge will usually recover normal characteristics when the cell is again worked regularly at normal rates. If not, then overcharging, i.e., a continued charge at normal rate and discharging to complete exhaustion, will re-establish normal conditions. It is recommended that the charging rate be not less than normal, except towards the end of a charge, when the rate may be cut down to one-third normal. *Second*, it should be kept in mind that, although excessive heating does no immediate harm to the battery, continuous working at high temperatures, as caused by excessive discharges, and more particularly by high-rate charges, will have an injurious effect, tending to shorten life of the battery.

The effect of sudden current rushes on cell voltage is a function of the internal resistance, which is on Edison batteries somewhat higher than on the corresponding lead batteries.

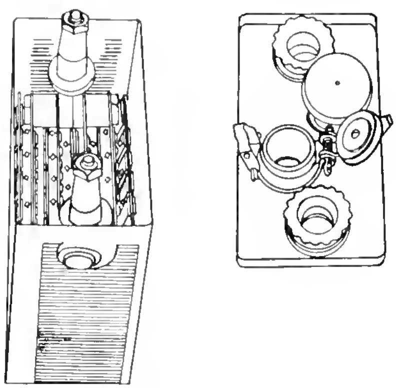


Fig. 4. Edison Cell

Edison batteries have not as high capacity when new as after some use. The improvement is caused by better conditions in the nickel electrode, brought about by regular charging and discharging. Overcharging (i.e., continued charging) expedites this improvement and is recommended by the manufacturers. Every cell is given three overcharge runs before leaving the factory, and this is always sufficient to bring the capacity up at least to the rating. The increase of capacity continues for twenty or more

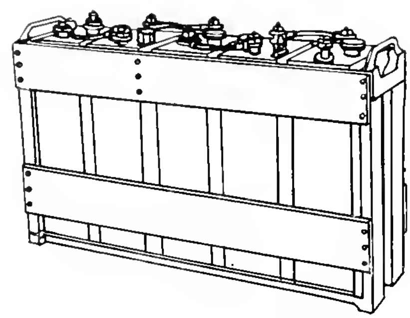


Fig. 5. Edison Vehicle Cells in Tray

runs (each consisting of a full charge and complete discharge).

In the operation of Edison batteries, two requirements are emphasized by the manufacturers—the necessity to keep the plates covered with solution, by adding pure water as needed, and to keep the steel containers dry and clean, external cleaning being recommended about once a month in ordinary service.

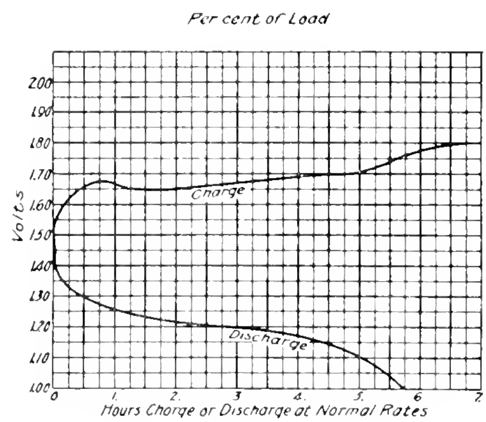


Fig. 6. Edison Cell. Normal Charge and Discharge Curves

Once in about 250 complete discharges it becomes necessary to renew the solution. Outside of the regular charge, which necessitates only the use of a voltmeter (gravity readings being of no effect as brought out before) no other manipulations are required. There being no sulphation in the action of an Edison cell due to the character of the solution, no overcharge is needed for the purpose of reduction. For the same reason an Edison cell may be left standing idle indefinitely without harmful results, and may be charged and overcharged indefinitely without injury.

Advantages of the Edison Battery

The general advantages of Edison batteries claimed by the manufacturers over the lead batteries are less weight; more compact and stronger construction of plates and container, easy operation and maintenance; and the various advantages due to lack of acid in the solution, such as the lack of sulphation and corrosion, the possibility of doing without lead burning and lead connections, etc. No acid fumes are given off although hydrogen is liberated by the Edison cells. Taking everything into consideration, the field of usefulness of the Edison cell is for the present in electric vehicles, and where weight, long life, mechanical strength and facility of operation are of greater importance than initial cost.

CHARGING SOURCES

Only direct current can be used to charge storage batteries. The necessary power may be taken from a direct current bus supplying regularly all kinds of other load, a separate direct current generator or a mercury arc rectifier.

Charging from a Direct Current Bus

The voltage of a direct current bus is sometimes equal to and sometimes higher than the normal battery voltage. When its voltage is equal to the normal battery voltage and cannot be raised for charging, it is necessary either to furnish a charging booster, i.e., a generator connected in series with the bus between bus and battery, so as to raise the available voltage while charging; or the battery must be charged in two parallel sections, with provision to connect the two sections in series again when discharging, and with a series resistance to take up the difference between the bus voltage and the voltage consumed by the battery when being charged. When the voltage of the bus is higher than the normal battery voltage, a variable rheostat must be furnished in series with the bus, between the bus and the battery, so as to regulate the voltage impressed on the battery.

Charging from a Direct Current Generator

A separate direct current generator used for charging a battery should be a shunt machine, so as to admit of varying the voltage between maximum and minimum charge limit when charging at normal rate. These limits are from 2.6 to 2.7 volts for the lead cell and 1.5 to 1.85 for the Edison cell. The voltage variation need not be restricted to manipulation of the generator field, if the speed of the generator can be regulated, either by adjusting the speed of the driving motor or by using pulleys of different speeds.

When the voltage variation possible with a charging generator is not sufficient for the total number of cells, the battery must be charged in two parallel sections with resistance between generator and battery, the same as with a direct current bus of voltage equal to normal battery voltage. In the case of a generator, however, the charging resistance (which always represents a loss of power) may be very much smaller than with a bus of equal voltage, as the voltage of a separate charging generator may be depressed for charging, while the bus voltage must be kept up to normal on account of other apparatus connected to it.

When the generator is compound wound, the series field should be cut out while charging. If this is impracticable, the battery must be charged in two parallel sections with series resistances. There are now on the market small capacity motor-generator sets at 125 volts, with very large

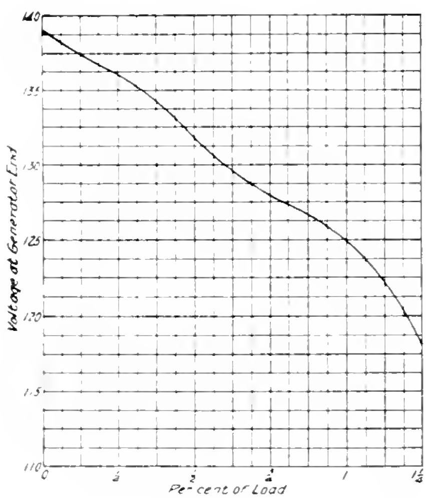


Fig. 7. Voltage Characteristic of Battery Charging Motor-Generator Set

voltage ranges (110–165 volts) for charging batteries, the motor end being either an induction motor or a direct current shunt motor, the generator being always shunt wound.

These sets are particularly well adapted for floating batteries, as they have a decided drooping voltage characteristic. (See curve Fig. 7.)

Charging from Mercury Arc Rectifier

The mercury arc rectifier presents a very cheap and economical means for charging batteries from secondary alternating current sources (100 or 200 volts) where the charging current does not exceed 50 amperes. Above 50 ampere charging current two or more rectifiers may be operated in parallel, but in general a motor-generator set will be found more suitable for such conditions. Rectifiers have very great voltage ranges, the 110-volt alternating current rectifier being able to furnish direct current voltage from 10 to 100 volts; and the 220-volt alternating current from 30 to 175 volts. They occupy small space and are free from moving parts.

The question has been raised as to whether or not the pulsating direct current obtained from the rectifier would have any effect on storage batteries different from that of the current obtained from a direct current dynamo. Laboratory tests and the results shown in practical operation have demonstrated that the results are the same in all respects for the two methods of charging. Especially in cases where the rectifier can be connected to an existing low voltage alternating current source, it is, commercially as well as from an engineering standpoint, preferable to any other kind of charging source for charging batteries, except in special cases, as brought out later on, under "Oil Switch Batteries."

OIL-SWITCH CIRCUIT-BREAKER BATTERIES

Motor and solenoid-operated oil-switches and circuit-breakers must have direct current for their control. When no other source of direct current is available in the station, a storage battery provides an unfailing, permanent supply.

How to Figure Size of Battery

The connections of these oil-switches and circuit-breakers are such that, ordinarily, in each control circuit only one or the other of two indicating lamps (140 volts, 8 c-p., showing whether the switch is closed or open) is loading the battery. Only when the main switch is being operated, i.e., either being closed or opened, an additional demand is made on the battery corresponding to the power necessary for this operation. This additional demand is very much greater than the permanent lamp load, but it is only momentary and disappears again as soon as the operation is completed. Just how great it may be it is impossible to state. While it is unusual to close or open manually more than two switch units at a time, a much greater number may be opened automatically as in the case of a heavy short-circuit or heavy lightning disturbance, when all the automatic switches connected to the section affected by the disturbances may open up at the same time. In general, the following assumption has been found a safe basis for the determination of the size of a battery for motor- or solenoid-operated switches and circuit-breakers.

Not more than two units—a unit contains all the elements required for the control of one circuit—will be closed at the same time; and not over one-half of the automatic units will open at the same time. When the number of automatic units is greater than twenty, only one-third of the total are assumed to open simultaneously. When different types of switches and circuit-breakers are installed in the same station, requiring varying amount of power for their operation, the above rule should be amended as follows: Not more than two units (choosing the ones requiring the greatest power) will be closed simultaneously. Of each class of units, not over one-half of the automatic ones will open at once. When the number of automatic units of any class exceeds twenty, only one-third of their total are assumed to open at once.

When totaling up the load, no consideration need be paid to the permanent lamp load on account of its comparatively small size. Due to the momentary nature of the main load, it is unnecessary to select batteries that will stand the calculated load in normal discharge. The voltage ranges, inside of which the solenoids and switch motors operate, are very large (70 to 140 volt for 125 volt apparatus), as under other circumstances they may be operated from exciter busses with automatic voltage regulators, which may increase or decrease the direct voltage within these limits. It has therefore been found satisfactory to use batteries of considerably smaller size than the total load, so long as the temporary and momentary current rushes do not bring the battery voltage below the safe working limit of the solenoids or switch motors. Careful tests have brought out the fact that suitably selected commercial lead batteries are able to furnish for one minute a current equal to twenty times the eight-hour discharge rate without dropping their voltage below 1.5 volts per cell. With a 60-cell battery corresponding to 125 volts normal, which is the standard for this class of work, the minimum discharge voltage will

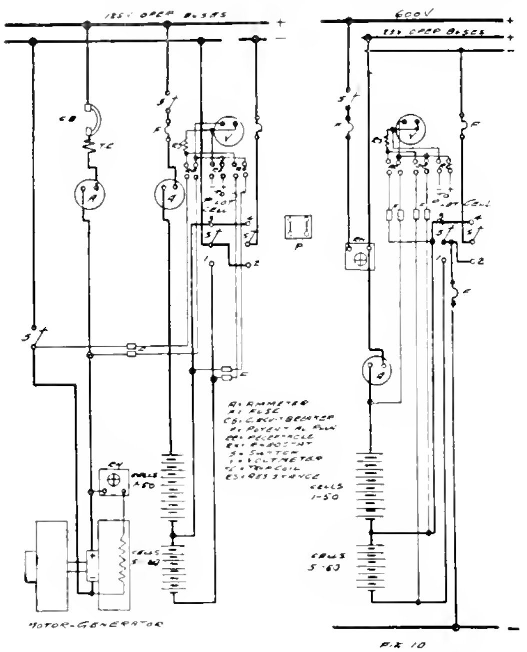


Fig. 8 Fig. 9

Fig. 8. Oil Switch Battery Floating on Motor-Generator
Normal: Close 1 and 2; start charge: Close 1 and 4; end charge: Close 3 and 4; motor-generator set alone: Close 2.
Fig. 9. Oil Switch Battery Floating on D-C. Bus

then be approximately 90 volts, which allows a large factor of safety.

When the operation of closing or opening the switch is complete, the battery voltage will go up again to normal, as the discharge is of too short a nature to exhaust the battery.

Connections

Switch control batteries are, where possible, connected to float on the charging source, so as to prevent a gradual discharge of the battery due to the permanent drain of the lamp load; otherwise it may happen that, especially just before the regular charge, the battery has been exhausted to such an extent that the sudden demand of switch operation will depress the voltage below the safe working limit of the solenoid of switch motor, thus jeopardizing the safety of the station.

The switching connections are shown in Fig. 8 for floating on a motor-generator set, and in Fig. 9 for floating on a direct current bus.

Operation from Direct Current Generator

When the charging generator is compound wound it is necessary to furnish reverse current protection for the generator to prevent the battery from discharging into the generator, if its voltage should drop below the battery voltage or when the motor side should open up accidentally or automatically. In such a case the battery would motor the generator with greatly weakened field, causing it to run away. This protection is obtained either by a "reverse current" or "underload" attachment to the circuit-breaker, the "reverse current" circuit-breaker opening up when the current in the generator circuit reverses, and the "underload" breaker when the current falls below a certain figure preparatory to changing its direction. The reverse current circuit-breaker is ordinarily preferable to the underload breaker, although slightly more expensive. Its operation is absolutely positive, whereas the underload breaker may open up at regular operation, if the normal load on the floating system is very small in comparison with the load which the generator has to supply during overcharge, and for which the breaker must be set. Shunt wound generators do not need any protection against reversal, as an occasional and temporary "motoring" of a shunt generator cannot produce any detrimental results beyond a drain from the battery, which is sure to be detected very soon. As the voltage of the motor power supply is generally fluctuating, causing in turn voltage fluctuations on the generator out of step with the battery voltage, it is generally recommended in the interest of steady service to omit reverse current or underload protection of any kind on shunt wound generators when floating.

Operation from Mercury Arc Rectifier

A mercury arc rectifier is not well adapted for use with switch control batteries, as it requires a normal load of about 25 per cent to keep the tube working. Frequently the normal lamp load is very much less than 25 per cent of the capacity of the rectifier required for charging and floating a switch control battery, even if the battery is floated at a lower voltage than the rectifier voltage, thus drawing a steady charging current from the rectifier, which would add to the load imposed by the indicating lamps.

Rectifiers that will stay in for loads lower than 25 per cent can be designed, but their cost is considerably greater than that of the standard type.

Operation from a Direct Current Bus

Direct current busses are used for charging sources especially in railway sub-stations, where 550 or 600 volts direct current is available. While solenoids are designed to operate with these voltages, the direct current supply in a railway sub-station with rotary converters cannot be considered as steady and permanent, not being in existence when the station is being started up from the alternating current end.

Charging Rheostat

The charging rheostat required with 550 and 600 volt direct current busses is a fixed resistance, and is placed on the floor behind the panels. While theoretically the charging resistance should be variable, to maintain constant charging current, the variations in charging current at 550 and 600 volts are negligible. At 250 volts bus voltage part of the resistance would have to be variable. The charging rheostat must contain sufficient resistance to ensure that the normal lamp load will cause a drop in the resistance sufficient to establish the proper floating voltage on the battery. It must be designed to impress on the battery 2.8 volts maximum per cell during overcharge. Its current-carrying capacity, while charging, should be equal to the charging current required for the battery *plus* the current representing the normal permanent load, and during normal operation equal to the current representing the normal permanent load.

The following example will explain the details brought out. A 60-cell battery, of 5 amperes normal charging current, is connected to a 600 volt bus. The normal lamp load is equal to 8 lamps = 2 amperes. In normal operation, i.e., when no overcharge is going on the resistance must be

$$\frac{600 \text{ volts} - 125 \text{ volts}}{2 \text{ amperes}} = \frac{475}{2} = 237 \text{ ohms}$$

with a current carrying capacity = 2 amperes. During the overcharge the current flowing through the resistance is 5 amperes (charging current) plus 2 amperes (normal lamp load) = 7 amperes total. The voltage then impressed on the battery must be 2.8 volts maximum per cell = $60 \times 2.8 = 168$ volts; and the resistance must be

$$\frac{600 - 168 \text{ ohms}}{7} = \frac{432}{7} = 62 \text{ ohms at 7 amperes.}$$

Part of the total resistance of 237 ohms must therefore be cut out during overcharge, preferably by means of a short-circuiting switch mounted on the rheostat box. Obviously it would be uneconomical to design all 237 ohms for 7 amperes, when 237 *minus* 62 (= 175) ohms will not be needed at a current exceeding 2 amperes. When at any future time subsequent to the first installation additional switch-units with indicating lamps are to be put in, the battery must be selected large enough to take care of the total final equipment.

With each new set of indicating lamps a new charging rheostat must be furnished in parallel with the original one. If for instance, in the case above, four more units are to be installed, a second rheostat should be supplied, parallel to the first one, as follows:

$$\text{For floating: } \frac{600 - 125}{1} = 475 \text{ ohms at 1 amp.}$$

$$\text{For charging: } \frac{600 - 168}{1} = 432 \text{ ohms at 1 amp.}$$

with a 100 ampere short-circuiting switch across 43 ohms.

Connections of Auxiliaries During Overcharge

As brought out before, floating batteries do not require regular charges but only occasional overcharges, unless the battery for any reason has been called on for a continuous discharge. During this overcharge the voltage would rise to a maximum of 2.8 volts per cell, equal to about 168 volts for 60 cells. The indicating lamps in the control circuit are mounted in openings in the switch board panel with little chance for ventilation, and should never receive too high a voltage to prevent burning out. Provision must therefore be made to limit the voltage on the lamps. For this purpose the battery is divided into two sections, the main body consisting of 50 cells and the second section of 10 cells.

As soon as the overcharge is started, the control circuits are thrown across the 50 main cells, with all 60 cells across the charging source. In this way the 10 end-cells will receive a heavier charging current than the 50 main cells, equal to the regular charging current *plus* current taken by the control circuits, and will be completely overcharged ahead of the main cells. On account of the relatively small number of end cells no pilot cell need be provided in the end section and voltmeter readings will be sufficient. As soon as the end section shows completion of overcharge, the end cells are cut out altogether and the main cells and control circuits are connected across the charging source, finishing up the overcharge of these 50 cells.

Another method sometimes asked for, for the purpose of limiting the voltage on the control circuit and lamps during overcharge, employs the so-called counter cells. Counter cells (or counter-electromotive-force cells) are merely unformed lead plates in an electrolyte of dilute sulphuric acid; they have no discharge capacity but set up an opposing e.m.f. of approximately 2½ volts per cell if normal current is passed through them, and 3 volts at 20 times normal current. In this case all 60 cells are connected floating across the charging source. The control circuits are connected ordinarily across the floating busses; but, while the overcharge is going on, they are disconnected from the busses by means of double-throw switches and thrown across the 60 cells with counter cells in this auxiliary circuit in opposition to the main battery, thus decreasing the battery voltage by the counter e.m.f. of the counter cells. With this arrangement the operation of the battery during overcharge would be simplified and all cells would be worked equally. It should, however, be noted that, aside from the increased cost and greater space required for the battery, the arrangement is inoperative, as the counter cells at heavy demand will depress the voltage for the auxiliaries below the safe working limit. A metallic resistance cannot be used either, as the drop of voltage across the resistance, while correct for the normal lamp load, would be too great when any solenoids or switch-motors are operated.

Frequently 53 cells are used instead of 60 cells, corresponding to 110 volts normal. With 53 cells the permissible drop of voltage, when the sudden demand during operation of a solenoid or switch-motor is thrown on, must of course be less than with 60 cells. The permissible maximum load with 53 cells should be figured as 18 times normal. In some instances a 53-cell battery will figure out cheaper than a 60-cell battery, especially when the load on the battery is considerably below the permissible maximum of the type of cell that must be used.

With a 53-cell battery the main body should contain 50 cells and the end section 3 cells.

Each battery equipment should contain a voltmeter with two scales—one to be the standard 150 volt scale and the other one for 3½ volts for the pilot cells. A separate resistance is furnished with the instrument to be used with the 150 volt range.

OPERATION OF SYNCHRONOUS MACHINES IN PARALLEL

Part III

By Lee Hagood

Lighting Engineering Department, General Electric Company

In Part I of Mr. Hagood's paper the general problem of parallel operation has been discussed. Particular reference is made to those systems having inductive loads, it being pointed out that the division of exciting, or wattless, current among the synchronous machines in parallel is entirely a matter of relative field excitation. Part II deals with the problem of power transmission in which it is shown that if synchronous machines are located at the distribution centers, they can be controlled by voltage regulators so as to automatically regulate the voltage and correct the power-factor. The present installment completes the paper, and covers chiefly a concrete example of a case where the voltages are controlled automatically only at the distribution centers.—Editor.

*Utica Gas and Electric Company

This company affords an example of a system operating under the condition of automatic voltage control by means of synchronous machines located at the principal centers of distribution. The unique feature of this voltage control is that the automatic voltage regulators are applied only to synchronous condensers.

Fig. 22 is a one-line diagram indicating the generators, synchronous condensers, length of the transmission lines, directions of flow of energy, approximate loads, etc., and in Fig. 23 the load curves are given for the different stations. Curve 1 represents the total kilowatts generated. The shape of this curve is characteristic of the load curves of the system, with the exception of the short period from 12:00 m. until 4:00 p.m., February 29th, this part of the curve being abnormal due to the fact that Trenton Falls was shut down to allow some repairs on the transmission lines. The usual condition is that it comes up around 7000 kw.

Errata, Part II (November Review) Fig. 8: Inscription should read "Vector Diagram Showing Effect of Wattless Current on Generator Voltage if a Given Amount of Energy is Delivered at Constant *Voltage*." Figs. 11 and 12, Inscription (in part) should read: "Two conditions of load are assumed, one at 0.60 p-f. and the other at 0.80 p-f., and the two corresponding curves of wattless *corrective* current are given. . . . ". Fig. 11, third line of data: "At 3000 kw., p-f. = 0.90 (Lag.)." Fig 12, third line of data: "At 3000 kw., p-f. = 1.00." Fig. 21, fourth line of data: "Angle between E_G and $E_R = \alpha$."

*The data in regard to this system is published through the courtesy of the Manager, Mr. A. T. Throop. It represents part of an investigation conducted by Mr. Throop and the writer to determine a method of operation by which the output of the system is attained economically with suitable voltage at the distribution centers.

immediately after the noon hour. There is a period of the year when the lighting load overlaps the day load, and then the total load curve differs in character from this one, but, otherwise than this, the summer and winter curves are very much the same. At the time this load curve was taken, the water supply was short at Dolgeville and at Little Falls. At the latter place it was not due to scarcity of water, but to some litigation which caused the forebay of station No. 2 to be temporarily closed. This is why so much steam power was used. It of the system, since care was observed that none of the synchronous machines had their fields weaker than was required for neutral excitation.

From Figs. 24 and 25 it is seen that the total wattless kv-a. runs around 8000 from 6:00 a.m. until the noon-hour, and from the noon-hour until 6:00 p.m. If all the synchronous generators were operated at such relative field excitations that the total kv-a. supplied by them were a minimum, each machine would operate at the resultant power-factor, which would be in the neighbor-

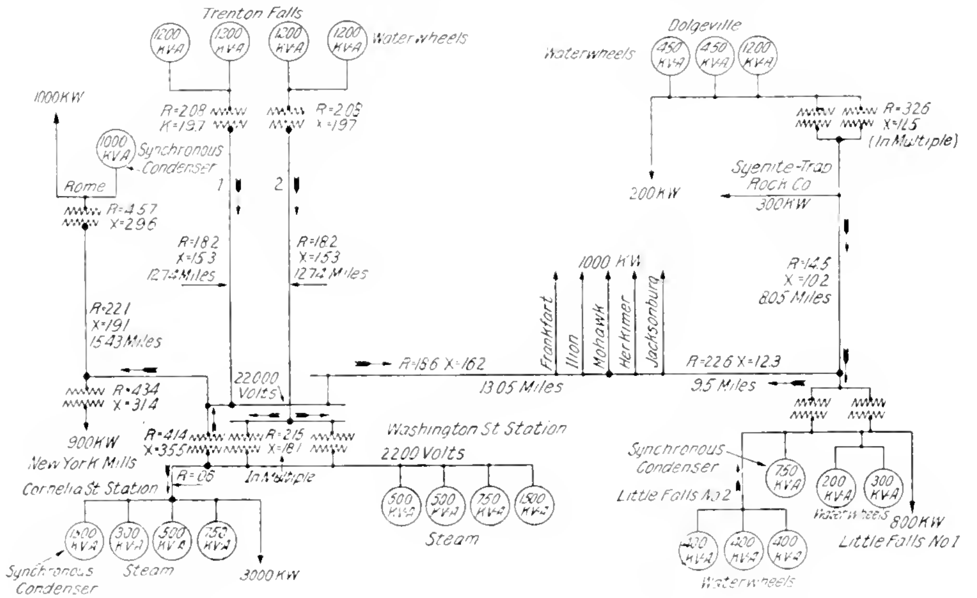


Fig. 22. One-line * Diagram Showing the Generators, Synchronous Condensers, Transmission Lines, etc., of the System of the Utica Gas & Electric Company

seems to occur usually that the water supply is plentiful at Trenton Falls and restricted at the other water power stations: hence it is desirable, in general, to always operate Trenton Falls at its full output.

In Fig. 24, curve 4 represents the total wattless kilovolt-amperes supplied to the system over different periods of the day. Curve 3 is the total kilowatts generated, and curve 2 the resultant power-factor of the system. Fig. 25 represents another set of similar curves for a different date. The total wattless kv-a. in both curves was obtained by summing up the wattless kv-a. supplied by each generator and synchronous condenser; this total necessarily equals the summation of the wattless kv-a. of all the individual induction motors, transformers, etc., hood of 0.65. It is assumed in this case that the synchronous condensers were not being operated. Now, if Trenton Falls delivered its full output of 4800 kw. at 0.65 power-factor, the transformers and generators involved would be carrying about 50 per cent overload, the voltage drop in transmission to Washington Street station would be about 28 per cent, and the losses in transmission would be excessive. The losses in transmission over the line and transformers would be about 10.5 per cent greater than would occur at unity power-factor, while those for the generators would be about 3 per cent greater. Thus in correcting the power-factor from 0.65 to 1.00, 13.5 per cent of the power delivered would be saved. If synchronous condensers were used located

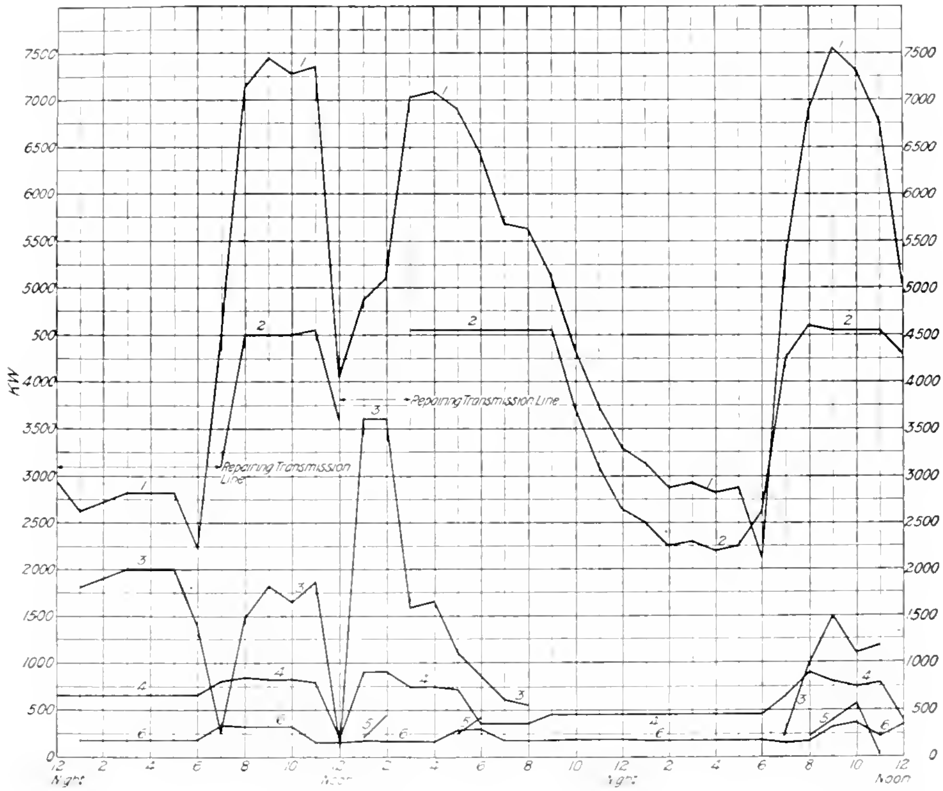
* At the time the tests were made transmission lines Nos. 1 and 2 were paralleled on the low tension side at Washington Street station; however, the present operation is to parallel them on the high tension side.

The values of the resistances and reactances given are the three-phase values. To obtain the resistances of a single conductor divide by 1.73.

in Washington Street station to accomplish this correction their inherent losses would be about 4 per cent; hence a net economy of 9.5 per cent or 460 kw., could be gained.

In operating the generators at 1200 kw. and around 1.00 power-factor, a busbar voltage of 2500 volts is readily obtainable, but with 1200 kw. and a power-factor around 0.70, the maximum voltage obtainable is about 2300 volts, though the exciter busbar is carried to its limit of 140 volts. Since the most favorable available taps in the transformers are 2200 to 22,000 volts at Trenton Falls and 22,000 to 2000 at Washington Street, we would expect only about 1800 volts (90 volts on the chart) at Cornelia Street station. Before the application of the synchronous condensers this extreme condition rarely obtained, because usually the generators at Washington Street station, Cornelia Street station, or elsewhere, were operated with heavy field excitation. However, times occurred when very bad voltage conditions existed at the Cornelia Street busses. Some of the worst cases are illustrated in Figs. 26, 27 and 28.

The data of Table I show three sets of readings taken in the Trenton Falls station. The set of readings on June 23rd shows the approximate conditions which existed after the installation of the 750 kv-a. synchronous condenser at Little Falls. The data given under June 26th show the same after the application of the three synchronous condensers, where no particular effort was made to correct the power-factor in the Trenton Falls line. On March 1st, however, we have a set of readings which shows the power-factor near unity in the transmission lines. This condition was accomplished by supply-



Feb. 29, 1912 Mar. 1, 1912

No. 1. Total kw. generated.
No. 2. Trenton Falls station.
No. 3. Washington St. station.
No. 4. Dolgeville station.
No. 5. Cornelia St. station.
No. 6. Little Falls station.

Fig. 23. These curves show the kilowatts generated at the various stations. They illustrate particularly the value of synchronous condensers for meeting any emergency condition: while the transmission line was down, not only did the synchronous condensers hold up the voltage, but they enabled the generators to deliver their maximum kilowatt output without danger from overloads due to the low power-factor. This was true especially for the steam units since the water supply was short at the water power stations.

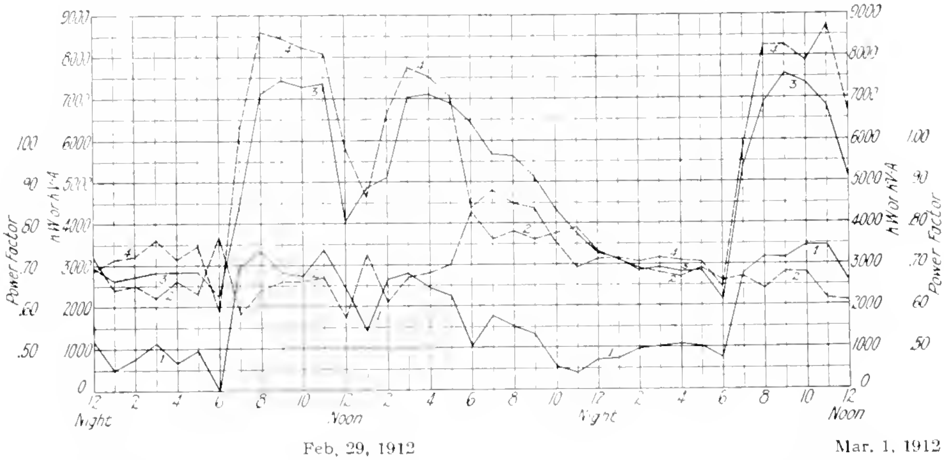


Fig. 24. Curve 4 shows total wattless kv-a. required at different periods of the day: Curve 1 is the amount automatically supplied by the synchronous condensers, while the remaining amount is furnished by the other synchronous machines, their fields being hand regulated

ing the necessary additional wattless corrective kv-a. by means of increased field excitation at Little Falls, Washington Street, and Cornelia Street.

Only the three synchronous condensers are available for automatic power-factor correction, and these can supply continuously a total of about 3250 kv-a. To bring the Trenton Falls line up around unity power-factor would involve additional to this about 4500 wattless corrective kv-a.

When the data published in this paper was obtained, the steam units in Cornelia Street station and some of the waterwheel units at Little Falls were operated as synchronous condensers, and the generators in Washington Street station were run partially loaded, but with full field excitation: in this manner, approximately 4500 wattless corrective kv-a. was supplied by hand regulation. At Cornelia Street station, the generators are belt connected and by slipping the belts these machines are operated conveniently as synchronous condensers; in so doing, about 1750 kv-a. was supplied at a loss of about 6 per cent of this kv-a. rating. At Little Falls Station No. 2, due to some *litigation, the fore-bay had been closed to the extent

*The litigation is now closed and the fore-bay has been opened, giving the full use of the available water power.

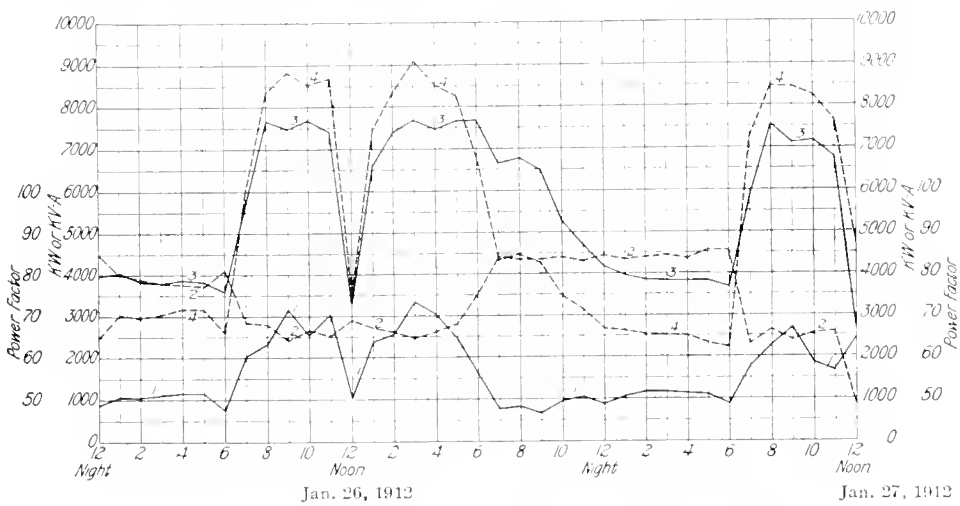


Fig. 25. These curves are similar to those in Fig. 24, but taken at another date. It is interesting to note that the character of the load conditions from day to day have such a close relation

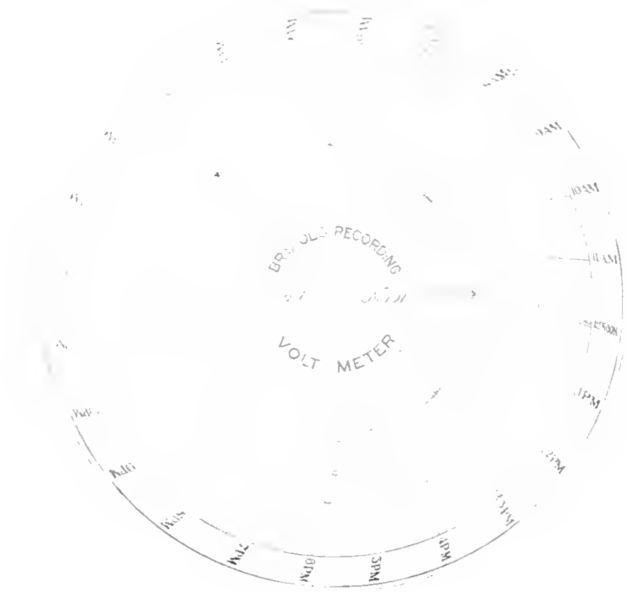


Fig. 26

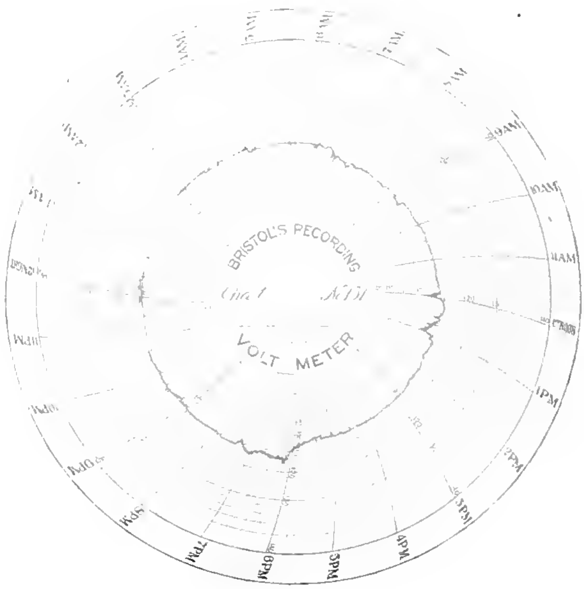


Fig. 27

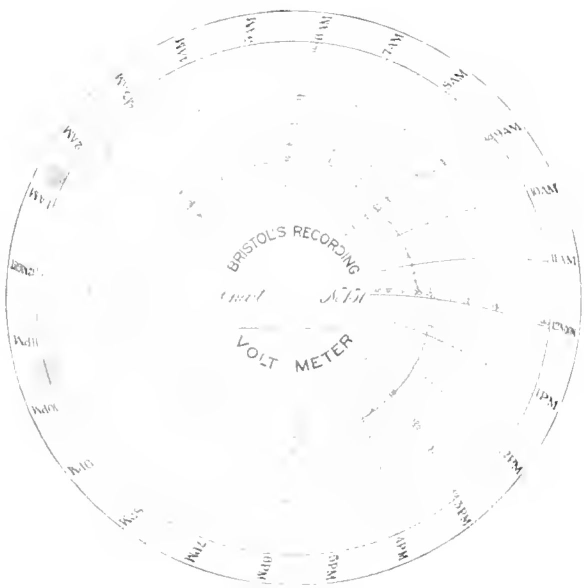


Fig. 28

Fig. 29

These voltage curves are from the 2200 volt busbars at Cornelia Street station. Figs. 26, 27 and 28 represent some of the voltage conditions which existed before the installation of the synchronous condenser, while Fig. 29 represents the character of the voltage regulation established by the application of a 1500 kv-a. synchronous condenser controlled by a voltage regulator that the maximum water flow was limited to about 350 h.p.; the economic operation of these units was found to be one unit run as a generator and the other two as synchronous condensers, delivering the rated kv-a.: these machines, as synchronous condensers, required in kilowatts about 8 per cent of their rating, or 32 kw., which enabled the generator to deliver about 100 kw. To operate these waterwheel units as synchronous condensers, it was first necessary to synchronize them by means of the power derived from the water flow, then to close the water gates, break the vacuum in the draft tubes, draw off the water, and allow the wheels to spin around in air, receiving electrical energy from the system. At Washington Street, a decided disadvantage accrues from running these units for power-factor correction, because the generators are not large enough to do so to any extent without operating the prime movers at light loads and hence inefficiently.

TABLE I

	June 23, 1911 (4:00 P.M.)	Jan. 26, 1912 (4:00 P.M.)	Mar. 1, 1912 (4:00 P.M.)
TRANSMISSION LINES			
Number 1			
Amperes	730	700	640
Kilowatts	2000	2250	2150
Power-factor	71	79	89
Volts	2300	2360	2200
Number 2			
Amperes	720	700	630
Kilowatts	2250	2400	2350
Power-factor	76	85	95
Volts	2300	2340	2260
Frequency	62	60	60.5
GENERATORS			
Number 1			
Amperes	360	345	315
Field amperes	92	96	79
Number 2			
Amperes	360	350	320
Field amperes	90	94	78
Number 3			
Amperes	360	340	320
Field amperes	90	92	83
Number 4			
Amperes	360	350	320
Field amperes	90	96	85
Exciter volts	138	133	115

To meet the requirements for wattless correcting kv-a. in a more efficient manner, and with less operating difficulties, a frequency changing set is being installed, which has its 60 cycle side designed for 2500 kw. at 0.70 p-f., and will be controlled by a voltage regulator. This set is therefore capable of supplying, or receiving, from the Utica system 2500 kw. at 0.70 p-f.; thus, at all times, the Utica system will derive the wattless corrective effect of not less than 2500 kv-a., and this will be under automatic control.

Figs. 30 and 31 illustrate the conditions in the Trenton Falls line, when care was observed to maintain a good power-factor. Fig. 32 is a similar set of curves for one of three tie-in lines extending from the Washington Street to the Cornelia Street station, while Fig. 37 shows the Rome transmission lines. Figs. 29 and 36 show the voltage curves at Cornelia Street and Rome stations, respectively. Figs. 33 and 34 show voltage curves at Little Falls station No. 1, and at Washington Street station.

Therefore, to accomplish voltage regulation at Cornelia Street station, Rome and Little Falls—the centers of distribution—and at the same time maintain a good power-factor on the Trenton Falls transmission line, most of the synchronous machines involved, except the synchronous condensers, were operated at full excitation so that together they carried a large part of the total wattless kv-a. The synchronous condensers were then enabled to carry automatically the fluctuations in the wattless kv-a., owing to the normal changes in load. The smallness in sizes of the synchronous condensers causes some difficulty in keeping them loaded within their limits; in fact, none of the synchronous condensers could inherently take care of the tendency of voltage variations at the point of its location, except the one at Rome. At Cornelia Street station the synchronous condenser must be assisted in its operation from time to time by juggling the field excitation of the other synchronous machines in the station, or those at Trenton Falls, or Washington Street station; and in a similar manner, the synchronous condenser at Little Falls must be assisted, either by changing the excitation of the machines near it, or those at Dolgeville. Whenever either the lower or upper limit of the voltage control of a synchronous condenser is reached, it is evidenced by a ragged spot on the voltage curve. On examination of the curves given, it will be seen that most of them show indications that the limits of the synchronous condensers have been reached. However, there is no reason why a finely adjusted regulator cannot effect a curve on a voltage chart

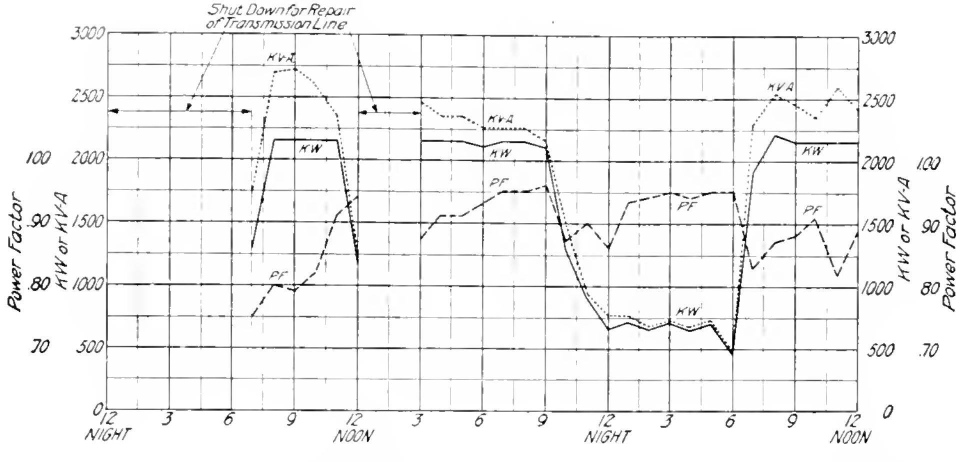


Fig. 30. *These curves represent the kw., the kv-a., and power-factor of the power generated for transmission line No. 1. The data is plotted from readings on station instruments at Trenton Falls

which is practically a straight line, provided the synchronous condenser is of suitable size.

The character of the load on the Utica system is such as to tend to promote bad voltage conditions, since it consists of various kinds of fluctuating loads, one of the large

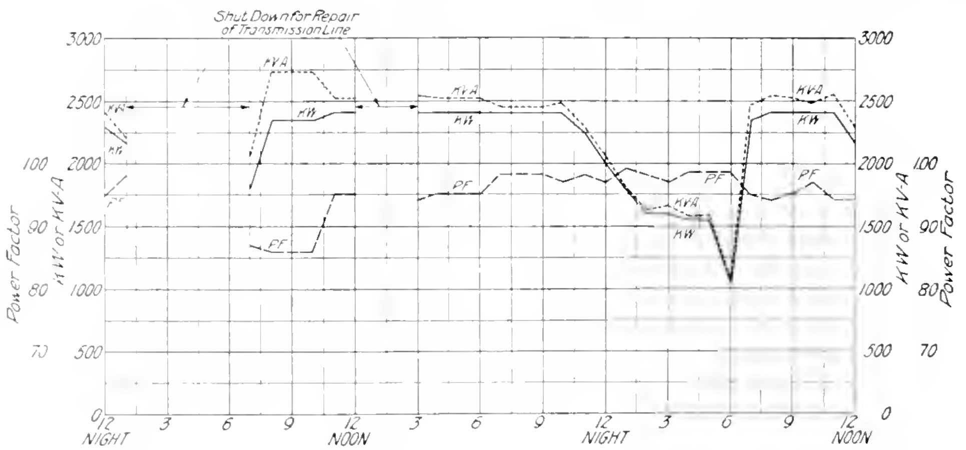


Fig. 31. These curves are similar to those in Fig. 30, except for transmission line No. 2

customers being a stone quarry and another a welding plant. Fig. 35 illustrates the character of the load produced by a welding plant.

An advantage that a synchronous condenser possesses, which is not usually appreciated, is that it tends to flatten out any unbalancing due to the load, producing balanced current conditions in the main circuits. Figs. 38 and 39 represent a synchronous condenser carrying considerable unbalanced current owing to the correcting of an unbalanced load.

It was stated in Part II that if the voltage at a distribution center were held at a given value by means of a synchronous condenser, with an automatic voltage regulator and the voltage at the generating station were lowered until the same value were reached,

*On February 29th, it will be noted that the power-factor takes an upward rise at about 9 a.m. This is due to the bringing on of excitation on the generators in Washington Street station and at Little Falls.

not only would the power-factor in the transmission line remain constant, but the voltage in the generating station would be regulated, thus avoiding the use of a voltage taken on the Cornelia Street station, and Fig. 41 a voltage curve taken on the Trenton Falls station. In the latter station the voltage had been adjusted so as to equal that at the

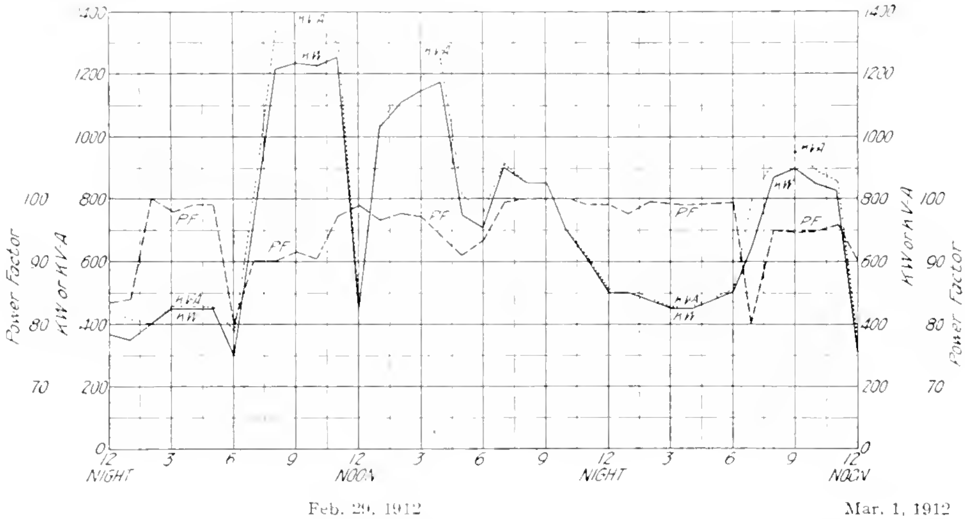


Fig. 32. One of three tie-in lines between Washington and Cornelia Streets, to illustrate the value of power-factor correction. The resultant power-factor of the load is from 0.65 to 0.70 p-f. during the day period

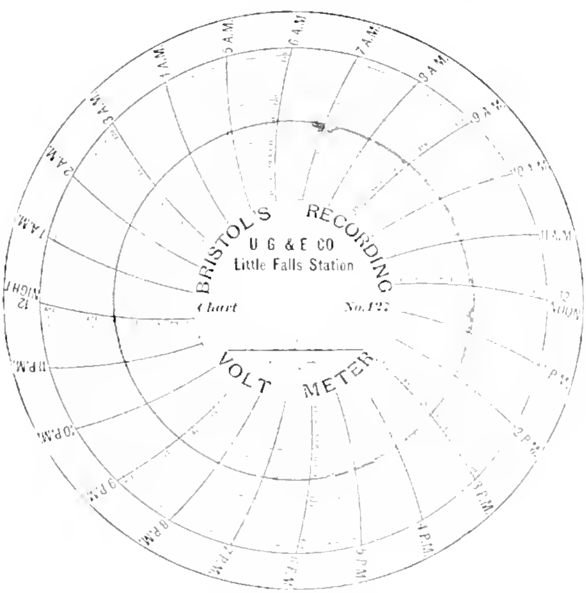


Fig. 33. Voltage chart from the 2200 volt busbars at Little Falls station No. 2. The ragged points in the curve are due to the load conditions being such as to carry the synchronous condenser beyond its range of voltage control

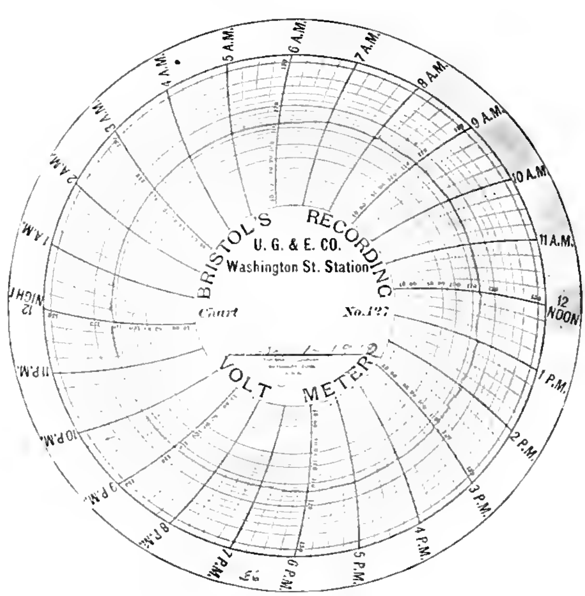


Fig. 34. Voltage chart from Washington Street station, the voltage regulation being effected by the synchronous condenser at Cornelia Street station

regulator at that point. Some station data was given in Fig. 18 to show that a constant power-factor could be maintained in this manner. This data was taken in the Rome station. Fig. 40 shows a voltage curve Cornelia Street station. It will be seen that both voltages remained practically constant through the twenty-four hours. The field excitation in Trenton Falls was adjusted only slightly at about 3:15 p.m. This was done

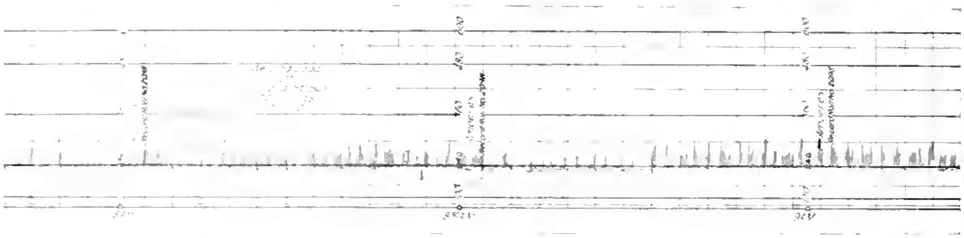


Fig. 35. This illustrates the variable character of a welding load. The power-factor varies around 0.60. This chart was taken from a feeder in Cornelia Street station

so as to bring the synchronous condenser at Cornelia Street station within its limits; otherwise than this, the field excitation in Trenton Falls was not changed.

Fig. 36 shows the comparative character of the voltage regulation before and after the installation at Rome of the 1000 kv-a. synchronous condenser, controlled by an

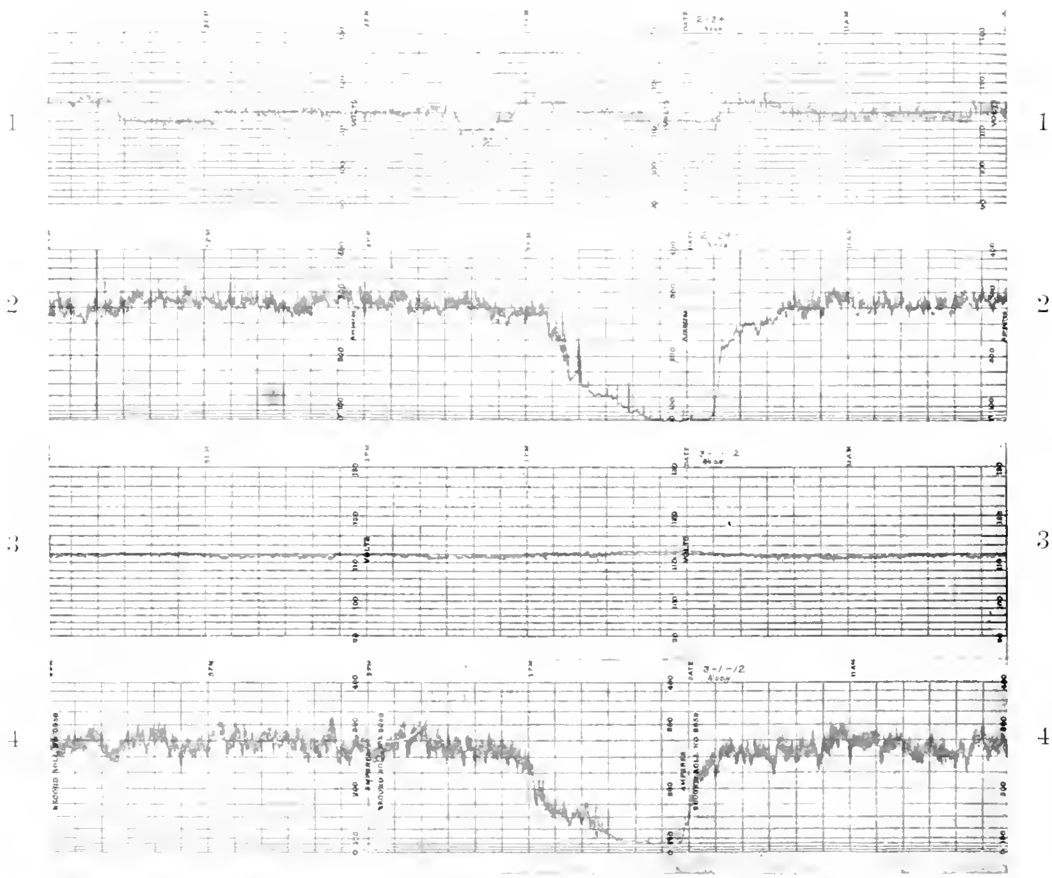


Fig. 36. The effect of automatic power-factor correction is illustrated by the above voltage curves taken at Rome. Curve No. 1 shows the voltage when controlled by a feeder regulator, but operated beyond its limit, and curve No. 2 the corresponding currents. Curve No. 3 shows the voltage regulation accomplished by a 1000 kv-a. synchronous condenser with a voltage regulator. Curve No. 4 shows the corresponding currents. Though the currents in curves 2 and 4 are approximately the same, the energy delivered in the former case was during the day around 600 and 700 kw., while with the corrected power-factor in curves 3 and 4, the energy delivered was around 1000 kw. It is interesting to note that the power-factor remains around 1.00 from no-load to full load. This was shown in Fig. 18

automatic voltage regulator. This machine is of suitable capacity to meet inherently any normal tendency towards voltage variation, provided the load does not exceed about 900 kw.

At the time curves 1 and 2 were taken, viz., on February 24, 1911, only about 700 kw. could be satisfactorily delivered to Rome on account of the excessive voltage drop, though 10 per cent was boosted by taps on the transformers and 10 per cent by the feeder regulator. The extreme range of voltage variation at this point was around 30 per cent. As will be seen by reference to curve 1 in Fig. 36, the voltage regulation was entirely unsatisfactory. This curve is typical of that obtained in this station under normal conditions. If the feeder regulator had not been operated beyond its limit, however, it could have effected a suitable voltage regulation. When curves 3 and 4 were taken, viz., March 1, 1912, the load at Rome was 1000 kw., which, as will be seen, is a considerable increase over that of the previous year. It is interesting to note that the current curves 2 and 4 are practically of the same magnitude, though 43 per cent additional power was delivered in the latter case.

TABLE II

	With Syn. Con.	Without Syn Con.
Busbar volts	* 111	* 98
Transmission line amperes	* 270	* 340
Transmission line power-factor	* 0.97	0.71
Transmission line kilowatts (indicating instrument)	*1020	* 820
Load amperes	370	* 340
Load power-factor	0.72	0.71
Synchronous condenser amperes	* 260	* 0

* Taken on station meters and instruments.

In Fig. 37, the actual kv-a. demand on the station is given in the dotted curve, No. 1. This is the kv-a. which would exist in the transformers and line if there were no synchronous condenser. When the data were taken, the synchronous condenser was operated just through the day, and during the night a feeder regulator was put in operation. The load, at the present writing, is around 1300 kw. During the periods of heavy loads, the feeder regulator is used non-automatically to boost the voltage so as not to overload the synchronous condenser. As stated before, without this assistance, the synchronous condenser is overloaded when approximately 900 kw. is exceeded.

The transformer bank in the station is rated 1500 kv-a. With the present equipment, the station is enabled to carry a continuous load of approximately 1400 kw. an increase due to the application of a synchronous condenser of about 100 per cent.

Not only did this synchronous condenser improve the voltage conditions at Rome, but great assistance was felt at the New York Mills and at Cornelia Street station. Though a feeder regulator is installed at the New York Mills, it is useless during the operation of the synchronous condenser at Rome.

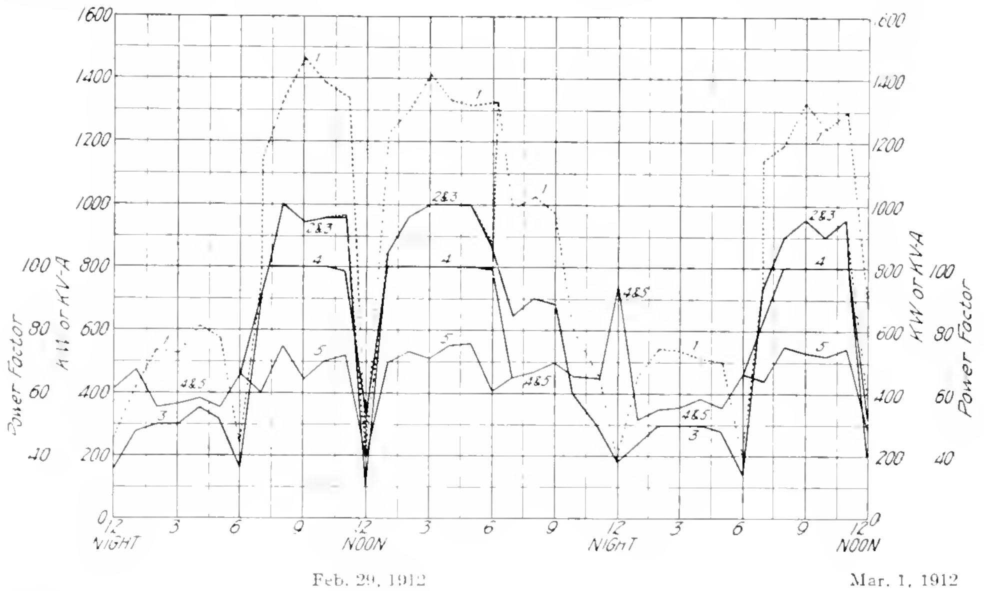
Table 2 is a set of readings which illustrates the effect of the synchronous condenser. The data marked "With Syn. Con." represent a normal condition of operation, and those marked "Without Syn. Con." were obtained to afford a comparison. To obtain the latter, the plunger on the alternating current coil of the voltage regulator was pushed to a position where the synchronous condenser operated neutrally. The cutting out of the effect of a synchronous condenser can be done instantaneously in this manner. The experiment was made a number of times to check up the accuracy of the readings and all the data taken was consistently the same. It is interesting to note that when the busbar volts dropped 12 per cent the actual load carried dropped 20 per cent; the load having fallen from 1020 kw. to 820 kw. On releasing the plunger, the kilowatts came up immediately to approximately their former value. This experiment illustrates very forcibly the importance of maintaining normal voltage for a load of induction motors.

It is usually appreciated that a lighting load will fall off in proportion to the square of the voltage. However, it is not generally appreciated that the same thing occurs with an induction motor load. With a heating and lighting load, the power consumed varies directly with the square of the voltage. With an induction motor load, practically the same thing occurs, since the speed of an induction motor changes approximately with the square of the voltage. This will make the power consumed vary substantially in this proportion, since the resisting torque is usually fairly constant. On decreased speed, the power-factor of induction motors tends to rise by a small amount. We do not get a rise in power-factor in the above case, because the loads on the motors had become reduced.

GENERAL DISCUSSION

Suitability of Synchronous Condensers

The question of the advisability of applying synchronous condensers to a system will depend entirely upon local conditions. However, it may be said in general that there are few cases where low power-factor exists that synchronous condensers cannot be economically applied. In cases where the steam stations are auxiliary to water power stations, and located near the distribution centers, such as is the case with the Utica Gas & Electric Company, the generators can be used for power-factor correction. Though this is advisable in general there are a number of reasons why synchronous condensers should be used in addition. Among these reasons are the following:



No. 1. Kv-a. demand caused by the loads low p-f.
No. 2. Kv-a. demand on the transformers and transmission line when synchronous condenser is operated.
No. 3. Kw. delivered to busbars.
No. 4. Power-factor of transformers and transmission line.
No. 5. Resultant p-f. of the load carried by busbars.

Fig. 37. Load curves of Rome station to illustrate the effect of a 1000 kv-a. 2200 volt synchronous condenser controlled by a voltage regulator. The synchronous condenser is only operated from 6 a.m. until 6 p.m.

First: Suppose the transmission lines go down, or difficulty is experienced due to low water; the steam generating units are thereupon called upon to do duty up to their limits; the boilers must be forced, etc.; and every additional kilowatt that can be put on the busbars is invaluable. If synchronous condensers of proper capacity are available their power-factor correction will, under such conditions, render valuable service in holding the voltage up and in enabling the prime movers to give maximum output without exposing their generators to any danger due to overload on low power-factor.

Second: Synchronous condensers are always valuable adjuncts to steam units, since they will take the swings in wattless kv-a., and allow the generators to run without voltage regulators. They possess also the property of absorbing the unbalanced load conditions, relieving the generators and transformers of this unsatisfactory duty.

Third: Synchronous condensers are independent of prime movers. In many cases generators may be operated to great advantage, say at 70 per cent power-factor, where 70 per cent of the kv-a. rating is supplied as corrective wattless kv-a. and 70 per cent as kilowatts. However, in running prime movers at 70 per cent full load, or below, their efficiency must be taken into consideration. This becomes of great importance on light loads, for the per cent losses at light loads may be considerably in excess of the benefits derived by the power-factor correction, as compared with using synchronous condensers whose maximum losses are only 4 per cent of their kv-a. rating.

Fourth: Synchronous condensers are especially designed for their purpose. They have a high armature reaction, small air gap, and are run at high speed. Due to these features of design they can be built remarkable cheap, and for their kv-a. output they occupy but a small amount of space as compared with alternators.

Fifth: Finally, synchronous condensers can always be located at the distribution centers, accomplishing the ideal condition of having the kilowatts delivered actually equal to the kv-a. demanded by the load. The magnitude of this benefit is appreciated in cases where the invested capital for a system up to the points of distribution, is from $75 to $150 per kv-a. Not only are the economies in kv-a. and losses accomplished, but a voltage regulation can be established at these points which will render satisfactory service for lighting, although from the same busbars, welding loads, stone crushers, or what not, may be supplied.

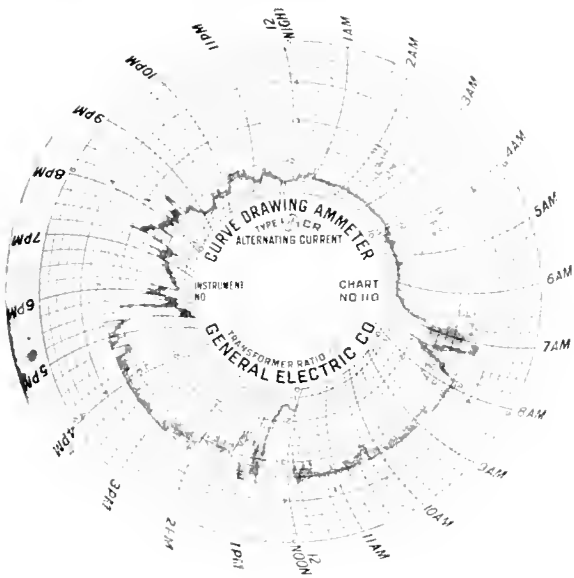


Fig. 38

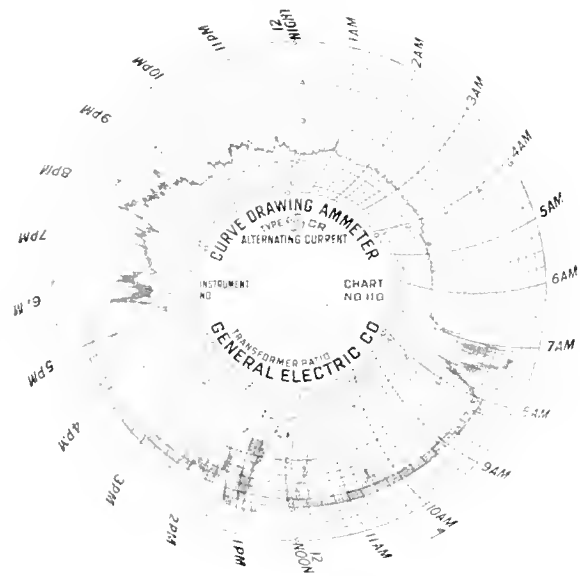


Fig. 39

These curves illustrate the ability of a synchronous condenser to compensate for unbalanced load conditions. Simultaneous charts were taken of the voltage on the different phases which showed balanced voltages. In effecting this compensation it is necessary for the synchronous condenser to carry the unbalanced current. This data was taken from the 1500 kv-a. two-phase synchronous condenser in the Cornelia St. station

What is said above in regard to synchronous condensers would apply to synchronous motors carrying loads, provided when automatically controlled the conditions were not such as to involve their operating under load on weak fields which would endanger their falling out of step. In Part II it was demonstrated that the safe condition of operation would be where a low voltage drop was maintained in the feeder or transmission line supplying the power. The most favorable condition for power-factor correction is where the motor supplies 70 per cent of its full load rating as wattless corrective kv-a. and 70 per cent as power. The generator side of a frequency changer set can also supply 70 per cent of its full load rating as wattless corrective kv-a. and 70 per cent as power, and yet does not possess any limitation in regard to operating on weak fields. In general, the correcting of power-factor with either a synchronous motor, or generator on a frequency changer, delivering power, is better than using a synchronous condenser; however the application of these two type of machines is somewhat restricted, hence there is a broad field for the use of synchronous condensers.

Method of Calculation

An approximate method has been deduced in Part II for determining the relations which exist in transmission lines and the wattless corrective kv-a. required for a given operating condition when the voltage differences between generating and receiving stations are maintained constant by means of automatic voltage regulators on synchronous machines. The cases considered were short lines where the charging current could be neglected. If the charging current must be taken into consideration, the value of I_w in the formula

$$V = I_e R + I_w X$$

should be obtained as follows:

$$(14) \qquad I_w = I'_w - \frac{I_c}{2}$$

substituting this value, we get:

$$(15) \qquad V = I_e R + \left(I'_w - \frac{I_c}{2}\right) X$$

V is the voltage difference between a generating and receiving station: if the difference is a voltage drop, V must be taken as positive and if the difference is a rise, V must be taken as negative. X and R represent the three-phase resistances and reactances between the points under consideration; I_e is the energy component of the current supplied the load; I'_w is the wattless component of the transmission line current at the receiving end; and I_c is the amount of wattless current required to charge the transmission line.

This formula is based on the assumption that the voltage drop, due to the charging current, is equal to $\frac{I_c}{2} X$, and that we can drop a very small quantity which should appear in the equation, namely $E_g\,(1-\cos\alpha)$, where E_g is the generating voltage and α is the phase relation between generating and receiving voltage. The exciting currents required by the transformers in the transmission line have been neglected, since this simplifies the problem and does not affect the accuracy of the results below the precision of the requirements.

Equipotential at the Generating Stations and the Distribution Centers

It has been demonstrated that if the voltage drop is maintained at zero value, not only does the power-factor remain constant, but the generators operate with a good voltage regulation without voltage regulators. The case cited was when the charging current for the transmission line was small and the actual power-factor at the receiving end was constant. If the charging current must be considered and the voltages are equal at the receiving and generating stations, the equivalent power-factor of the line is constant since

$$\frac{I_e}{I_w} = \frac{X}{R}$$

The power-factor at the receiving end is dependent upon the relation between I'_w and I_e and therefore cannot be exactly constant; but in most cases met in practice the power-factor at the receiving end will be practically constant, except at very light loads.

This method of operation offers a great

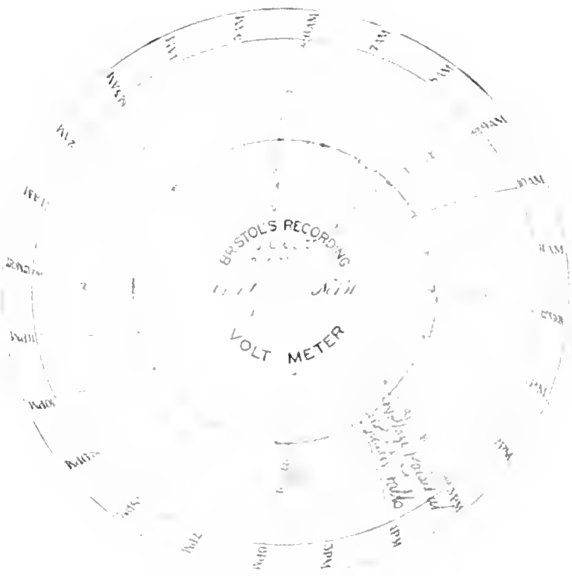


Fig. 40. Voltage Chart from the Cornelia Street Station Busbars

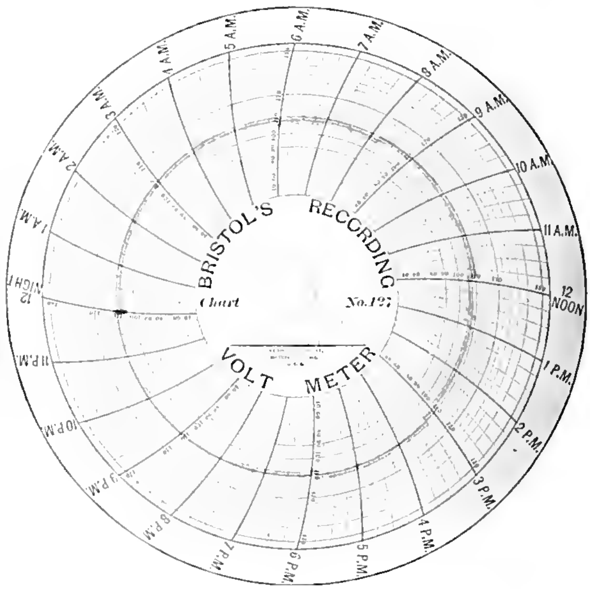


Fig. 41. Voltage Chart from the Trenton Falls Busbars

These curves illustrate that if the voltage is controlled by means of a synchronous machine with a voltage regulator at a distribution center, and if the voltage at the generating station is brought to the same value, then the generating voltage will maintain practically constant without further changes in their field. The ragged effect of the curve taken at Cornelia Street station is due to the synchronous condenser being operated outside of its limit. These two charts were taken on the same day many advantages: for example, the main generating units can be operated with individual exciters, and transformers can be used without taps. By using individual exciters for each generator, rather than using a common exciter bus in each station, we reduce the probability of interrupted service. It would be a great convenience in operation to have equipotential at the generating stations and distribution centers, since the transformer voltages for a system could be standardized and the troublesome problem of arranging for suitable taps avoided. Furthermore, the power delivered at all times is at practical minimum kv-a., and at practically minimum losses. Operating the generators at minimum kv-a. offers considerable opportunity to use the prime movers always at an efficient point on their load curves.

Voltage Regulation

Too much emphasis cannot be attached to the importance of good voltage regulation, for good voltage regulation contributes more to satisfied customers than can any other one possible condition.

Customers using lighting loads are more sensitive in the matter of poor voltage regulation than those using power. However, in the latter case it is also very important to both the seller of power and the consumer that the voltage be furnished at its proper value.

Since the power consumed by any load must necessarily fall off substantially as the square of the voltage, it is of serious importance to the central station to maintain the voltage as high as is consistent with good operation.

The following tabulation shows the effect of reduced voltage on induction motors for values of 10, 20 and 30 per cent below normal:

Maximum H.P. output:
- 90 per cent voltage—19 per cent lower
- 80 per cent voltage—36 per cent lower
- 70 per cent voltage—51 per cent lower

Approximate full load efficiency
- 90 per cent voltage—1 per cent lower
- 80 per cent voltage—3 per cent lower
- 70 per cent voltage—5 to 10 per cent lower

Approximate full load power-factor
- 90 per cent voltage—2 per cent higher
- 80 per cent voltage—3 per cent higher
- 70 per cent voltage—4 per cent higher

Approximate full load heating
- 90 per cent voltage—15 per cent higher
- 80 per cent voltage—40 per cent higher
- 70 per cent voltage—75 to 200 per cent higher

Starting torque and starting current for squirrel cage motors:

Starting torque
- 90 per cent voltage—19 per cent lower
- 80 per cent voltage—36 per cent lower
- 70 per cent voltage—51 per cent lower

Starting current
- 90 per cent voltage—10 per cent lower
- 80 per cent voltage—20 per cent lower
- 70 per cent voltage—30 per cent lower

In regard to operating induction motors at voltages higher than normal, this would be done at the sacrifice of making the power-factor slightly worse. However, there would be a gain in efficiency, in torque and output. In most cases, however, 10 per cent above normal voltage represents the average upper limit for satisfactory conditions. The exact limit, of course, would depend upon matters of design. In general, however, induction motors are designed with the maximum flux density occurring just above the normal operating condition.

In regard to lighting loads, the importance of voltage regulation is usually appreciated by everyone and it is frequently specified in contracts that the voltage variation will not exceed 2 or 3 per cent. The reason of this is evident when we consider the incandescent lamp itself. A change in voltage not only causes a change in candle-power, efficiency, life, power consumed, etc., but the physiological effect of flicker, color of light, etc., is most objectionable to the customers. The magnitude of this effect will be appreciated when it is remembered that a 2 per cent change in voltage causes a variation of approximately 8 per cent in candle-power.

From what has been said above, it may be seen that the question of voltage regulation at distribution points is of the utmost importance.

CONCLUSIONS

By controlling automatically the field excitation of synchronous machines in parallel to accomplish power-factor and voltage control, the following may be obtained, viz.:

First. Kilovolt-Amperes Supplied can be Approximately Equal to the Kilowatts Required

As seen from the case of the Utica Company, power-factor correction enables a system carrying an inductive load to increase its load without adding to its equipment of generators, transmission lines and transformers. Furthermore, not only can a large reduction in I^2R losses be obtained, but the prime movers are enabled to operate on efficient points on their load curves, without danger of overloading the generators on low power-factor.

Second. Excellent Voltage Regulation

A voltage regulation may be obtained at the end of a transmission or feeder line of about 2 per cent on each phase, independent of the variable character of the loads and their power-factors, and whether or not they are balanced or unbalanced on the phases. For example, a synchronous condenser makes possible the supplying of a lighting load and welding machine loads, rolling mill, stone quarries, etc., from the same busbars.

Distribution of power at proper voltage should appeal to central station men, when it is appreciated that, in general, the power consumed by a customer varies with the square of the voltage. It will be remembered that when the voltage at Rome was dropped 12 per cent, instead of the customers consuming 1020 kw., they consumed only 820 kw., making a net loss in the sale of power of 200 kw.

Third. The Use of Large Reactances for Current Limiting Purposes

It was shown in Part II that considerable reactance is a very favorable condition in circuits transmitting power, when the voltage is regulated by means of synchronous machines with automatic voltage regulators located near the loads. Since this is the case, no objection can be raised to the use of large inherent reactances in generators and transformers, or the application of external reactances. The destructive effect of short circuit currents of large magnitude is well known. It is very important, therefore, where a large amount of power is generated to have all the circuits, particularly near the generators, contain enough reactance to limit the current to values below where any damage can be caused. In confining short circuit currents to reasonable limits, the cost of oil switches will become greatly reduced; in fact, it will be possible, in many cases, to eliminate the use of automatic oil switches, except in the feeder circuits, or where selective action is required.

Fourth. Flexibility in Design of Transformers, Induction Generators and Induction Motors

Since power-factor correction can be so cheaply applied, the demands of customers will become less exacting in regard to guarantees of power-factor for induction motors and induction generators and of the per cent magnetizing current for transformers. This will allow designing engineers more freedom in design.

Fifth. Increased Output of Transmission Lines

In designing a transmission line, the voltage regulation is usually the limiting feature, rather than the losses, and this increases greatly in importance, as the length of line increases. The latter comes about due to the fact that on no-load, or very light load, the voltage at the receiving end will be greater than at the generating end on account of the negative exciting current, while, as soon as the load comes on, we might find a very large drop in voltage.

Sixth. The General Use of 60 Cycles, Instead of 25 Cycles

Since 60 cycle generators, transformers and transmission lines have inherently more reactance than 25 cycle, 60 cycle is therefore preferable. Heretofore, on account of the serious reactive drop, 25 cycles has always been advocated for long transmission lines. There are reasons otherwise why 25 cycles has been a favored frequency. Among them, questions in design of induction motors, synchronous converters, etc. As a matter of fact not only can generators, induction motors, transformers, synchronous converters, etc., be designed satisfactorily for 60 cycles, but in general, they are cheaper. If the question therefore of voltage regulation is correctly solved, it goes without saying that 60 cycles should be the favored frequency for all purposes.

Seventh. Finally, Equipotential Can be Established at the Generating Stations and the Distribution Centers

From no-load to full load on a system, the voltage of the generating stations and that of the distribution points may be maintained at the same values. This is the case where the voltage is held up at the distribution points by means of automatic power-factor correction, so that the voltage drop is zero and the power-factor in the transmission lines and generators will remain substantially constant from no-load to full load. Since the generating stations will not require voltage regulators, each main generator can have its individual exciter; furthermore the troublesome question of taps on the main transformers Is avoided, since the voltage is practically the same in all the transmission lines.

FURTHER INVESTIGATION INTO NATURE OF CORONA AND DIELECTRIC STRENGTH OF AIR

By F. W. Peek, Jr.

For several years Mr. Peek has been conducting an exhaustive study into the nature of corona by the aid of a short high voltage line, and his articles on this and allied subjects are among the most valuable which appear in the Review, since the subject is of the highest economic importance. The present paper, which may after all be regarded as one of the series, divides itself into four sections. The first part shows how corona values, calculated from the laws and formulæ already established by the author, check with values as actually noted on working lines by other investigators. The second section touches on the practical importance of recent experiments with the stroboscope, and the discovery of the difference between the corona on the positive and negative halves of the a-c. wave. The third deals with visual corona, and gives a theory explaining the apparent greater dielectric strength of air around small conductors than around large. The concluding section has something to say on the future. What is going to be the effect of corona on future transmission developments? How can we raise the critical voltage?—Editor.

The corona characteristics of transmission lines can be accurately predetermined from laws of corona already published.* Corona phenomena have been still further investigated with a view to a better understanding of the nature and properties of the loss, and the behavior of air above the elastic limit. While this latter investigation is rather more of a theoretical nature than the former investigation, many points have been observed which have an apparent future practical application. In this paper a few of the interesting and peculiar phenomena will be described generally without speculation as to their cause. It may first be of interest, however, to compare losses measured on practical transmission lines, in different localities, with the losses calculated from the corona formulae.

Agreement of Calculated Losses and Measured Losses on Commercial Transmission Lines

It is generally difficult to make an exact comparison as in most cases where losses have been measured on practical lines all of the necessary data has not been recorded, such as temperature along line, barometric pressure, voltage rise at end of line, etc.

The several examples given are ones in which it has been possible to obtain sufficient data to make comparison. In Fig. 1 the drawn curve is calculated from the formulae for the temperature, barometric conditions, etc., under which measurements were made. The crosses represent measured values. This agreement between measured and calculated losses is very interesting, as it is for a long three-phase line at very high altitude. In Fig. 2 are similar comparisons on a single-phase line at different frequencies. These measurements were made before corona was a factor in practical transmission. An exact agreement could not be expected, as the wave shape was not known and was probably not a true sine wave. Another rather interesting comparison is made in a recent publication describing the system of the Au Sable Electric Co.‡ The line is 125 miles long and of No. 0 copper cable. With 140 kv. at the generating end, the voltage at the far end is 165 kv. Thus the loss per mile is greater at the far end than at the generating end.

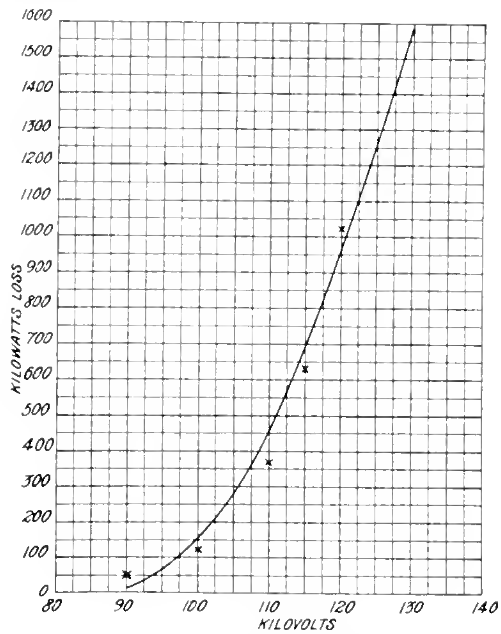


Fig. 1. Comparison of Calculated and Measured Losses

The x are measured values. The drawn curve is calculated from corona formula (6). Diameter of wire 0.375 in. (No. 0 cable.) Spacing 124 in. Three-phase. Line length 63.5 miles. Barometer 23.8 in. Temperature 51 deg. Fahr. The tests for corona loss were carried out on Shoshone-Leadville transmission line by Mr. G. Faccioli. Test made on operating line three-phase and at high altitude. The check is interesting because of the number of variables taken into account.

The average calculated loss per mile is 15 kv. The article states that the actual average loss by preliminary rough measurements was 15 to 20 kw. per mile. The above examples

* A.I.E.E. Proceedings, July, 1911, G.E. Review, Oct., 1911.
† A.I.E.E., July, 1911, Law of Corona, I; June, 1912, Law of Corona, II.

are given to illustrate how well the formulae may be applied in the predetermination of the corona losses of commercial transmission lines.

The corona formulæ from which calculations were made are given here for convenience.

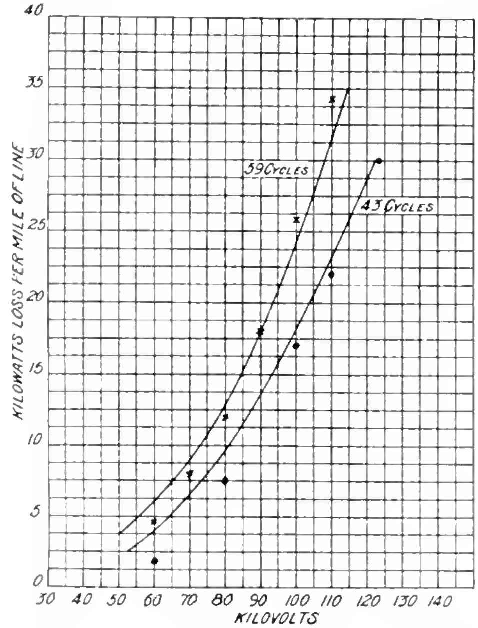


Fig. 2. Comparison of Calculated and Measured Losses

The x and • are measured values. The drawn curve is calculated from corona formula (6). Diam. of wire 0.064 in. Spacing 48 in. Single-phase. Tests made on short line for Stanley G-I Electric Company by Mr. A. B. Hendricks, 1903-1904. This shows check at two frequencies.

Corona Formulae †

(3) Disruptive critical volts (parallel wire)

$$e_0 = 21.1\ m_0\ \delta\ r\ \log_\epsilon s/r$$

effective kilovolts to neutral.

(5) Visual critical volts and gradient (parallel wires).

$$e_v = 21.1\ m_v\ \delta\ r \left(1 + \frac{0.301}{\sqrt{\delta r}}\right) \log_\epsilon s/r$$

effective kilovolts to neutral

(6) Power loss (fair weather)

$$p = \frac{344}{\delta} f \sqrt{r\ s}\ (e - e_0)^2\ 10^{-5}$$

Kilowatt per kilometer single conductor.

(7) Storm power loss. Power loss during storms is higher and can generally be found with fair approximation by assuming $e_0 = 0.80$ of fair weather e_0. *It generally works out practically that the e_0 voltage is the highest that should be used on transmission lines.*

The above voltages are to neutral. To find voltage between lines multiply by 1.73 for three-phase, and by 2 for single-phase.

Notation

$\delta = \frac{3.926\ b}{273 + t}$

b = barometric pressure in cm.

t = temperature in degrees cent.

f = frequency—cycles per second.

m_0 = irregularity factor.
 = 1 for polished wires.
 = 0.98 − 0.93 for roughened or weathered wire
 = 0.87 − 0.83 for cables

m_v = 0.72 for local corona all along conductor; 0.82 for decided corona all along con. } Seven strand cable.

m_v = 1 to 0.93 for wires.

r = radius of wire in cm.

s = spacing in cm.

Difference in Corona at the Positive and the Negative Halves of the A-C. Wave

Coming now to some of the very recent investigations the stroboscopic study of a-c. corona will first be described. When a-c. voltage is applied between two parallel wires separated by a distance greater than thirty times their radius, and the voltage is gradually increased, the first evidence of stress is corona, or glow, at or near the conductor

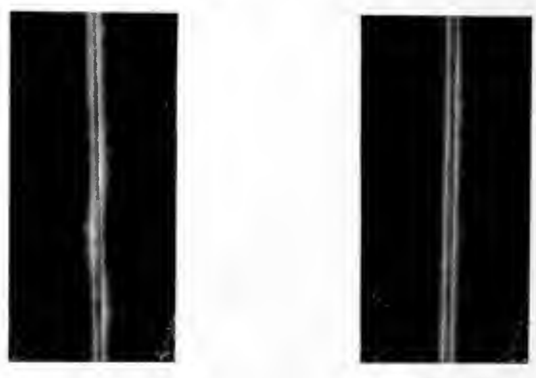


Fig. 3. Corona on Polished Parallel Wires without Stroboscope

surface. If the wires are polished at the start, the glow is quite even, as shown in Fig. 3. After operating a short time reddish beads or tufts form along the wire, while

† N.E.L.A., June, 1912.

* The stroboscope consists of a disk revolving on the shaft of a small synchronous motor. In front of the revolving disk is a stationary disk which may be rotated relatively to the motor field. The stationary disk contains a peep hole, while the revolving disk contains half as many equally spaced slits as the motor has poles. The conductors are observed through the peep hole and the revolving disk. By changing the position of the stationary disk corona at any part of the wave may be seen.

at the surface of the wire there is a bluish white glow. If the conductors are examined through the stroboscope * so that one wire is always seen when at the positive half of the wave and the other when at the negative half of the wave, it is noticed that the reddish beads or tufts are formed when the conductor is negative and the smooth bluish white glow when the conductor is positive. This is illustrated in Fig. 4. If the originally polished wire is examined after the tufts form it will be found that at the spots where the tufts appear it is still highly polished, while in between the polished spots it is oxidized. Sometimes the negative corona takes the form of a helix after voltage has been applied to the conductor for a short time. This is illustrated in Fig. 5.

It was observed that when voltage was applied between two needle points, and very gradually increased, a condition could be obtained such that corona apparently extended all the way between the points without spark-over. The explanation that offered itself was that the corona does not really bridge the two needles, but that the, say, positive corona extends past the center point, and as each needle is alternately positive the two positive coronas overlap on the eye and appear to bridge across (see Fig. 6). This really lead to the stroboscopic investigation, which confirmed the above assumption.

Fig. 5. Copper Wire

Polished at start. Note negative corona apparently following spiral "grain" of wire. Diam. 0.26 cm. Spacing 120 cm. Volts 200,000.

The positive and negative coronas from points are shown in Fig. 7. To the eye the negative appears as a reddish point, or tuft, while the positive appears as a fine bluish white spray extending well past the center line. The positive discharge from a point always reminds one of steam under pressure issuing from a nozzle.

It appears that positive and negative

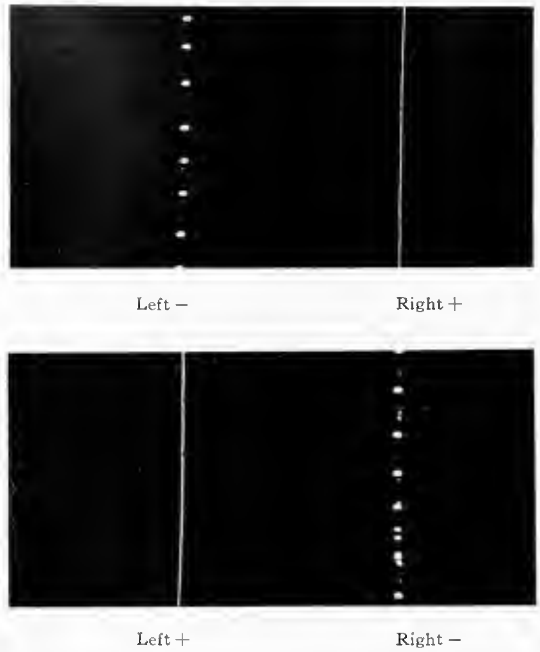


Fig. 4. Corona on Parallel Wires

Iron—first polished and then run at 120,000 volts for two hours to develop "spots." Diam. 0.168 cm. Spacing 12.7 cm. Photographs taken through stroboscope at 80,000 volts.

coronas start at different voltages, and that therefore near the critical voltage there is an excess of one or the other, as for instance, positive. If the fan-like brushes which are often seen discharging from high voltage apparatus, such as insulators, bushings, etc., are closely examined, it will be seen that near the base there is a reddish point, while the fan streamers have a bluish color. The point and the streamers do not occur simultaneously but alternately: the red point is negative and the fan positive.

Spark Over and Corona

It was stated above that corona is the first evidence of stress, or that the elastic limit has been exceeded, when two parallel wires are spaced greater than about thirty times their radius. If under this condition and after corona has formed the voltage is sufficiently increased, spark-over will occur. At very small spacings the first evidence of over stress is spark-over, and corona cannot form.

The reason for this can be shown mathematically. It is simply stated here as a very interesting fact. The experimental curve is shown in Fig. 8. For the small spacings below the triangular point of intersection of the curves corona can never form.

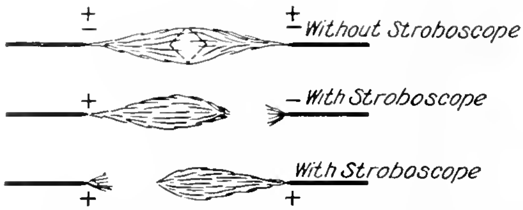


Fig. 6. Diagrammatic Representation of Corona Flow from Positive to Negative Wires, and Vice Versa

Visual Corona and Why Air is Apparently of Greater Strength Around Small Conductors than Large Ones

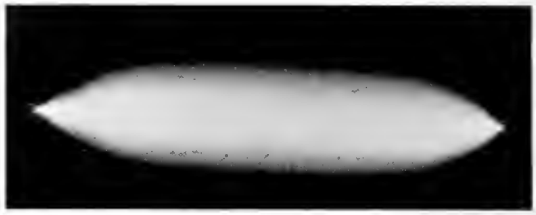
Perhaps of most theoretical and practical importance is the work under this heading and we will give a brief description of this work. Visual corona appears always first at the surface of a wire, as the unit stress or unit rupturing force is greatest there. This is because the unit stress is greater the greater the flux density. As can readily be seen in Fig. 9, the density is greatest at the surface. It is convenient to express this stress in terms of the gradient or kilovolts per centimeter (measured radially) which is proportional to the density. Thus the gradient in kilovolts per centimeter at rupture is a measure of the dielectric strength of air, in the same way that kilograms per square centimeter at rupture is a measure of the mechanical strength of, say, a copper wire. For parallel wires the gradient at the surface, and hence where the stress is greatest and the elastic limit is first exceeded, is:

$$\frac{de}{dx}=g=\frac{e}{r \log_\epsilon s/r}$$

That is, if the voltage between the surface of the conductors and a point in space at infinitesimal distance dx cm. away is de, then the gradient in the limit at the surface is

$$\frac{de}{dx}=g=\text{kilovolts per centimeter}=\frac{e}{r \log_\epsilon s/r}$$

If e is e_v, the observed voltage to neutral at which visual corona starts, g is a measure of the stress at breakdown, which we will call g_v. It would naturally be expected that g_v would be constant for all conductors, or in other words, air would break down under the same constant unit stress independent of the size of the conductor; just, for instance, as different sized rods of the same material would be expected to break down at the same unit stress of kilograms per square centimeter. It has long been known, however, that air is *apparently* stronger at the surface of small conductors than large ones. (The *apparent* strength curve is given in Fig. 10.)



1. Without Stroboscope 72,000 volts

Left − Right +
2. With Stroboscope 72,000 volts

Left + Right −
3. Same as 2; Stroboscope rotated 180 deg.

Left + Right −
4. Same as 3; voltage increased to 84,000

Fig. 7. Corona Between Copper Needle Points, Using a 20.5 Cm. Gap

Of course, this does not mean that the voltage required to start corona is greater for small wires than for large ones (it is lower for the small conductors at a given spacing), but that the term g_v, or unit stress in the expression,

$$e_v = g_v \, r \log_\varepsilon s/r$$

is greater for air around small conductors than large ones.

This *apparent* greater strength of air around small conductors was long attributed to a film of condensed air at the conductor surface and hence having a greater relative effect for the small conductors. We have given another reason for this which still later experiments at low air densities seem to confirm.

During our first investigations we found that the relation between the *apparent* strength of air and radius of conductor could be expressed by the simple formula

$$g_v = g_0 \left(1 + \frac{0.301}{\sqrt{r}} \right)$$

where g_0 is constant and is about 30 kv. per cm. This means that the stress at the conductor surface at break down is not the same for all diameters, as already stated, but always constant at a distance $0.301\sqrt{r}$ centimeters from the surface; or

$$g = \frac{e_v}{(r + 0.301\sqrt{r}) \log_\epsilon s/r} = 30.$$

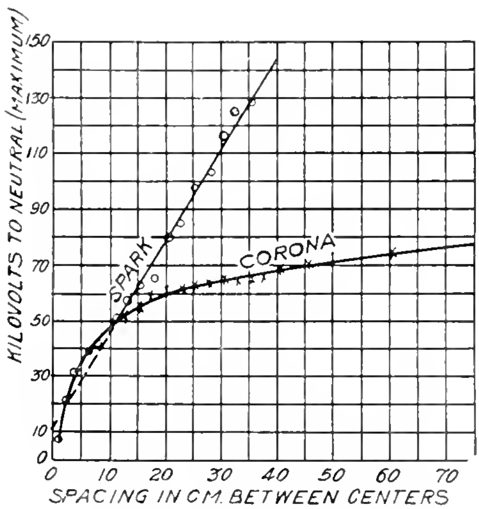


Fig. 8. Spark and Visual Corona Voltage for Parallel Wires

Test No. 160. Size No. 2. Diam. 0.654 cm. Polished copper. Corrected to 25 deg. Cent. and 76 cm. barometer.

This is shown in Fig. 11. The explanation seems to be this: Air has a constant strength g_0 for a given density, but a finite amount of energy is necessary to cause rupture or start corona.* Hence the stress at the conductor surface must exceed the elastic limit g_0, or be increased to g_v in order to supply the necessary rupturing energy between the conductor surface and finite radial distance

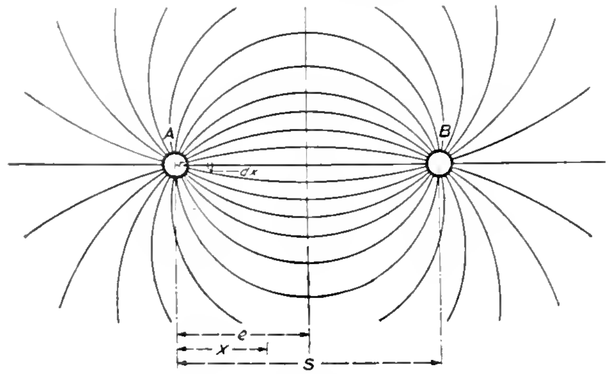


Fig. 9

Fig. 9. Visual Critical Voltage Gradient—Two Parallel Wires

in space away ($0.301\sqrt{r}$ cm.) where the stress is g_0 and break down occurs. This also lends itself nicely to the electron theory.

For instance, speaking somewhat loosely, suppose corona is caused by free ions which are moved from the conductor surface and accelerated by the dielectric field; these soon collide forming other free ions, which in turn are accelerated, forming more free ions by collision. The number of ions per unit volume thus is progressively increased; until finally at $0.301\sqrt{r}$ cm. from the conductor surface, where the number of ions per unit volume becomes sufficiently great, corona appears. $0.301\sqrt{r}$ centimeters is much greater than the mean free path of the ion, so there must be a number of collisions in this distance. It is interesting to speculate upon what would happen if the conductors were placed closer together than the necessary energy storage or accelerating distance $0.301\sqrt{r}$ cm. This has been investigated, but is not yet in form for publication.

Thus far the discussion has been limited to air at a constant density, or, in other words constant pressure and temperature. The above energy explanation can be still further checked now by considering air at different densities.

The value of g_0 given, 30 kv. per cm., is for air density at sea level (25 deg. C., 76 cm.

* This rupturing energy must not be confused with the corona loss. It is the energy to start breakdown so that loss can occur.

barometer). This has been taken as the standard, or for the density factor $\delta=1$. Air at other densities, due to change in temperature and barometric pressure, is expressed as a factor of this. The relative

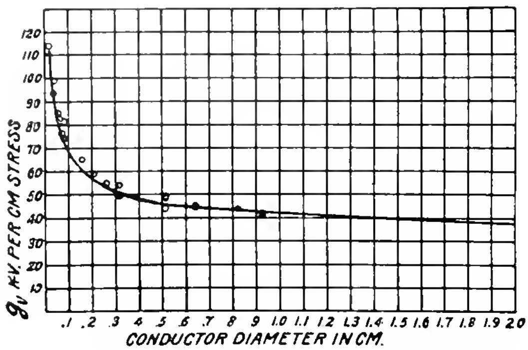


Fig. 10. Visual Critical Voltage Gradient, Two Parallel Wires

density for any pressure or temperature is

$$\delta=\frac{3.92\ b}{273+t}$$

For instance, if the temperature is kept at 25 deg. C. and the pressure is reduced to 38 cm.

$$\delta=\frac{3.92\times 38}{273+25}=0.50.$$

or ½ atmosphere. As the air density, or δ, is decreased the air is less able to resist the electric stress. Theoretically the strength of air should decrease directly with δ, or

$$g_0=30\ \delta.$$

g_v, however, the *apparent* strength of air, if the energy theory is true, can not decrease directly with δ because the energy storage distance or the acceleration distance must also change with δ; thus the energy storage distance should be $0.301\sqrt{r}\ \phi\ (\delta)$, or the complete expression should take the form

$$g_v=g_0\delta\left(1+\frac{0.301}{\phi\ (\delta)\sqrt{r}}\right)$$

We have found experimentally that

$$\text{energy storage distance}=0.301\ \frac{\sqrt{r}}{\sqrt{\delta}}\text{cm.};$$

that is $g_v=30\ \delta\left(1+\frac{0.301}{\sqrt{\delta\ r}}\right)$.

How well the theory is checked from this standpoint is shown in Fig. 12 over a range of 1 to 1/50 of an atmosphere. ($r=0.254$ *cm.*) We have found that the effect is the same whether δ is varied by change of temperature or change of pressure. The law for the visual critical corona voltage may now be written:

$$e_v=g_v\ r\ \log_\epsilon\ s/r=30\ \delta\left(1+\frac{0.301}{\sqrt{\delta\ r}}\right)r\ \log_\epsilon s/r$$

where e_v is volts to neutral. It may be of interest to note that with a pair of smooth wires, of a known diameter, high voltages may be accurately measured anywhere by noting the spacing at which corona starts, the temperature and barometric pressure, and substituting in the above formulae.

The Corona Limit of High Voltage Transmission

The question is often asked, what is the limiting distance imposed on high voltage transmission by the corona limit of voltage? In the first place it does not seem at present, except in very rare instances, that corona will be the limiting feature at all. The limiting feature will, in all probability, be an economic one: the energy concentrated naturally at any given point will be exceeded by the demand in the surrounding country before the transmission distance becomes so great that voltages above the corona limit are necessary. A quarter of a million volts may be used (except at high altitudes) without an excessive conductor diameter or spacing. (See Tables I and II.)

These tables will give an approximate idea of the voltage limit imposed by corona. In general it will be found advisable to operate below the e_0 voltage. Above e_0 the storm loss becomes an important factor. Calculations should generally be made from formulæ for each special case.

To find the voltage at any altitude multiply the voltage found above by the δ corresponding to the altitude, as given in Table II.

For single-phase or two-phase find the

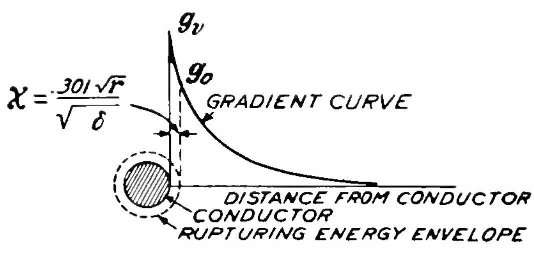


Fig. 11. Rupturing Energy in Air Surrounding One of Two Parallel Conductors

three-phase volts above and multiply by 1.16.

There are a number of ways of increasing the corona voltage, as for instance: An aluminum conductor equivalent in conduc-

TABLE I. CORONA LIMIT OF VOLTAGE
Kilovolts Between Lines Three-Phase—Sea Level—Cables

Size B.&S. or Cm.	Diam. in Inches	SPACING-FEET					
		8	10	12	14	16	20
0	0.374	95	98	102	104	106	109
00	0.420	104	108	111	114	117	121
000	0.470	114	118	121	124	127	132
0000	0.530	125	130	135	138	141	146
250,000	0.590	138	144	149	152	156	161
300,000	0.620		151	156	161	165	171
350,000	0.679		161	166	170	175	180
400,000	0.728		171	176	180	185	192
450,000	0.770		178	184	190	194	200
500,000	0.818		188	194	199	205	210
800,000	1.034		...	234	241	244	256

tivity to a given copper conductor has a greater diameter and therefore a greater corona voltage. The voltage difference is, for equal conductivity, about 25 per cent in favor of aluminum. A conductor with a core of a less expensive metal might be used, as a copper or aluminum cable with a protected steel center, etc. Of course, in such an arrangement possible, or rather probable, electrolytic action between conductor and core must be considered, as well as the mechanical problem of different coefficients of expansion due to heat.

One method of increasing the corona voltage is by subdivided conductors. For instance, suppose a copper wire of the desired conductivity is decided upon, but it is found that with the given diameter and voltage the corona limit will be exceeded. If the given required copper of each conductor

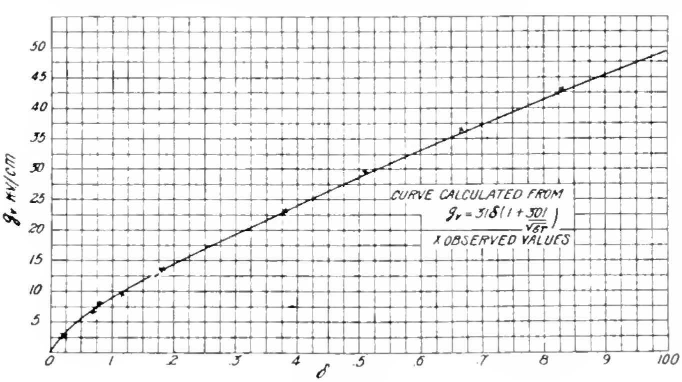


Fig. 12. Effect of Air Density on Visual Corona

is now subdivided into a number of smaller conductors, and these smaller conductors are symmetrically arranged in the proper way the corona voltage will be greatly

TABLE II. ALTITUDE CORRECTION FACTOR

Altitude Feet	δ	Altitude Feet	δ
0	1.00	5000	0.82
500	0.98	6000	0.79
1000	0.96	7000	0.77
1500	0.94	8000	0.74
2000	0.92	9000	0.71
2500	0.91	10000	0.68
3000	0.89	12000	0.63
4000	0.86	14000	0.58

increased. For example, by this method, in one particular case, the corona voltage was increased from 89 kilovolts to 115 kilovolts without increasing the amount of copper or the spacing between lines.

We are likely to think of corona as affecting only very high voltage transmission lines and of little other practical importance. It may, however, exist at almost any voltage, as it depends not only on voltage but also upon the configuration of the electrode and the spacing. It will exist in cables, on insulators, coils, switches, etc.; in short wherever air is present, and where damage may be done by mechanical bombardment of small streamers, and by electro-chemical action (ozone, and nitrous oxide) unless means are taken to prevent it. In most cases its prevention is fairly simple. We, as engineers, are likely to think only of the present practical side. However, such of the investigations which at present may appear only theoretical, open up as it were a trail into the future, which by degrees becomes a practical road. It is by such experiments that the inherent properties of electricity in general may be found and understood.

RECENT DESIGNS OF POWER LIMITING REACTANCES

By Eugene D. Eby

Transformer Engineering Department, General Electric Company

This matter of power limiting reactances is referred to in an editorial on page 735. Little has been published on the subject, although the matter has been under discussion for some years, and the necessity for practical reactances, for limiting the amount of power which may flow into a fault, has long been realized. Dr. Steinmetz' article in the September, 1911, Review, described the functions of the apparatus in considerable detail, indicated the baffling nature of some of the difficulties encountered in their development and specified the positions in which the reactances should be located for maximum protection. Readers should certainly consult his article. The present paper by Mr. Eby takes up the matter of the physical construction of the apparatus, such as method of winding, bracing, spacing and supporting, and the structure of the core; and includes a section on operating characteristics of coils now in regular production.—Editor.

With the development and improvement of electrical machinery, and the increasing demand for and application of electric power in nearly all fields of industry, there have come also new and important problems in its generation, distribution and utilization. The present central station and transmission system are extremely modern things. A score of years ago there were no such plants as exist to-day. Likewise many of the most disturbing factors in present-day operation of our large capacity, high voltage stations were then unknown. One of the many problems which have engaged the attention of the electrical profession during the past few years is concerned with the protection of generating and transforming apparatus from the disastrous mechanical effects of short-circuit currents.

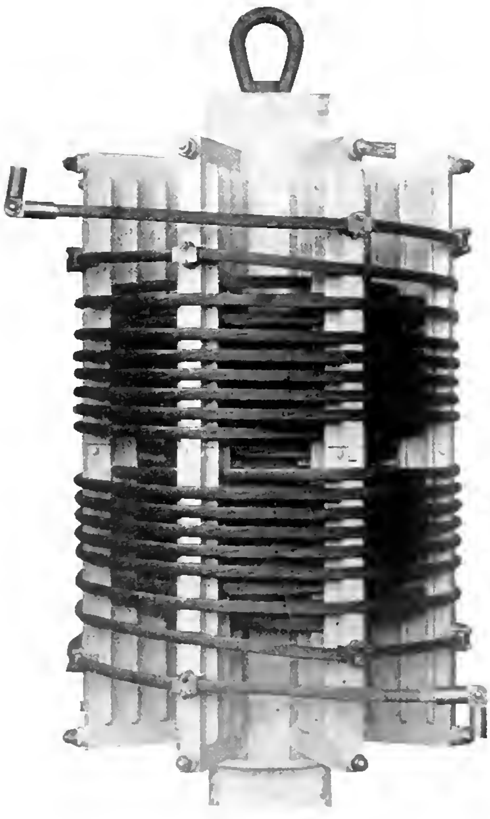


Fig. 1. 300 Kv-a. Current Limiting Reactance for Use with 15,000 Kv-a., 11,000 Volt, 50 Cycle Turbo-Generator

As is generally understood, it was formerly considered desirable to specify low reactance in the design of generators and transformers for the sake of the improved regulation. With small capacity stations not capable of maintaining normal terminal voltage in the event of short-circuit, this feature was not particularly detrimental. In the case of high power stations, however, low reactance is now recognized as correspondingly dangerous. A short-circuit of one unit in a station, where several large machines are operating in parallel, may mean the brief concentration at that point of almost unlimited power. Neither generators, transformers, nor switches can safely withstand such current rushes. The logical protection of the apparatus therefore lies in the limitation of the current flow; and such limitation is most easily secured by the insertion of reactance in the circuit. Briefly, these are the reasons which led to the development and use of the so-called current-limiting reactance coils, the subject of this paper.

The design of reactance coils for current limiting purposes in connection with large generators and transformers presents certain difficult problems. Such coils must be built without iron cores, to avoid saturation of the magnetic circuit at times of short-circuit, with consequent loss of effectiveness. They must be able to withstand the very severe mechanical strains incident to instantaneous overloads. They must have a large factor of safety against unknown transient voltages. They must be able to endure temporarily the heating effects of short-circuit currents until the circuit breakers are opened. Their end turns must receive special attention, both with respect to insulation and mechanical bracing. In fact, they must be capable of subjection, with safety, to unknown and uncertain values both of current and potential.

During the past year the development and standardization of the reactances to meet these requirements has been completed. The period of development extended over several years. Various materials and designs were tried before the present construction was finally adopted. A lengthy study and investigation by the manufacturer and an exhaustive series of tests conducted at the Fisk Street Station of the Commonwealth Edison Company in Chicago, have confirmed the design and its effectiveness in actual service.

Description of Design

The winding of these reactances consists of bare, stranded copper cable, wound under tension upon specially-treated wood supports which are bolted to a cylindrical concrete form or core (Fig. 1). The cable is wound in the so-called back-turn section form, which offers the advantages of accessibility of terminals, their removal farthest from the core and from each other, and the easy securing of the end turns. The majority of designs employ a single cable. Where

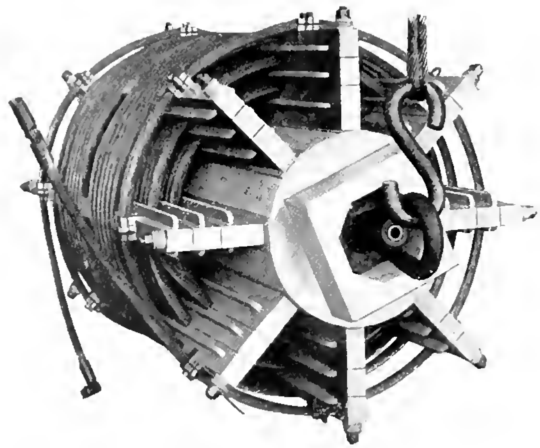


Fig. 3. End View of Three-Layer Coil Showing Arrangement of Concrete Core, Winding, Supports and Details

the capacity of one cable is not sufficient, two are wound in parallel (Fig. 2 and Fig. 10). The coil usually consists of three layers (Fig. 3). When especially small cable is used, it is wound in five layers. Such a construction is illustrated in the cut appearing on the cover of this publication. The mechanical spacing of the turns provides electrical insulation. Two turns at each end of the coil are given extra spacing, to insulate them against the voltages which accumulate on the end turns at times of short-circuit. A distance of several inches is allowed between the two sections of the coil. The final turn at each end is rigidly secured by alloy clamps to the outer wood supports. Standard interleaf terminals are joined to the ends of the cable with a high-melting solder.

The coil supports consist of strips of selected, resin-filled maple, the disruptive strength of which must exceed 75 kilovolts per inch across the grain, and 50 kilovolts per inch along the grain. The ends of the supports are bolted to the concrete core with radial brass bolts. The faces of the sup-

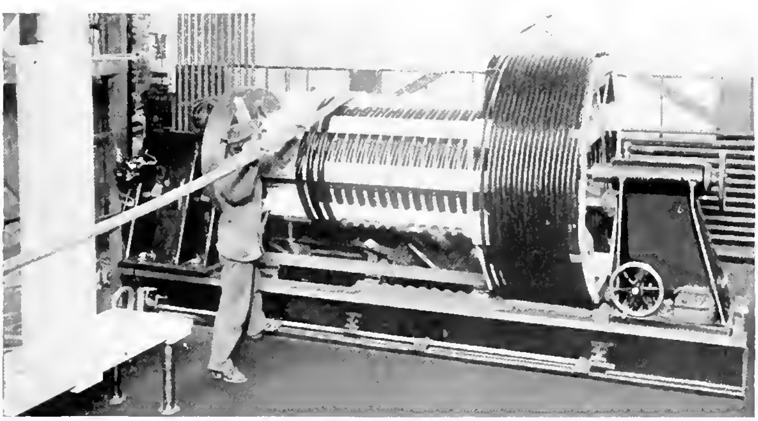


Fig. 2. Winding 400 Kv-a. Reactance with Two 1,250,000 cm. Cables in Parallel

ports are grooved to receive the cable, and the wood is protected from contact with the copper by heat shields of asbestos shellaced into the grooves. The leakage distance between layers of the winding and between winding and core, over the surface of the wood, is increased by barriers of the same material, dovetailed into the sides of the supports. To protect the wood from contact with the concrete, a strip of sheet insulation is placed under each of the first layer of supports. The woodwork and pressboard are finished with several coats of a cream-colored insulating enamel, which makes easy the inspection for removal of dust and dirt. The detailed arrangement of parts is well illustrated in Fig. 3.

Fig. 4. 12 Inch Core with Hexagonal Extensions

Fig. 5. 24½ Inch Core with Square Extensions

(These cuts have not been made to the same scale)

The form or core consists of specially mixed concrete, of such proportions as will afford greatest hardness and strength. Each core is poured in a collapsible cast iron mould, and allowed to stand until fully set. After removal from the mould, the surface is finished with neat cement and rubbed smooth. Before being used, each core is covered inside and out with several coats of a light yellow creosote paint. The core is cylindrical in shape, hollow, and provided with hexagonal or square extensions at the ends for mounting and bracing when installed. (Figs. 4 and 5.) A cored recess in each end receives a large nut or washer for lifting purposes.

In the cylindrical surface of the core near each end are embedded cast alloy sockets to receive the radial brass studs which clamp the wood supports to the core. The nuts on these studs rest upon heavy insulating washers; and around each stud is placed a tube of pasted mica as additional insulation.

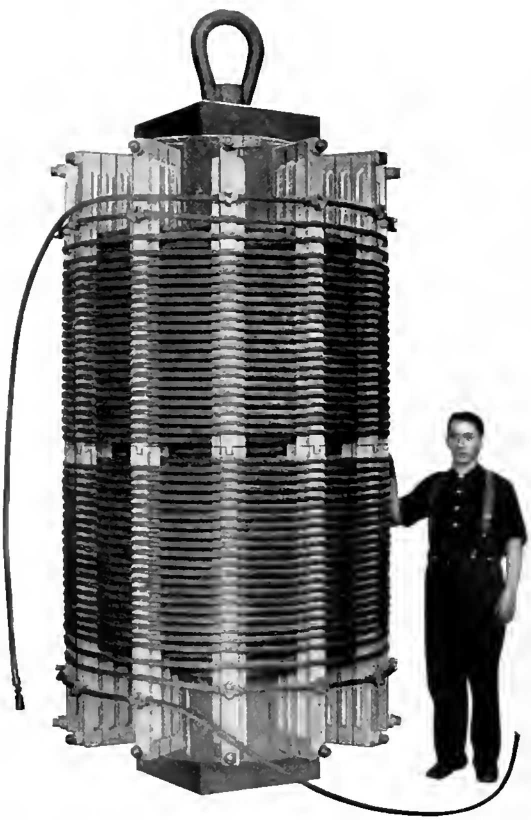


Fig. 6. 720 Kv-a. Busbar Reactance Built for the Commonwealth Edison Co., Chicago

For lifting the reactance during manufacture and installation, there is provided a heavy steel stud, engaging with a large cast alloy nut in the lower end of the core, and passing through a removable cast iron washer in the upper end. Cast steel eye-nuts are supplied for attaching crane hooks or tackle. The lifting stud is made of sufficient size so that the reactance may be turned to a horizontal position and lifted without bending the stud (Fig. 3). A name plate, mounted on a brass support in a conspicuous position, contains the rating of the reactance in cycles, kv-a., volts and amperes, and specifies the voltage of the circuit for which it is designed (Fig. 1).

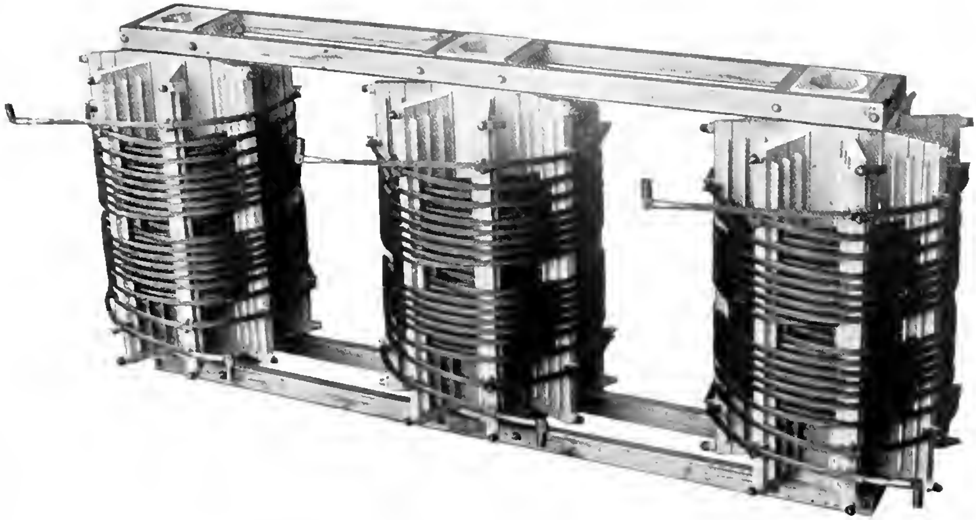


Fig. 7. Bank of 6 Per Cent Reactances for Three-Phase, 50 Cycle, 15,000 Kv-a., 11,000 Volt, Turbo-Generator. Showing Method of Mounting and Bracing

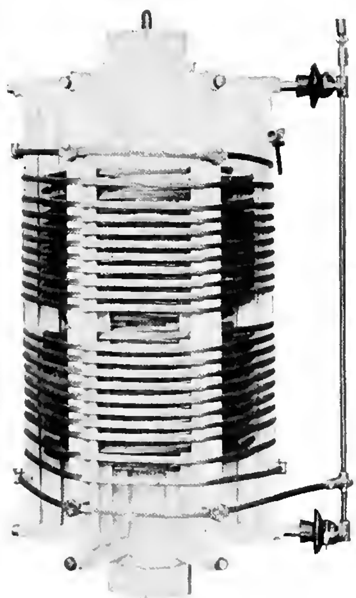


Fig. 8. Special Provision for Carrying Lower Lead to Overhead Bus

Operating Characteristics

Reactances of the type described have been built for the standard operating frequencies of 25, 50 and 60 cycles. In the majority of cases they have been designed to develop between terminals six per cent of the circuit voltage with normal current flowing. Designs have been built, however, for from $2\frac{1}{2}$ per cent to 10 per cent. Normally they are designed for a temperature rise of 40 degrees C. above a 25 degree room, measured by the increase in resistance method. An insulation test of $2\frac{1}{2}$ times the circuit voltage, or $4\frac{1}{3}$ times the normal potential to ground, is applied between the winding and concrete core.

The voltage characteristic of these reactances is a straight line, secured by the absence of all magnetic material in their construction. By a careful series of tests it has been found safe to install and operate them at a distance of approximately half their diameter from any iron or steel structures without appreciable heating in the latter. The losses in a set of reactances, confined wholly to copper losses due to resistance and eddy currents, vary from 0.1 per cent to 0.4 per cent of the generator capacity.

For immediate protection to generating units, the reactances are connected in series with the generator leads to the busbars.

With three-phase machines, one reactance is connected in each of the three line leads. With two-phase machines, one reactance in each phase is sufficient. For the protection

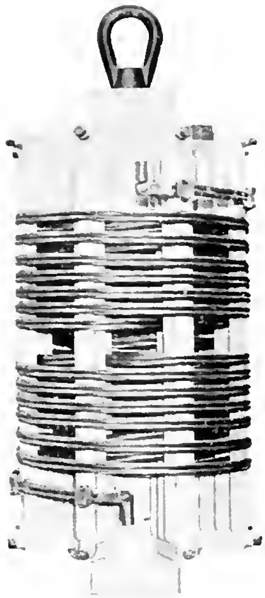


Fig. 9. High Current Reactance Showing Double Cable Winding

of transformers, the reactances are located between the busbars and the transformer terminals, preferably on the low tension side. To sectionalize the busses in a large station, and limit the transfer of energy between sections, large reactances are placed in the connections between corresponding busses. In this case the transfer of energy through the reactances is not due to difference of potential, but to phase displacement between the sections. It is usually considered sufficient that such reactances should pass 20 to 25 per cent of the capacity of one section normally, and limit the transfer at times of short-circuit to the rated capacity of the section. *

The recommended method of bracing the reactances in service is illustrated in Fig. 7. Heavy timbers are clamped with brass bolts to the square extensions at the ends of the concrete cores. As the only tendency for motion is toward each other, sufficient bracing is provided in this manner. The open construction of the coils permits easy inspection and blowing out of collected dust or dirt, since all parts are visible and accessible. There is practically no cost for maintenance or repairs.

The production of current limiting reactances already has been considerable. One operating company alone has over fifty of them in service. During the past year sales have been made to a dozen different customers, among them the Isthmian Canal Commission and the New South Wales Government Railways of Australia. In size the coils have varied from 30 kv-a. per phase, for use with 1500 kv-a. generators, to 720 kv-a. busbar sectionalizing reactances for the Commonwealth Edison system of Chicago. (Fig. 6.) Still larger capacities are contemplated for use with 25,000 kv-a. generators proposed for a Pacific Coast system.

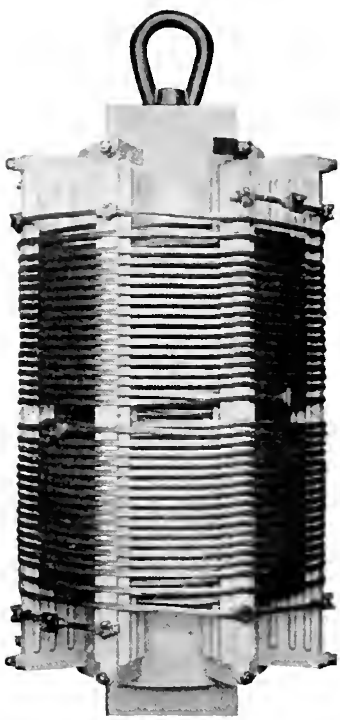


Fig. 10. Reactance with 25 Per Cent and 50 Per Cent Taps, Arranged for Bar Connections

Their general acceptance throughout the country by many of the larger operating companies is a tribute to the design and the attention given to this problem by the manufacturers.

*See paper by Dr. C. P. Steinmetz on "Power Limiting Reactances," in the GENERAL ELECTRIC REVIEW, September, 1911.

VOLTAGE REGULATION OF POLYPHASE FEEDERS BY AUTOMATICALLY CONTROLLED FEEDER VOLTAGE REGULATORS

By M. Unger

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Satisfactory voltage regulation of polyphase feeders by means of feeder regulators automatically controlled by contact-making voltmeters requires that the phase displacement between the currents in the windings of the contact-making voltmeter shall be the same as the displacement between the voltage and the current of the feeder under regulation; and, furthermore, that the actual value of the compensating current in the voltmeter winding shall be proportional to the current producing the line drop, if this is to be corrected for in addition to the variations in the supply. The article constitutes primarily a discussion of a number of methods of connecting automatically controlled single and polyphase regulators to polyphase feeders; the simpler of which answer all ordinary requirements for balanced load and unity power-factor, while the more elaborate are intended to bring about a fulfillment of the conditions outlined above in those cases where the load is unbalanced and the power-factor low.—Editor.

Automatic voltage regulation of single-phase feeders by means of feeder regulators is well understood and gives no particular difficulty. The voltage regulation of polyphase feeders is naturally more complicated, in view of which the following discussion is given to this problem and recommendations are made as to methods to be used for obtaining satisfactory results.

Selection of Regulators

For regulation of polyphase feeders, either single-phase or polyphase regulators may be used. If a polyphase regulator is used it is evident that the voltage across only one phase can be controlled, while the voltage of the other phases will depend upon the voltage variation effected by the regulator as called for by the particular phase regulated, upon the load, and upon the line characteristics, etc. If the load is fairly balanced this should prove satisfactory, as, for example, in cases where the main load consists of polyphase motors, while only a small lighting load is taken from the regulated phase.

By using single-phase regulators, one for each phase, and each individually controlled, perfect regulation of the voltage of all phases can be obtained. It is, of course, evident that if it is desired to regulate only one or two phases, one or two single-phase regulators (one per phase) are required.

In case it is desired to regulate for constant voltage at or very near the station, the controlling apparatus usually consists of a potential transformer and a contact-making voltmeter for each regulator. This kind of regulation is usually obtained without difficulty. With three single-phase regulators used on a three-phase feeder, a certain amount of see-sawing of the regulators is, however, usually to be expected, as each regulator in adjusting the voltage of its phase disturbs the voltage across the other phases to a certain extent. It will therefore be found that when one regulator starts to operate the other two will follow, but after some adjusting will come to rest, the amount and number of adjustments depending primarily on the amount of the adjustment of the first regulator.

In most cases it is required that regulators maintain constant voltage at a distant point, as, for example, the center of distribution; that is, the regulators are to take care of the line drop in addition to any voltage variations of the supply. As these requirements are the most common ones they will be considered in detail.

One Single-Phase Regulator on a Three-Phase Feeder

The connections as shown in Fig. 1 are the same as those used for single-phase regulators controlling single-phase feeders, the voltmeter being compounded to take care of the line drop (resistance drop only considered). A study of the vector diagram, however, will show that the compensation obtained with these connections on a three-phase feeder is not correct. In this diagram the triangle ABC represents the three-phase voltage of the supply or generator. The regulator has its secondary winding in series with the line C, while its primary winding is connected across BC. The secondary voltage of the regulator is therefore combined with the generator phase voltage BC. The potential transformer is connected across phase BC on the line side of the regulator. A high non-inductive resistance is connected in series with the potential winding of the contact-making voltmeter, so that the current in this winding will be practically in phase with the feeder voltage BC. The current transformer, which is connected in the feeder leg C, will supply a current to the compensating winding of the contact-making voltmeter, which will be practically in phase with the current in the feeder C.

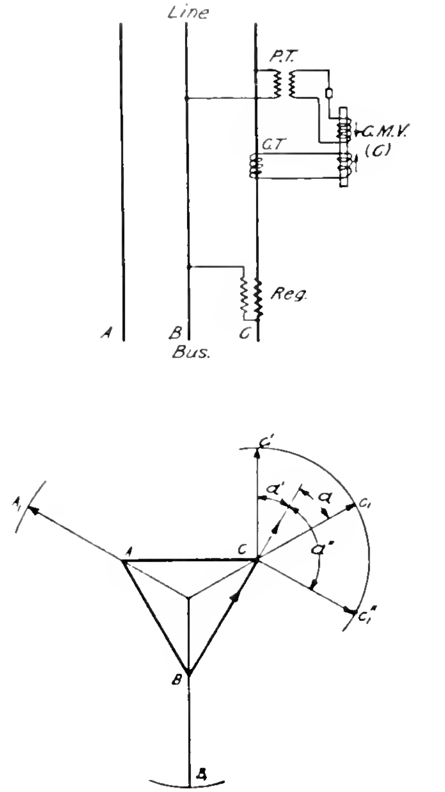


Fig. 1. One Single-phase Regulator on 3-phase System Current Transformer in One Leg of Phase

It is, of course, evident that in order to obtain proper compensation the currents in the two windings of the contact-making voltmeter must have the same phase displacement with respect to each other as that which corresponds to the power-factor of the feeder. If, for example, the power-factor of the feeder is 100 per cent, then the currents in the two windings should be in phase, but opposing each other in effect. By referring to the vector diagram, however, it will be seen that with a feeder power-factor of 100 per cent, the feeder current CC_1, or the corresponding secondary current of the current transformer has a phase displacement $\psi = 30$ deg. to the phase voltage BC, or to the current in the potential winding of the contact-making voltmeter. The two currents of the contact-making voltmeter are therefore displaced 30 deg. from each other. Good regulation can be obtained under these conditions, provided that the power-factor of the feeder remains constant. This condition is nearly fulfilled in the case of incandescent lighting load.

We will now assume that the power-factor of the feeder is not constant. As an illustration the diagram is made for a feeder power-factor of 50 per cent, corresponding to a phase displacement of the feeder current of 60 deg. with respect to the feeder current at 100 per cent power-factor. Depending upon the phase rotation of the system, the feeder current will now be either CC_1' or CC_1''. In the former case the currents in the contact-making voltmeter windings are displaced $\psi' = 30$ deg. while in the latter case the displacement is $\psi'' = 90$ deg. It is evident that if the phase rotation happens to be such that when the feeder power-factor varies from 100 per cent to 50 per cent the feeder current

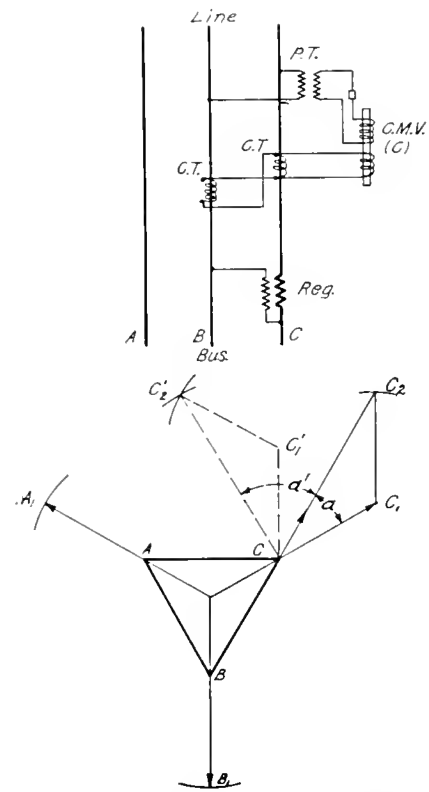


Fig. 2. One Single-phase Regulator on 3-phase System. Current Transformer in each Leg of Phase

changes from CC_1 to CC'_1, the line drop compensation to be obtained may be fairly satisfactory. With the reversed phase rotation, the compensation will be very poor; in fact, with 50 per cent feeder power-factor there will be no compensation at all, as the phase displacement of the currents in the contact-making voltmeter is 90 deg.

The connections shown in Fig. 1 are generally unsatisfactory, therefore, on account of incorrect phase displacement between the currents of the contact-making voltmeter windings. Furthermore, if the load on the system is unbalanced, the current in the compensating winding will not have the proper value to give correct compensation, even if the phase displacement were correct. The connections shown in Fig. 1 should not be recommended, therefore, unless the conditions are those of balanced load and constant power-factor.

For satisfactory regulation, as stated above, it is evident that some means must be used whereby the displacement between the currents in the contact-making voltmeter windings will be the same as the displacement between feeder current and voltage, corresponding to the power-factor of the feeder. Furthermore, the actual value of the compensating current must be proportional to the current causing the line drop of the phase that is being regulated.

The voltage drop across a certain phase of a three-phase system is the resultant of two drops, which are proportional to the currents of the two line legs of this phase. This resultant drop is that which would be produced by the resultant of these two currents flowing through a single leg of the line. The correct compensation can therefore be obtained.

We will first consider the case where the line power-factor is 100 per cent; that is, the currents in feeders C and B are CC_1 and BB_1 respectively. By connecting the contact-making voltmeter to the current transformers, as shown in Fig. 2, the compensating current will consist of one component proportional to and in phase with CC_1 and another proportional to and in phase with BB_1 reversed, so that the resultant compensating current is represented by CC_2. This current is in phase with the current in the potential winding of the contact-making voltmeter and it is also proportional to the current causing the line drop. For a line power-factor of 100 per cent, all necessary requirements for proper compensation are therefore fulfilled.

If we now assume that the line power-factor decreases to, say 50 per cent, corresponding to a phase displacement of 60 deg., the resultant compensating current will be CC_2', which is displaced 60 deg. from the current in the potential winding of the contact-making voltmeter. This current is again directly proportional to the current causing the line drop.

From the above discussion it is evident that with the connections shown in Fig. 2 proper

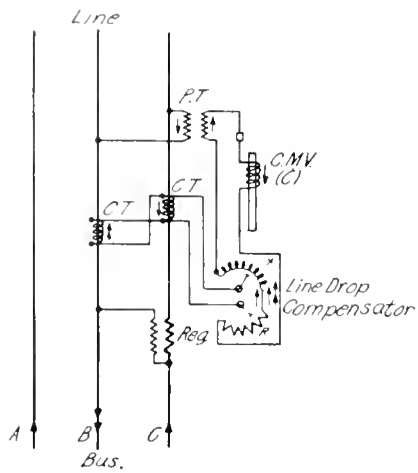


Fig. 3. One Single-phase Regulator on 3-phase System with Line Drop Compensator. Current Transformer in each Leg of Phase

phase displacement of the currents in the contact-making voltmeter windings is obtained if the load on the system is balanced, and the compensating current will be in proportion to the current causing the line drop. This also holds true if the load is unbalanced. Attention should be called to the fact that with the connections shown in Fig. 2 it is absolutely immaterial what the phase rotation is, as in either case the phase displacement of the currents in the contact-making voltmeter windings will be correct. For one phase rotation the compensating current will be leading and for the other lagging with regard to the current of the potential winding.

The connections shown in Fig. 2 are satisfactory under practically all conditions for regulating the voltage of one phase of a three-phase system. The regulator may be either single-phase or three-phase, the same controlling apparatus being required in either case.

With the connections shown, compensation for resistance line drop only is taken care of and this is usually satisfactory in cases where the reactance drop is small. If, however, the very best regulation is required in cases where there is both resistance and reactive line drop, a line drop compensator should be used and the connections should then be made as shown in Fig. 3.

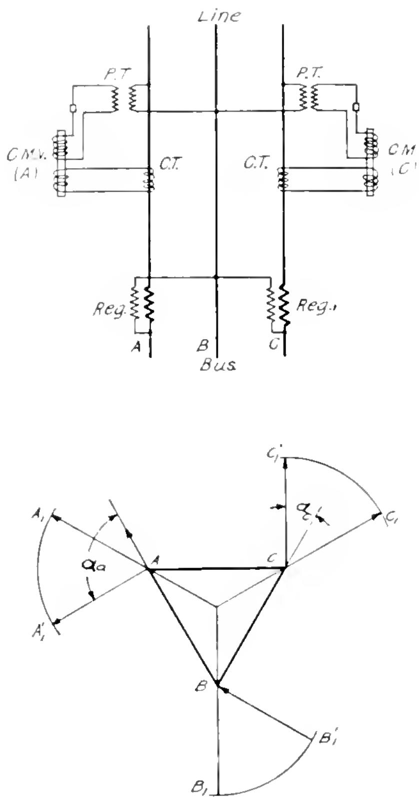


Fig. 4. Two Single-phase Regulators on 3-phase System. Connections similar to those of Fig. 1

Two Single-Phase Regulators on a Three-Phase Feeder

The connections shown in Fig. 4 correspond to those for a single regulator, shown in Fig. 1. It will be seen by referring to the vector diagram of Fig. 4 that the regulators change the phase voltage of the supply in directions *BC* and *BA*; that is, each regulator apparently changes the voltage of its phase without disturbing the voltage of the other regulated phase. However, while this may be true, the change of voltage by one regulator will cause a change in the current of all three feeders and this is liable to give trouble.

We will assume that the load is non-inductive and balanced, so that the current in feeder legs *A* and *C* will be represented by AA_1 and CC_1. It is evident that the compensating currents will be displaced 30 deg. from the corresponding currents of the potential winding of the contact-making voltmeters, leading in one phase and lagging in the other. If now the power-factor of the feeder drops to say 50 per cent, the feeder currents will lag 60 deg. behind the previous positions; that is, the feeder currents will now be represented by AA_1' and CC_1'. The phase displacement between the currents in the contact-making voltmeters *A* and *C* is therefore 90 deg. and 30 deg. respectively. It is evident, therefore, without further discussion that with the connections shown proper line drop compensation cannot be obtained where the power-factor is variable. The compensation will also be disturbed by unbalancing of the current in the three legs of the feeder.

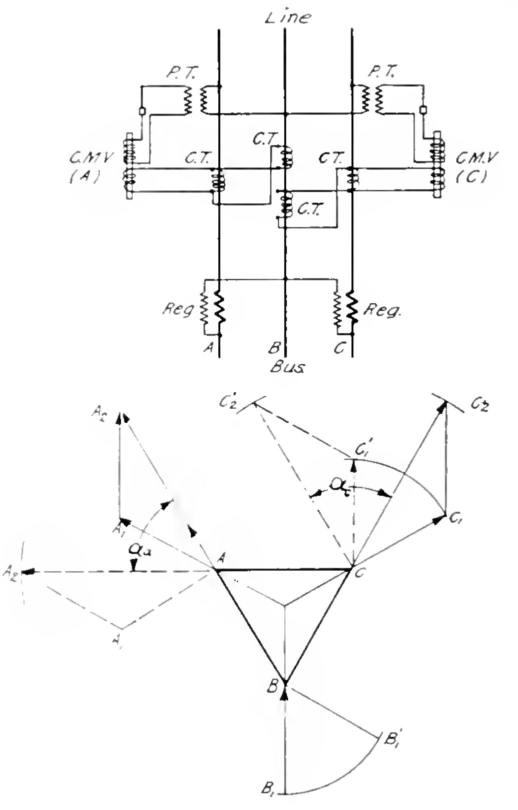


Fig. 5. Two Single-phase Regulators on 3-phase System. Connections similar to those of Fig. 2

A peculiar disturbance occurs where the load is made up of three-phase motors. This may be explained as follows: If the voltage should be higher on one phase of the motors, the current in this phase will increase, while it will decrease in the other phases. The result is that the regulator on the high voltage phase will still further increase the voltage while the other regulator will decrease the voltage of its phase. The disturbance grows until both regulators reach their limits, one in maximum boosting position and the other in maximum lowering position, or until the current taken by one phase of the motors becomes zero.

The condition just described has been noticed in actual practice at the Lynn Gas & Electric Company. During the daytime the load was made up of three-phase motors, with a power-factor of about 75 per cent. The regulators were connected up as shown in Fig. 4. The regulation of the feeders was better with the regulators disconnected. At night, the load was made up mostly of incandescent lamps, the power-factor being

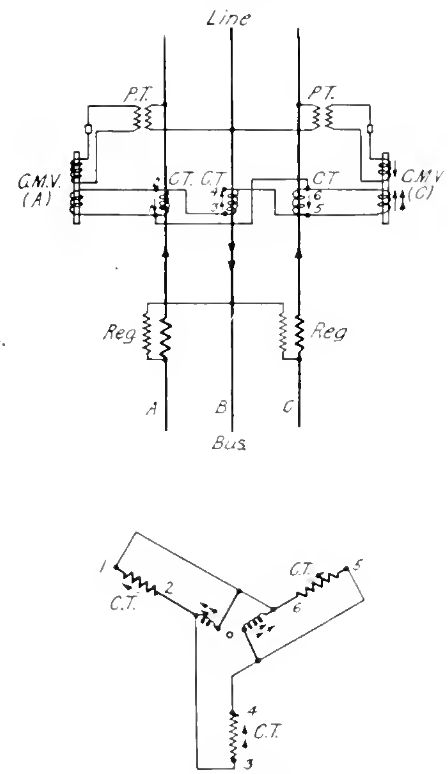


Fig. 6. Two Single-phase Regulators on 3-phase System, using one current transformer on middle leg instead of two as in Fig. 5

about 100 per cent. Under these circumstances the regulation became fairly satisfactory, partly on account of the high power-factor, and partly on account of the fact that a slight difference in phase voltages did not unbalance the feeder currents as badly as with a motor load.

The unsatisfactory conditions described will be corrected if the connections shown in Fig. 5 are used. These are similar

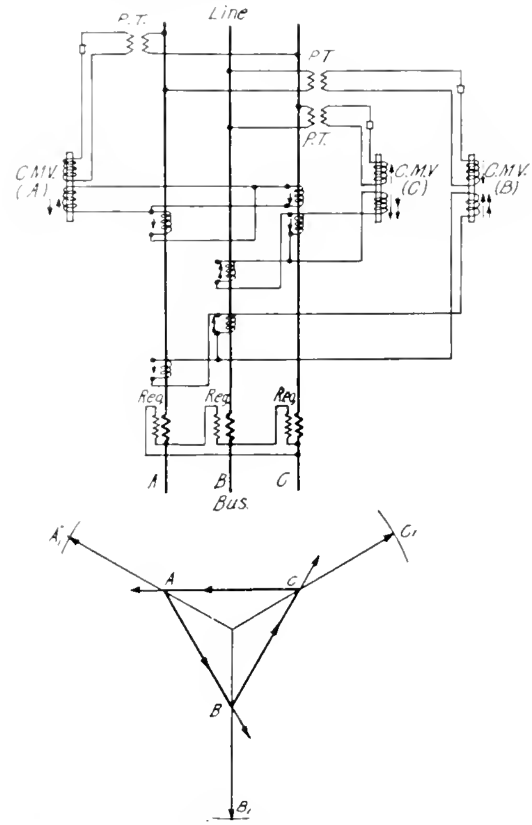


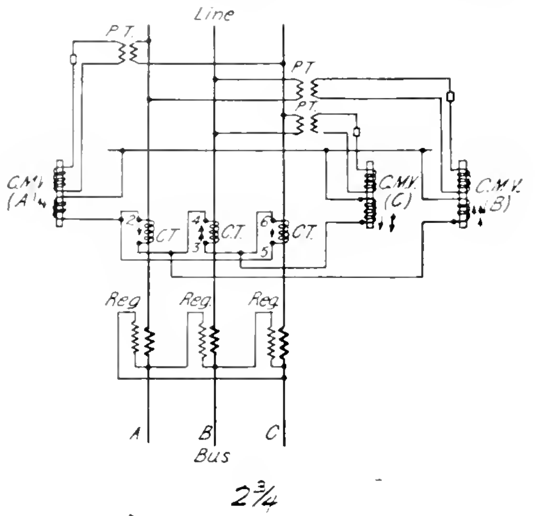
Fig. 7. Three Single-phase Regulators on 3-phase System, giving Independent Regulation of each phase

to those for a single-phase regulator, shown in Fig. 2. The vector diagram shows plainly that with these connections proper phase displacement of the currents in the contact-making voltmeters is obtained, and the disturbance of the compensation due to unequal feeder currents is eliminated.

The connections shown in Fig. 5 can be simplified as shown in Fig. 6, where instead of using two current transformers on the middle feeder, one current transformer is used, the current of this transformer flowing through the compensating windings of both contact-making voltmeters.

With further reference to the installation of the Lynn Gas & Electric Company, the connections were changed to those shown in Fig. 6. The results obtained were entirely satisfactory. Under no conditions was it possible to make the two regulators hunt, the regulators operating apparently independently of each other, each having a definite stable position.

In case of incandescent lighting load only, the connections shown in Fig. 4 may give



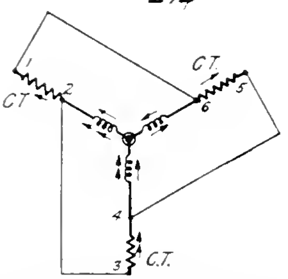


Fig. 8. Three Single-phase Regulators on 3-phase System, employing three current transformers instead of six as shown in Fig. 7

satisfactory results, but the connections shown in Fig. 6 are recommended for all cases.

To take care of both resistance and reactance line drops it is, of course, evident that one line drop compensator for each voltmeter should be used, in which case the compound winding of the voltmeters is to be omitted.

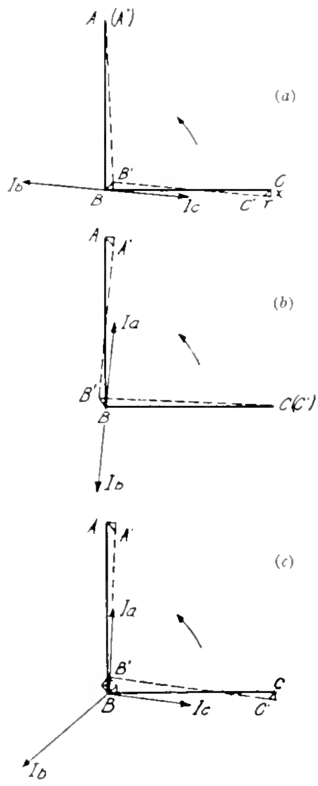
Three Single-Phase Regulators on a Three-Phase Feeder

The diagram, Fig. 7, shows the correct connections for independently regulating each phase of a three-phase system. However, instead of using six current transformers as shown, it is quite sufficient to use one transformer for each feeder, in which case the secondary of each current transformer is connected in series with the compensating windings of two contact-making voltmeters. The correct connections for this arrangement are shown in Fig. 8, which needs no further explanation.

We do not know of any installation using these connections, but we are quite confident that they will give satisfactory results.

Three Single-Phase Regulators on a Three-Phase Four-Wire Feeder

In this system, which is used by some of the largest central stations in this country, the motor load is connected to the three phases, while the lighting load is connected between phases and the fourth wire, which is usually grounded. The regulators are connected between the neutral, or fourth wire, and the phases, the connections being in



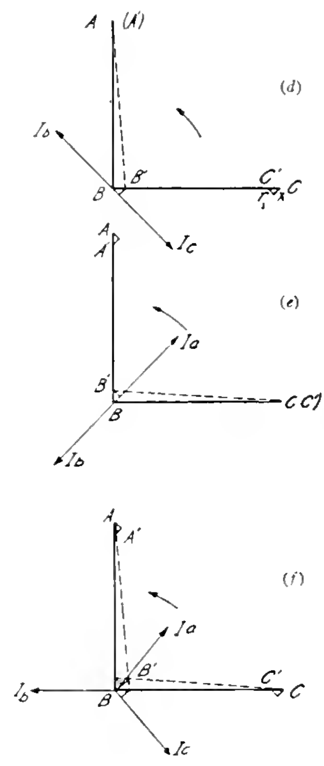


Fig. 9 Fig. 10

Vector Diagrams of 2-phase 3-wire Systems, showing Unbalancing of Voltages

100% power-factor

(a) Phase AB—No load.
Phase BC—Full load.
Voltage AB = BC = 100.
Voltage A′B′ = 96.
Valtage B′C′ = 90.

(b) Phase AB—Full load.
Phase BC—No load.
Voltage AB = BC = 100.
Voltage A′B′ = 90.
Voltage B′C′ = 104.

(c) Phase AB—Full load.
Phase BC—Full load.
Voltage AB = BC = 100.
Voltage A′B′ = 86.
Voltage B′C′— 96.

71% power-factor

(d) Phase AB—No load.
Phase BC—Full load.
Voltage AB = BC = 100.
Voltage A′B′ = 100.
Voltage B′C′ = 86.

(e) Phase AB—Full load.
Phase BC—No load.
Voltage AB = BC = 100.
Voltage A′B′ = 86.
Voltage B′C′ = 100.

(f) Phase AB—Full load.
Phase BC—No load.
Voltage AB = BC = 100.
Voltage A′B′ = 86.
Voltage B′C′ = 86.

this case the same as for single-phase feeders. This system makes it possible to obtain perfect regulation for the lighting load.

There is, however, one important point that should not be overlooked in this connection and that is the drop in the fourth wire. If this is considerable, due to unbalanced load or imperfect grounding, then proper regulation cannot be obtained without further compensation,

Two Single-Phase Regulators on a Two-Phase. Three-Wire or Four-Wire System

While a two-phase, four-wire system can be regulated by means of two single-phase regulators, each phase to be considered as a single-phase feeder, and in this way absolutely correct regulation is obtained, the results will not be so satisfactory if the system is two-phase, three-wire, although this method of regulation is used successfully in several installations.

By referring to the vector diagrams in Figs. 9 and 10, it will be seen that unbalancing of the phase voltages even at balanced loads is inherent with the two-phase, three-wire system. The diagrams are drawn approximately to scale. It has been assumed that the resistance and the reactance have equal value and are the same for all three lines. The resistance and the reactance drop of each outside wire at full load is assumed to be 5 per cent of the normal voltage. *AB* and *BC* represent the phase voltages at the generator terminals, while *A′B′* and *B′C′* are the load voltages. The currents are represented by *Ia*, *Ib*, *Ic*. It is assumed that $AB = BC = 100$ and the diagrams give the approximate values of load voltages under different load conditions.

Referring to the diagrams, it will be seen that under practically all conditions of load the phase voltages will be unbalanced, and correct line drop compensation can not be obtained by utilizing the current in the outside wire only. The drop in the third or common wire must also be considered.

Fig. 11 shows connections by means of which theoretically correct line drop compensation is obtainable. It will be seen that the drop in the line is deducted at the proper phase angle from the generator voltage, and correct compensation is obtained for all conditions of load.

General Notes

In using interconnected current transformers for the contact-making voltmeters or line drop compensators, care should be taken to see that the compensating current thus obtained will not cause undue heating of the apparatus in question.

Using two interconnected current transformers on a three-phase system, the resultant

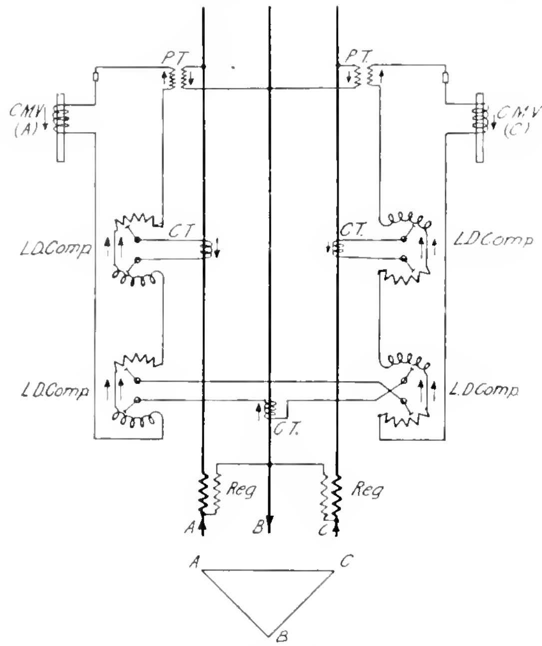


Fig. 11. Two Single-phase Regulators on Two-phase 3-wire System

current is 1.73 times that of each individual transformer, and in a two-phase system the resultant current is 1.41 times that of each individual transformer.

In case of a three-phase feeder, it is possible to obtain proper phase relation and current values for the contact-making voltmeters by using three Y-connected potential transformers and one current transformer for each voltmeter. On 2200 volt systems this would, however, require either potential transformers of special ratio or else special resistances for the voltmeters. The connections as shown are therefore to be preferred.

Summary

Polyphase regulators will not give independent regulation to the different phases of the polyphase circuit. In cases of unbalanced load, the voltage of only one phase can be controlled by their use.

The voltage of each separate phase may be controlled independently by means of a single-phase regulator for each phase. The number of regulators required depends upon the number of phases which it is desired to regulate.

The connections shown in Figs. 1 and 4 will give satisfactory operation for the regulation on one and two phases respectively of a three-phase system only when the power-factor is constant and high, and when the load is fairly well balanced.

The connections shown in Figs. 2, 6 and 8 will give satisfactory regulation for one, two and three phases respectively for all conditions of load, and are recommended for all cases.

The above connections will regulate for resistance drop only.

Where it is desired to regulate for reactance drop also, one line drop compensator will be required for each voltmeter connected, as illustrated in Fig. 3 for the regulation of a single phase.

If the load is balanced and the power-factor fairly constant for all loads, approximately correct compensation can be obtained on a two-phase three-wire feeder by considering each phase as a single-phase feeder. The lower the resistance and the reactance of the third wire, the more nearly correct will be the compensation. If absolutely correct compensation is required, the connections shown in Fig. 11 are recommended, although these connections have to our knowledge never been used.

NOTES ON THE USE OF TUNGSTEN FILAMENT LAMPS WITH PARABOLIC REFLECTORS

By G. H. Stickney

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To obtain the best results from parabolic reflectors, the light source should approximate a point as nearly as possible, since from the principle of the reflector only those rays of light that emanate from the exact focal point are reflected in a beam parallel to the axis. The larger the source, the more divergent the beam. The crater of the electric arc fulfills this optical requirement better than any other illuminant and has been supreme in high power work. The development of the concentrated tungsten filament lamp, however, has been responsible for the present extensive adoption by automobile manufacturers of electrically lighted headlights, which has resulted of course in the installation of complete electric lighting outfits in almost all cases. The author further points out that the shorter the focal length of a parabolic reflector for a given diameter, the greater the amount of light flux in the beam, and therefore the desirability of as small a lamp bulb as is consistent with good design; also, that it is important that the light source be accurately centered at the focal point and that the reflecting surface be kept in perfect condition.—Editor.

For all ordinary lighting problems light sources of relatively large dimensions are advantageous, in that they tend to minimize intrinsic brilliancy and glare and to improve diffusion. For use in connection with lenses and parabolic reflectors, however, the effectiveness of the light source depends, in a large degree, upon its being concentrated into a small space. The nearer the light source dimensions approach the ideal point (that is, zero dimensions), the nearer do the lighting effects approximate the sharp, clearly defined beams so desirable in light projection.

The crater of the electric carbon arc meets these conditions better than any other illuminant, and hence has been used very extensively, especially for high power work. There is, however, a very considerable demand for a lower power concentrated light source, producing a steady light on either direct or alternating current circuits, which will avoid the necessity of expert adjustment, trimming and other attendance. To meet this demand in the past, the stereopticon type of carbon incandescent lamp has been made. In lamps of this type the filaments have been coiled up into certain special forms, designed to approximate the point source as nearly as possible. Owing, however, to the low degree of concentration and the relatively low power and efficiency obtainable, the application has not been very extensive. With the drawn tungsten wire now used for incandescent lamp filaments, an enormous increase in the possibilities of incandescent lamps for this purpose has resulted, not only on account of the greater brilliancy and efficiency of the filament as a light producer, but very largely on account of the smaller space into which the filament can be coiled. This filament is put into the lamp in the form of a ductile wire, and can be handled much more freely and coiled more closely than was ever possible with any other form of filament.

Many are familiar, in a general way, with the progress which has been made in applying this type of lamp to automobile headlights and small power searchlights. Before discussing these applications, however, it seems best to outline briefly some of the relations between the light source and the parabolic reflector.

Parabolic Reflectors

By a parabolic reflector is understood a concave reflector having a specular reflecting surface so formed that all sections through the axis of the reflector are parabolas of the same focal length. The peculiar property of the parabolic reflector which makes it of interest in light projection is that of reflecting all beams of light, emitted from the focal point and incident upon any point of the reflector, along lines parallel to the axis. Thus, a perfect parabolic reflector, with an absolute point source located at the focus, would emit a beam of light composed of parallel rays and equal in diameter to the reflector. The intensity of this beam at all distances from the reflector would be equal, except for what loss was encountered in passing through the air or other transmitting medium. See Fig. 1.

The ideal parallel beam is, however, never realized in practice, partly because there is no such thing as an absolutely accurate parabolic reflector, but principally because no true point source of light can be obtained. Even with the high power arc, such as is used in large searchlights, the dimensions of the crater are sufficient to cause a distinct angular dispersion. The effect is illustrated in Fig. 2. If F is the focal point of the reflector and A-B the light source centered as accurately as possible at the focal point, then the rays of light incident at any point on the reflector (as C) will be reflected so that the angle of reflection and the angle of incidence with respect to the tangent to the parabola at that point will be equal. Obviously but one ray of light, viz., that pro-

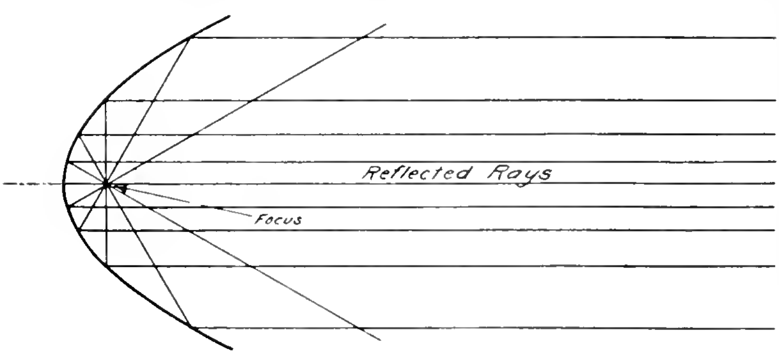

Fig. 1

ceeding from the exact focal point F, will be reflected along the line C-F^1 parallel to the axis. All other light will be reflected in different directions, as for example, light from A will be reflected along the line C-A^1 and light from B along the line C-B^1. Thus, from C and from every other point on the reflector, dispersed cones of light will be emitted over an angle which is equal to that which the source subtends with reference to the particular points. From this it will be seen that

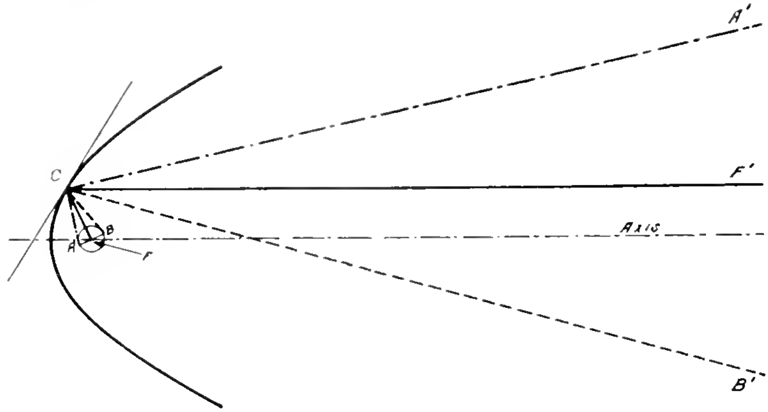

Fig. 2

the angle of dispersion will increase with increase in the size of the light source and decrease with increased distance of the light source from the reflector; that is to say, with increased focal length. At a considerable distance from the reflector, sufficient so that the reflector becomes essentially a point, all of these cones may be considered to coincide or merge into a single cone, and the relation which exists for one cone holds approximately for all. Therefore, in considering the effect of a searchlight at a great distance, say one hundred times its diameter, we may say:

1. For a light source of given dimensions, everything else being equal, the reflector having the greater focal length will give the greater concentration of beam.

2. For a reflector of a given focal length, the angle of dispersion of reflected light is approximately proportional to the dimensions of the light source.

With increasing focal length, the parabolic curve opens out very rapidly, so that where the diameter of the reflector is limited, a reflector of longer focal length will cover a smaller solid angle about the light source. Now, in the case of the concentrated filament lamp, there is approximately the same intensity in all directions, so that the light flux which strikes the reflector (and is, hence, available in producing the beam) is nearly proportional to the solid angle covered by the reflector. Therefore, for a given diameter of reflector, the shorter the focal length the greater the amount of flux which will be available to form the beam.

Fig. 3. Electric Automobile Headlight

In practical work the diameter of the reflector is usually limited by the cost and the possibilities of accurate work, as well as the space available, so that the most desirable focal length becomes a compromise between the degree of convergence required and these other factors.

Another item which enters into this determination when tungsten filament lamps are used, is the bulb diameter of the lamp. This is determined by the wattage; that is, a high wattage lamp requires a large bulb diameter. Therefore, in planning a lamp and reflector combination, it is necessary to provide a reflector with a focal length great enough so that the filament (which is usually placed in the center of the bulb) can be located at the focal point without mechanical interference of the bulb and reflector. Preferably the bulb diameter should be slightly less than twice the focal length of the reflector; otherwise the center of the reflector should be cut away to allow clearance.

This discussion should also call attention to the necessity of accurately centering the light source at the focal point. Even though the reflector be properly designed, a satisfactory beam will not be obtained unless the filament is accurately located at this point. This can usually be checked by projecting the beam on a distant surface and adjusting the position of the lamp until a properly concentrated beam is attained. The filament must not only be in the axis of the reflector, but also at the right distance from the vertex.

Another feature which should be considered is the condition of the reflecting surface. The projection of the beam depends upon accurate specular reflection. If the reflector is warped or dented, light will be diverted one way or another. A rough grained surface, or one having tool marks or scratches, even though microscopic, will lose in efficiency according to the amount of surface affected. Dirty or tarnished surfaces not only cause some of the light to be lost by absorption, but usually a much larger percentage to be diverted by diffusion.

Candle-power

Candle-power ratings are frequently applied to parabolic reflector beams, and this has been the subject of some discussion. If the rays were parallel, as in the ideal case, candle-power could not apply on account of the failure of the inverse square law. 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 by the atmosphere, intensities of such distances will be inversely proportional to the square of the distances. In working at long range there is no reason why the intensity of the beam cannot be specified in candle-power, provided 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. The writer has, on occasion, specified also the distance

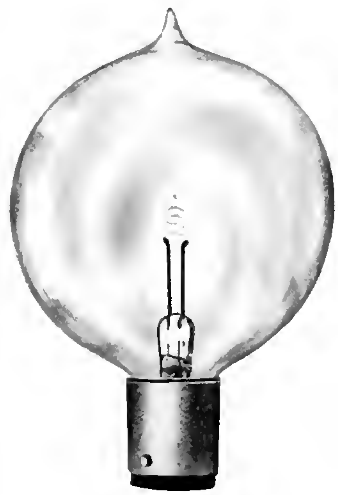

Fig. 4. Concentrated Tungsten Filament Lamp

at which the measurement was made, so as to give an idea of the accuracy of the test. *

If the beam be quite narrow, the maximum candle-power or the 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.

Multiplying Factor

The beam candle-powers obtainable with a parabolic reflector are enormous as compared to the original light sources without reflectors. This, of course, is due to the fact that a large part of the flux of light, instead of being radiated in all directions, is condensed into a relatively small angle and thus attains a very much higher intensity. The ratio of beam candle-power to the ordinary mean spherical candle-power of the light source is sometimes called the "multiplying factor." This depends upon the proportion of light falling upon the reflector, the angle of dispersion and the efficiency of the reflector, or, in other words, on the diameter and focal length of the reflector, the dimensions of the light source and the reflecting efficiency of the surface.

Measurements have shown a beam candle-power of over 6000 produced by an automobile headlight combination, consisting of a 6 in. parabolic reflector and a 15 candle-power automobile headlight lamp. This corresponds to a multiplying factor of 400 and will give an idea of the magnitude of multiplying factors which may be encountered. Much higher values have been obtained with lamps having more concentrated filaments. Greater concentration, however, is not desirable for headlight work, as too narrow a beam would not be satisfactory for this service.

Automobile Headlights

As has been intimated, the first application of the concentrated tungsten filament lamp has been in connection with parabolic reflectors for automobile headlights (Fig. 3). This equipment gives a powerful beam, clear, reliable and absolutely steady. Owing to the absence of dust, vapor and intense heat, the reflector is easily kept clean and maintained in perfect order. It also allows the use of a reflector extending well around the light source so as to utilize a very large percentage of the light rays. So successful has this application been, that electric headlight lamps are being adopted on nearly all of the better makes of automobiles. Of course, the convenience of turning lights on and off, the assurance that they will not blow out and other similar considerations have had an important bearing upon their popularity.

Lamps for this service are made for 6 volt battery circuits and range in size from 9 to 24 candle-power. They operate at about 1 watt per candle-power. For the general appearance of the lamp, see Fig. 4.

Other Reflector Applications

Similar lamps promise to perform a very useful service in connection with headlights on electric cars and steam locomotives, as well as for revolving lights in light houses and light ships and other signal work.

Lens Applications

The same peculiarity which has rendered the concentrated filament lamp so effective with parabolic reflectors makes them equally desirable for use with lenses. While they cannot hope to compete with the arc for large moving picture and stereopticon work, there is apparently no reason why this type of lamp should not be adopted for the lower power machines, such as are used in homes. The same advantages of simplicity and maintenance, cleanliness and adaptability which were mentioned in connection with the parabolic reflectors can be secured from these lamps when used with lenses.

At present the application of these lamps is limited to circuits where low voltage can be obtained, as for example battery circuits or alternating current circuits where transformers or compensators can be used.† There appears to be no reason, however, as the demand is developed, why the concentrated filament lamp should not be made in reasonable sizes for 110 volt circuits. It will, of course, not be practicable to secure as great a degree of concentration on the higher voltages on account of the greater length of filament. Moreover, the filaments are not likely to prove so hardy; but, from experimental samples which have already been made up, there is every reason to anticipate that a very serviceable lamp can be produced.

The principal applications, besides small stereopticon and moving picture work, will be in advertising projectors, light house lenses, signal lights and, possibly, theatrical spot light effects.

*It will be noted that F. Nerz, in "Searchlights, Their Theory and Application," specifies the intensity in beam candle-power (or rather, the German equivalent) and a discussion of this question will be found in Franklin's "Electric Lighting," page 102.

† The 100 watt concentrated filament lamp designed for stereopticon work is an exception, being now available in 100-130 volts.

ELECTRICITY IN THE TEXTILE INDUSTRY

CONVENTION OF MILL POWER SPECIALISTS AT GREENVILLE, S. C.

The Mill Power Department of the General Electric Company held its annual convention, October 7–11, at Greenville, S. C. Three features are especially notable: the visiting of mills which are said to be the last word in the application of electricity to textile machinery; valuable consultations between members present at which the results of much intensive research work was discussed; and the splendid Southern hospitality of the ladies and gentlemen of Greenville.

At the start, when the city was reached, many of Greenville's prominent citizens were found waiting with their cars to take the entire party to the Dunean mill. This mill is the only completely individually driven electric textile mill (with the exception of the card room) in the United States. A thorough inspection of this mill was made. The picker room has installed 5 h.p. 1800 r.p.m., 220 volt three-phase 60 cycle induction motors mounted on the A frames of the pickers, belting direct from the motor to the beater shaft. All of these motors have standard picker room treatment in order to protect them against damage by water during the occcasional fires which occur in the picker room. The card room in this mill uses a light group drive, it being less expensive to replace this drive with individual motors in case similar results can be shown in the preparatory machinery as in the picker, spinning and weave rooms. It is understood that experiments are going on at the present time along this line in order to determine if it is economical to equip the cards, combers, slubbers, drawing frames, etc., with indiviual motors. In the spinning room 5 h.p. 1800 r.p.m. geared motors are used, a steel cut pinion on motors meshing with a cloth gear. The twisters are similarly equipped, using $7\frac{1}{2}$ h.p., 1800 r.p.m. motors with the same type of gear equipment. On each of the frames thus far mentioned there is installed an oil switch.

The weave room consists of 1200 Compton Knowles looms, dobby head, and jacquard type varying from 30 to 40 inches width. This room is peculiar in the fact that it has saw-tooth roof construction, and a tar-concrete floor laid on the ground, eliminating the usual basement required for the line shafting of the weave room. Each loom is equipped with a $\frac{1}{3}$ h.p. 1800 r.p.m. totally enclosed loom motor, mounted on a bracket rigidly connected to the loom and geared to the friction element on the loom. The wiring of the weaver room is all in conduit. Flexible conduit is used to the motors, and triple-pole snap switches are mounted on condulet box just above the floor and between the looms. The spoolers and cloth room machinery all use individual motors. According to various tests made by different engineers the individual drive should give 12 to 13 per cent more production than a similarly equipped mill using a steam engine mechanical drive, assuming the other factors in the mill, labor, management, etc., are the same.

A motor trip to the Sans Souci Country Club followed the visit to the Dunean mill. The men present were given guest cards at the exclusive Poinsett Club, where all the privileges of this splendidly-appointed club were extended to them during their stay. The evening was spent in a closed meeting in which technical and commercial subjects were discussed. On Wednesday morning an automobile trip of 13 miles was made through cotton fields where the party had an opportunity to see ripe cotton, some of which was in the process of picking. They were taken to an electrically-driven cotton gin and shown the process of separating the fiber from the seed. From there, the inspection progressed to a cottonseed oil mill, and the various processes by which the cottonseed, obtained from the gin, are linted and pressed in order to extract the waste cotton and oil. At Simpsonville a typical Southern electrically-driven mill of 10,000 spindles was inspected. The preparatory departments of this mill are driven by a 500 kw. 3600 r.p.m., 600 volt Curtis turbine, using the 4-frame drive in the spinning room and group drive in the other departments. The turbine, working condensing, uses the spray-nozzle system at condensing pond for cooling the circulating water. An open meeting to which mill officials and consulting engineers were invited was held in the afternoon. Papers by Mr. J. E. Sirrine, Mr. R. E. Barnwell, an informal talk by Mr. John A. Stevens and a stereopticon lecture by Mr. E. D. Boler on recent cotton fiber investigations, were features of interest which were warmly discussed. Mrs. J. E. Sirrine gave the ladies of the party a delightful tea in the afternoon at her beautiful home. The brilliant occasion and the warm Southern hospitality shown are fragrant memories which will be treasured by the ladies of the party, many of whom had not been South before. The members of the Mill Power Department, their guests and wives, were entertained by the members of the Poinsett Club and their ladies at a reception and dance in the evening.

Thursday morning was occupied with the inspection of the 100,000 volt Greenville substation of the Southern Power Company which has a capacity of 20,000 kw. The 10,000 kw. steam turbine reserve station located at the same place was also visited. Inspections were made of the Monaghan Mills, Woodside Mills and the Westervelt Mills. The first two of the above named operate with a heavy group system, taking secondary power from a hydro-electric company. The Westervelt Mill is practically a duplicate of the Dunean Mill in the size and class of goods manufactured. The electrical equipment consists of individual motors on the ceiling in the picker room, group motor drive in the card room and weave room and 4-frame motors in the spinning room.

A trip to Pelzer occupied the afternoon. Here the first mill to transmit power any distance was visited and the old motors put in eighteen years ago were found operating and in perfect condition. It is interesting to note the fact that when the first hour of starting arrived the negroes came out to this mill with pails to catch the electricity as it fell from the wires. Others expected the wires of the transmission line to drive the mill by moving as in rope drive; and when they found that this did not occur burst in tears, and said electric power was a failure and there would be no work at the mill. The annual dinner to the representatives of the Mill Power Department and their guests formally closed the convention.

Among the invited guests were many prominent citizens of Greenville.

NINETEEN-TWELVE CONVENTION OF TRANSFORMER AND REGULATOR SPECIALISTS

The Second Annual Meeting of the Transformer and Regulator Specialists of the General Electric Company was held at the Maplewood Hotel, Pittsfield, October 2nd, 3d and 4th. About sixty were present at each of the several sessions, comprising designing engineers, department engineers, commercial representatives of Local Offices, Supply Department Managers and the following District Officer transformer and regulator specialists representing all the District Offices of the Company: L. W. Carnagy, A. H. Abbott, J. L. Buchanan, V. A. Hain, R. Oliphant, A. D. Silva, E. D. Monk, B. C. J. Wheatlake, H. G. Harvey, J. O. Case, J. M. Hayes, W. B. Clayton.

On the first day, the morning session, following the formal opening by M. O. Troy and introductory remarks by C. C. Chesney and W. S. Moody, was taken up by papers and discussions on the design of large power transformers. In the afternoon session the representatives were taken through the Works, where the design and construction was explained in more detail. In the evening session Mr. Faccioli presented a very excellent paper on "High Tension Transformers," in which a very close analogy was drawn between the problems of high voltage transformer design and those of transmission line engineering. Papers were also read by prominent transformer specialists, covering the opportunities and activities of the specialist in the field. On the second day, the morning session was given over to the presentation and discussion of papers on small distributing transformers and lightning arresters. The morning session was closed by an extremely interesting paper by Dr. Steinmetz on "Transformer Strains due to Over-Current, Over-Voltage and Over-Frequency." (This Paper is reprinted in this issue of the GENERAL ELECTRIC REVIEW.) In the afternoon session, the Specialists were again taken through the Works, where attention was given to the careful detail of building the distributing transformers. In the evening, the representatives saw "Are You a Mason?" at a local theater. On the third day, the morning session was taken up by papers and discussion on rectifiers, ozonators, electric hardening and annealing furnaces, feeder regulators, etc.; and, by unanimous consent of the Specialists, the automobile ride through the Berkshires, arranged for the afternoon, was omitted, and discussion of the various papers extended through the extra session. In the evening Mr. Chesney entertained the Convention at an excellent old fashioned Thanksgiving dinner at the Country Club.

BOOK NOTICE

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Following the publication of *The Principles of Scientific Management* by Frederick W. Taylor in *The American Magazine* innumerable letters were received requesting further information. Mr. Gilbreth handled these letters; and he has now compiled in the *Primer* the salient questions and answers, in a logical and connected form with an extremely good index. In answering the questions Mr. Gilbreth has quoted freely from the works of those men who have made a most thorough study of the subject under discussion, or he gives actual results obtained in shops using this form of management. The *Primer* takes up in detail the definition of terms used, and the laws and principles involved in Scientific Management. It next deals with the application of the laws and the effect on the worker. The last section, on the relation of Scientific Management to other lines of activity, touches on National welfare and industrial supremacy; and thus brings out the fact, too little appreciated at present, that Scientific Management will benefit whole communities. In the *Primer* we may find the answer to all questions which are likely to arise on reading any of the recent publications on Scientific Management.

W. G. K.

ELECTRIC CENTRAL STATION DISTRIBUTION SYSTEMS

Their Design and Construction

By Harry Barnes Gear and Paul Francis Williams

D. Van Nostrand Company

347 Pages 139 Illustrations $3.00 net

About a year ago, the reviewer heard the electrical engineer of a central station complain that "All of the information on distributing systems was under the hats of the operating men." Fortunately, this statement is now no longer true due to the publication by Messrs. Harry Barnes Gear and Paul Francis Williams of a book entitled "Electric central station distribution systems, their design and construction."

This volume has been carefully written by two men well versed in their subject. It contains chapters on transmission and convention, line transformers, secondary distribution, special schemes of transformation, protective apparatus, overhead construction, lines and accessories, underground construction, cable work, properties of conductors and alternating current circuits.

While the authors have pre-supposed a certain amount of knowledge of the theory of electricity, most of the subject matter has been so written as to be easily comprehended by practical men who have not had the advantage of a theoretically technical education. This effect is largely secured by compiling the data in convenient tabular form.

One of the most interesting sub-divisions in the book is that devoted to distribution economics. The authors cover in detail information regarding the selection of economic sizes of conductors, minimum annual cost, fixed charges, losses and their regulation, determination of best sizes of conductors for different typical cases, diversity factor for different classes of consumers, diversity of different points in the system, total diversity factors for light and power users.

Another interesting chapter is that devoted to voltage regulation. It is a matter of regret to the reviewer that the authors have made no comment on voltage control by means of synchronous condensers used with automatic voltage regulators, and it is to be hoped that when this work is re-written, they will fit see to touch upon this subject.

As an indication of the rapidity of electrical progress, it is significant to note that there has been an interesting addition to the methods of voltage control since the publication of this work. The reviewer refers to voltage control of alternating current feeders by means of automatic feeder regulators of small kw. capacity mounted on poles and installed at the center of distribution.

J. R. W.

ELECTRICAL INJURIES

By Charles A. Lauffer

Published by John Wiley & Sons

78 Pages 50 cents

Dr. Lauffer is the Medical Director, Relief Department, of the Westinghouse Electric & Manufacturing Company, and is admirably placed for undertaking the preparation of a handbook on this important subject. Unlike many so-called handbooks, this volume is of exceedingly handy size and may be readily carried in the pocket. The book possesses the several obvious advantages which result from its having been written by a man who, in addition to enjoying a wide practical knowledge of medicine and surgery, is also well versed in electrical matters. The treatment is very practical and includes sections on causation of electrical injuries, prevention, pathology, symptoms and treatment. The matter of artificial respiration has been recently receiving a great deal of attention from the National Electric Light Association and other professional bodies, and Dr. Lauffer's section on this subject will, therefore, be read with considerable interest.

MOTOR-DRIVEN AIR-COMPRESSORS FOR THE BETHLEHEM STEEL COMPANY

The accompanying photograph illustrates two special "Chicago Pneumatic" motor-driven compressors furnished to the Bethlehem Steel Company and recently installed in the power house of their South Bethlehem, Pa., plant for starting gas engines. They are entirely self-contained, having full sub-base on which are also mounted the motor and outboard bearing; and the compressors present an attractive and substantial appearance due to the sturdy construction and the enclosed motors and gear casing. The compressors are duplicates, and have two-stage air cylinders 16 in. and 8 in. diameter by 14 in. stroke. At 155 r.p.m. each has a displacement of 504 cubic feet, the final pressure being 250 pounds. Each compressor is driven by a 150 h.p., 230 volts, direct current motor running at 800 r.p.m., with outboard pedestal bearing. The motors are equipped with automatic self starters, and pressure regulators. These starters can be seen mounted on panel boards behind the first compressor. An extra wide face rawhide pinion is mounted on the extended motor shaft and this meshes in cut teeth in the face of a heavy fly-wheel mounted on compressor shaft, the gearing being enclosed in a heavy gear casing for the protection of operatives. The Chicago Pneumatic Tool Company build this same type of compressor in capacities from 31 to 2200 cubic feet per minute for any pressure and for any current conditions depending on whether single stage, duplex or multi-stage.